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ECONOMIC DECISION MAKING MODEL FOR GEOTHERMAL SLUDGE DISPOSAL ALTERNATIVES (EDM-GSD)

VERSION 1.0

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San Francisco Operations Office

EXECUTIVE SUMMARY

The Economic Decision Making Model for Geothermal Sludge Disposal Alternatives-Version 1.0" (EDM-GSD 1.0) is a microcomputer-based dynamic model developed to assist in determining the benefits and costs of various geothermal solid waste treatment procedures. It is intended for use by geothermal managers in dealing with geothermal waste and treatment process issues as a means to assist in overcoming the technical and economic barriers to expanded geothermal energy utilization.

The model is based on a 50MW flash plant. However, it is designed to provide the user with sufficient flexibility when inputing data to analyze all types of geothermal plants. Default values for economic and technical parameters can be overridden by the user through the input of specific data. In addition, data can be changed for any year of an analysis to account for desired changes in input parameters such as costs and distance to disposal sites.

The results of the model will allow the user to:

- Determine current geothermal plant disposal costs;
- Evaluate the cost-effectiveness of alternative treatment techniques; and
- Evaluate the economic effects of changes in disposal regulations.

It is recommended that further work be conducted in the areas of process options and cost functions to ensure that all viable disposal alternatives have been included and default costs refined. Currently, for example, Version 1.0 contains four process options to select from: Bioleaching, Solidification, Detoxification and Metal Removal. The program has been developed so that additional treatment technologies may be incorporated.

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Order software packages from National Energy Software Center, Argonne National Laboratory, 9800 South Cass Avenue, Argonne, IL 60439. Order documentation without complete package from NTIS.

List of Figures and Tables

1.0 INTRODUCTION

1.1 Purpose and Specification

The model is designed for use by geothermal managers involved in R&D planning, and plant operations. It's purpose is to allow geothermal managers to quantitatively explore alternative waste disposal techniques using a personal computer-based dynamic model. It requires some general knowledge about the workings of a geothermal plant but does not need, nor will it produce, detailed energy/waste disposal analysis data for engineering applications.

The technical specifications of EDM-GSD 1.0 are summarized in Table 1. Modifications to the program will be necessary if compatible equipment is not used.

1.2 The Structure and Scope of EDM-GSD

For the purposes of this model we conceptualized a 50 MWe flash plant as shown in Figure 1. "Raw" effluent from the last thickener of this plant is sent to a filter press for solidification and eventual disposal, while the resulting supernate liquid enters the plant's reinjection stream. For this model, the 'solidified' portion of the "raw" effluent will be referred to as sludge, while the remaining liquid portion will be called supernate. Although we are referring to the sludge as a solid, it is actually only about 65% solids by weight, and is usually classified as a liquid by EPA. Hence, throughout this manual we will be referring to the sludge as a solid but analyzing it as a liquid under EPA regulations.

Using the above definition, EDM-GSD 1.0 approaches sludge and supernate disposal with the underlying assumption that current municipal and industrial

TABLE 1

EDM-GSD VERSION 1.0 SPECIFICATIONS

PROGRAM LANGUAGE

Microsoft Quick-Basic[1]

OPERATING SYSTEM

DOS 3.0 or greater[2]

RANDOM ACCESS MEMORY REQUIRED

640 K BYTES

DISK DRIVE REQUIRED

One hard drive

PRINTER REQUIRED

Output is formatted for 8 1/2 x 11 inch paper.

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1 Quick-Basic is a registered trade mark of Microsoft Incorporated.

2 Copyright IBM and Microsoft.

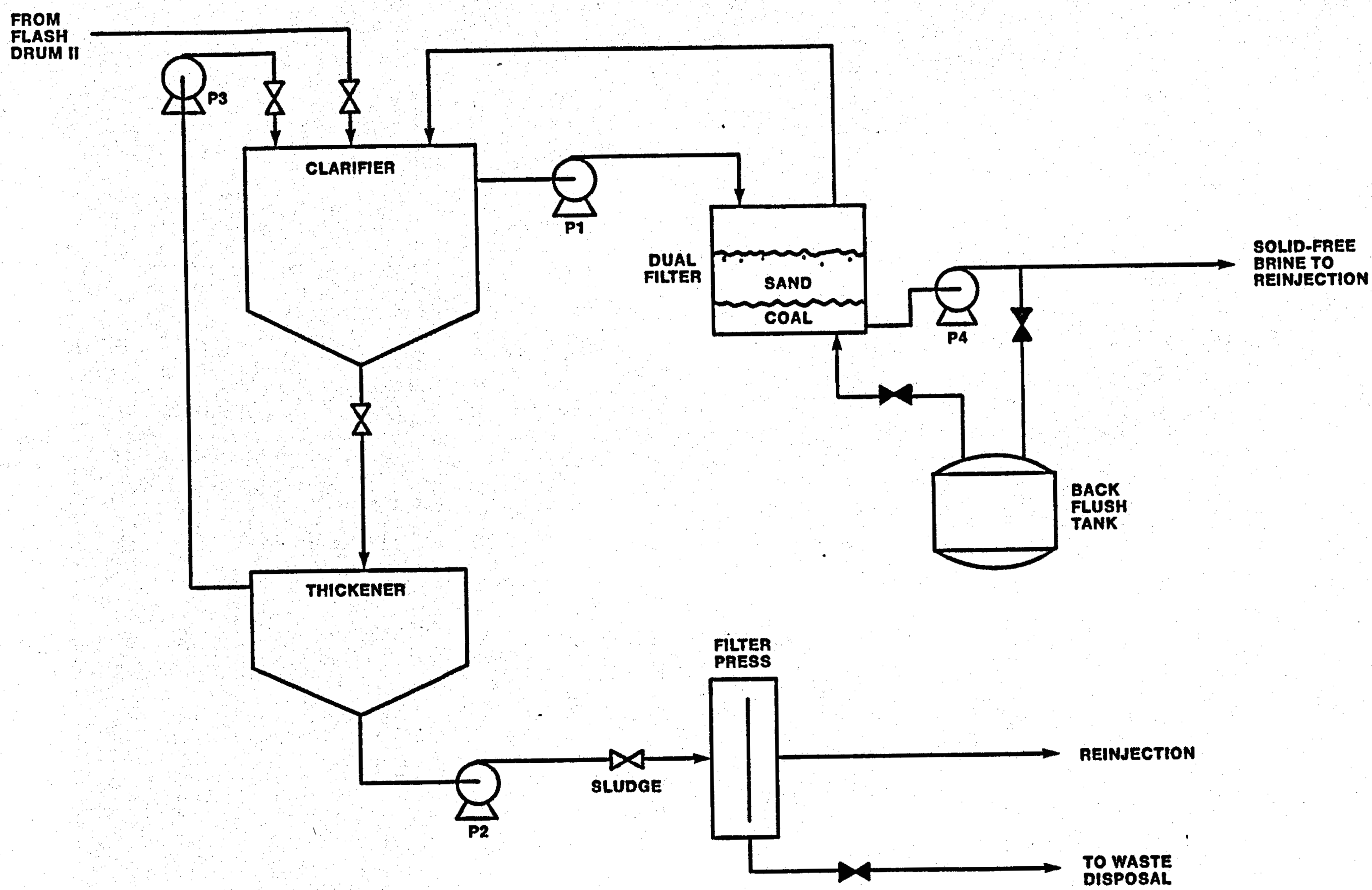

Figure 1
GEOTHERMAL SLUDGE SUPERNATE SEPARATION SYSTEM

clean-up procedures may be used to treat geothermal by-products. EDM-GSD does not account for wastes from any H_2S control mechanisms that may be employed at a plant. In adopting this approach, a 'Mass Flow Rate' (MFR) structure has been incorporated into the model to determine process costs and operating parameters. The MFR structure provides a user with the distinct advantage of integrating raw effluent and resulting sludge/supernate data with treatment and hauling cost values. The incorporation of the MFR structure and its role in determining model outputs are shown in Figure 2.

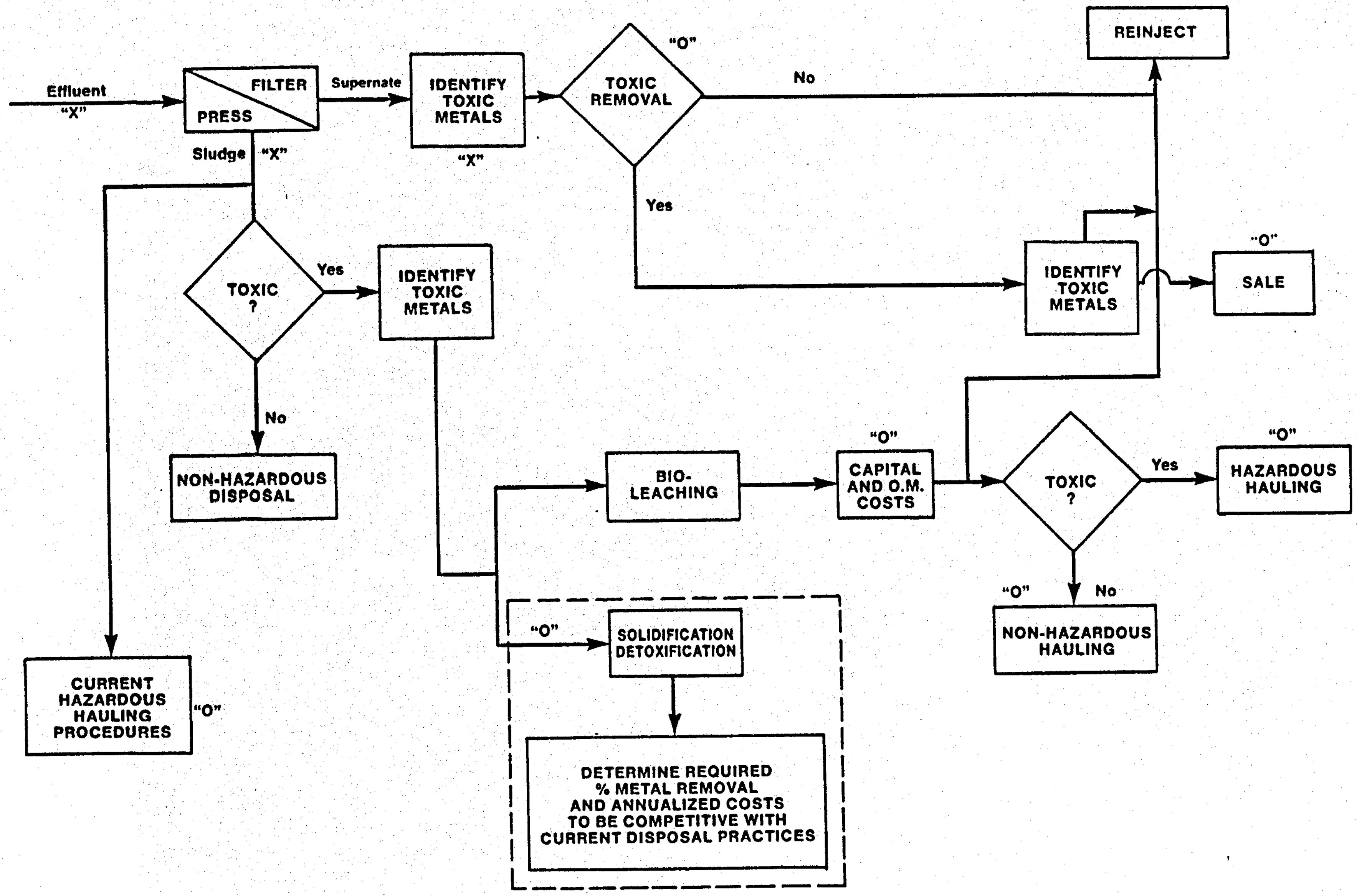

Figure 2
THE MFR PROCESS IN THE EDM-GSD MODEL

For every 'X' point on the figure, a flow rate (in lbs/hr) for effluent, sludge and supernate, and a concentration level for each of twenty-three minerals (in parts-per-million) will be either model-calculated or inputby the user. For every 'O' point, costs for sludge and supernate treatment procedures and current hauling practices will be calculated based on the initial flow rate.

In general, for most of the data inputs, default data values have been provided to allow for initial runs of the model. These values are not necessarily applicable to all geothermal facilities, and the user should always input site specific data for subsequent runs of the model if such data are available.

1.3 Capabilities

Overall, EDM-GSD 1.0 provides the user with a number of outputs based on inputs completed and options selected. Specifically, the program first calculates the current disposal cost for the sludge exiting the last filter press. It then estimates the cost of installing and operating a user-selected industrial treatment processe or approximates the annual cost of an innovative process based on current disposal costs. Lastly, it compares the user-selected treatment process with current disposal on a $/yr and $/kWh basis.

The ability to incorporate user-supplied initial data and to accept default-override values gives EDM-GSD 1.0 the versatility to be utilized with increasingly refined inputs. Thus, initial runs using rough estimates as inputs can eventually be replaced with improved engineering and economic data acquired over time, or by changing individual yearly data for the period of analysis.

EDM-GSD 1.0 contains a number of assumptions regarding components and costs of alternative waste disposal systems that are not relevant to all geothermal facilities (see Appendix A), but are included to maintain a uniform base of model execution. Where such assumptions have been unavoidable, they have been purposely conservative. The case-specific inaccuracies these assumptions may produce can be further reduced by fully utilizing the default value override capabilities of the program. However, no claim or warranty is made regarding the accuracy of EDM-GSD 1.0 results when used for engineering purposes. Rather, results should be used as an planning tool to compare the different process alternatives with various 'down-stream' acceptance scenarios. The operating procedures to attain these results and an explanation of model structure, execution and output will be presented in the following chapters.

2.0 USING EDM-GSD 1.0

2.1 Program Organization

EDM-GSD 1.0 is structured around a series of data and process option (d&p) "sub menus" that quantify and display cost and economic aspects of current and alternative geothermal waste management. In order to clarify this structure, the "driving menus" and the data flow sequences for the driving menus will be first summarized and diagrammed (Figure 3) followed by a brief description of the d&p menus and related important data flow sequences.

2.1.1 Driving Menus

<u>Main Menu</u>: The Main Menu interconnects the data portion (A) of the model with the process portion (B). Specifically, a user after accessing and completing the necessary data inputs, returns to the Main Menu to first access and select a process option. The Main Menu also enables the user to return to DOS for program termination.

<u>Data Input/Edit Menu</u>: The Data Input/Edit Menu contains all of the economic and technical data needed for program execution in 6 sub menus. A user must complete these six sub menus, as requested by the program, in order to proceed to the process portion of the model.

<u>Process Options Menu</u>: The Process Options Menu has a total of four treatment options to choose from. Included among these are two innovative "black box" processes, sludge detoxification and solidification, for which cost parameters are approximated by the program.

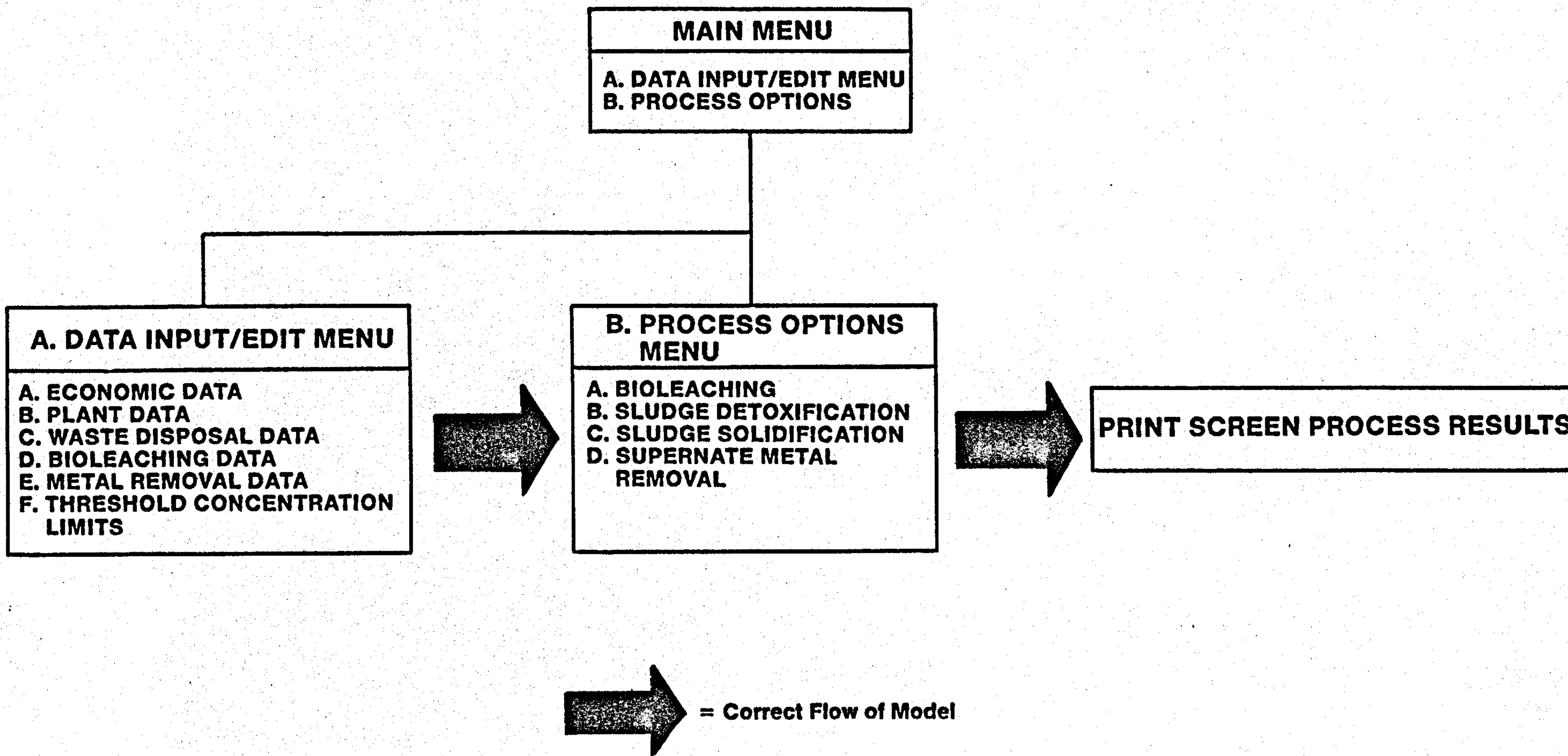

Figure 3
DRIVING MENUS SET-UPS

2.1.2 Data Input/Edit Sub Menus[1]

DATA INPUT/EDIT MENU

Economic Data: The Economic Data sub-menu contains four data inputs needed for life-cycle analysis of geothermal solid waste disposal. These are: real annual escalation rate, annual inflation rate, annual discount rate and number of years for analysis or time span over which the user wants to estimate disposal and treatment costs (maximum of 30 years). The program uses these data inputs to account for the time value of money when calculating the various capital and O&M costs involved.

Plant Data: The Plant Data sub-menu contains the data inputs necessary for liquid and solid flow analysis as well as general plant information. Separate data inputs are accepted for the effluent data and resulting sludge/supernate data.

For the effluent data the following data inputs are accepted: plant size, plant capacity factor, effluent flow rate, percent dissolved metal, bulk removal and flow separation coefficients for the filter press, total solids, total dissolved solids and twenty three individual metal concentrations.

For the resulting sludge and supernate flows the following data inputs are accepted: plant size, plant capacity factor, flow rate, total solids, total dissolved solids, and twenty three individual metal concentrations.

Effluent data, sludge data and supernate data may be separately saved for later use on a different run of the model.

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1. Grouped by driving menu. Further explanation available in Section 2.2 -"Program Execution".

Waste Disposal Data: Data for waste disposal costs are contained in the Waste Disposal Data sub-menu. Specifically, the user enters values for liquid and solid hauling/handling and transportation costs and distance to disposal sites for both hazardous and non-hazardous wastes. As in the case of the Plant Data Menu, data may be saved for later use.

Bioleaching Data: Bioleaching is a promising waste detoxification technique. Seven basic factors which determine the characteristics of this technique and an additional cost reduction factor which accounts for annual cost reductions due to process improvements are contained in the sub-menu. These are: capital cost, O&M cost, reduction in O&M cost, equipment life, nutrient dosage, nutrient cost, liquid residency time and the individual metal removal efficiencies.

Metal Removal Data: Two distinct categories of data inputs are contained in the Metal Removal Data sub-menu. The first category contains three commonly used liquid waste detoxification techniques, while the second contains potential market prices for the removed metals and minerals.

The three commonly used detoxification techniques are: (1) lime precipitation, (2) aluminum-based precipitation, and (3) iron-based precipitation. All three contain seven of eight factors previously described in the bioleaching sub menu with the respective precipitant dosage rates replacing that of the nutrients, and a liquid residency time not being required.

The second category contains default spot market prices (as of May 5, 1987) for twenty-three metals/minerals that may be removed from the supernate. Specific metal price data may be input and saved by the user for future use.

Threshold Concentration Data: The Threshold Concentration Data contains the concentration limits above which a waste is considered hazardous. In most of the United States and by Federal law, two types of limits are used: the soluble threshold concentration limits (STLC) for liquids disposal and the total threshold concentration limits (TTLC) for solids disposal. Based on EPA test procedures[1], most geothermal waste is considered a liquid. Hence, the program lets the user know if the waste being analyzed is hazardous under STLC before and after a treatment process. The sludge solidification process compares waste to TTLC limits after processing. California standards are used as default values for the model, and may be edited and saved by the user for future use.

As the preceding briefs indicate, the Plant Data d&o - and specifically the effluent flow data - plays a crucial role in determining the inputs for the bioleaching and metal removal d&o. The Plant Data d&o must thus be accessed before the bioleaching or metal removal data can be entered.

2.2 Program Execution

This section of the manual provides a sequential description of the model from installation and runtime procedures to output results, allowing the user to preview and become familiar with the model's content and correct operation.

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1 Commonly known as the "paint filter test", the procedure involves placing a sludge on a filter mesh and determining if liquid drips from it within an allotted time period (usually 5 minutes). If liquid drips, the sludge is considered to be a liquid waste. If liquid does not drip the sludge is usually considered a solid

2.2.1 Installing EDM-GSD 1.0

EDM-GSD 1.0 is prepared for use with the DOS 3.0* operating system. Users are advised to copy the master disks provided with the manual onto back-up blank disks and the hard disk of the computer to protect against loss.

The files contained on the EDM-GSD 1.0 master disk include the main executable file "SM.Exe," help files with the extension .HEL, and default and data files with various extensions signifying the d&p menu under which they were saved.

EDM-GSD's run command is "SM" <return>. This command will generate the introductory logo after which the Main Menu is displayed. At this time the user should note the features that will become common for all menus. Specifically, a "Press F1 for Help" display in the upper right-hand of the screen, and a Z-key option that will always return the user to the previous menu screen (at this point the default DOS drive). The model is now ready for use.

2.2.2 Runtime Descriptions

This section of the manual provides a complete description of the model's content as it appears on the monitor. To accomplish this task the actual menu is first displayed followed by a brief explanation of the individual data selections. A condensed version of these briefs may be located on the model help screens which may be accessed by pressing the F1 key for the displayed screen. While accessing user menus and inputting data the following should be noted all user menus are accessed by a single keystroke (either letter or number) while data input requires hitting the "enter" key after entering a value.

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*Copyright Microsoft Inc. and IBM.

Main Menu

```
                                        PRESS F1 FOR HELP

|------------------------------|
|          MAIN MENU           |
|------------------------------|
|                              |
|   A. DATA INPUT/EDIT MENU    |
|   B. PROCESS OPTIONS MENU    |
|                              |
|                              |
|   Z. QUIT. RETURN TO DOS     |
|                              |
|------------------------------|
  ENTER SELECTION =====>
```

The driving menus A and B must be accessed sequentially if logging on for an initial run of the model. Any attempt to access a menu out of order will result in a beep tone from the computer followed by an error message requesting correct input sequences. Assuming "A" is keyed in, the data requirements for the menu are displayed as follows.

A. Data Input/Edit Menu

```
                                        PRESS F1 FOR HELP

|----------------------------------------|
|          DATA INPUT/EDIT MENU          |
|----------------------------------------|
|                                        |
|  A. ECONOMIC DATA                      |
|  B. PLANT DATA                         |
|  C. WASTE DISPOSAL DATA                |
|  D. BIOLEACHING DATA                   |
|  E. METAL REMOVAL DATA                 |
|  F. THRESHOLD CONCENTRATION LIMITS     |
|----------------------------------------|
|  Z. RETURN TO MAIN MENU                |
|----------------------------------------|
      ENTER SELECTION =====>
```

The sub-menus are described below.

A. <u>ECONOMIC DATA SUB-MENU</u>

```
                                                    PRESS F1 FOR HELP

      DATA INPUT/EDIT          ECONOMIC DATA

     A. ANNUAL ESCALATION RATE -      1.00 %
     B. ANNUAL INFLATION RATE -       2.00 %
     C. ANNUAL DISCOUNT RATE -        3.00 %
     D. YEARS FOR ANALYSIS -          30 YRS

     Z. RETURN TO MAIN MENU

      ENTER SELECTION TO CHANGE VALUE
                 OR Z TO RETURN=====>
```

A - Annual Escalation Rate

The real annual escalation rate, as defined by the Electric Power Research Institute, is the rate of increase of an expenditure due to resource depletion, increased demand and decreasing manufacturing capabilities. It does not include the inflation rate. To input a value enter "A", then key in a value (in percent). Press return to both view the new value on-screen and to proceed to the next desired input. Users are recommended to use the 1.0% default value.

B - Annual Inflation Rate

Key in the appropriate <u>real</u> inflation rate. (Default value of 2.0% is for model testing pruposes only.)

C - Annual Discount Rate

The discount rate is the rate used to determine the time value of money for a given period of time. (Default value of 3.0% is for model testing purposes only.)

D - Years For Analysis

This feature allows the user to select the number of years (up to a maximum of 30) over which he or she wishes to perform an analysis. Very often, this would mean the remaining life-time of the geothermal power plant that is being investigated.

The economic data (sub-menus) cannot be saved on a separate file for future use. It will default to the same values, however, when starting up the program. Specific data can be used for different runs of the model as long as the user is continually logged on.

B. PLANT DATA SUB-MENU

```
                                                    PRESS F1 FOR HELP

|-----------------------------------------------------------|
|                 PLANT DATA INPUT MENU                     |
|-----------------------------------------------------------|
|                              |                            |
| EFFLUENT DATA                | SLUDGE + SUPERNATE DATA    |
|  A. EDIT DEFAULT DATA        |  D. EDIT DEFUALT DATA      |
|  B. INPUT DATA FROM FILE     |  E. INPUT DATA FROM FILE   |
|       FILENAME.PTA           |       FILENAME.PTB         |
|  C. OUTPUT DATA TO FILE      |  F. OUTPUT DATA TO FILE    |
|       FILENAME.PTA           |       FILENAME.PTB         |
|                              |                            |
|-----------------------------------------------------------|
|                                                           |
|                  Z. RETURN TO MENU                        |
|                                                           |
|-----------------------------------------------------------|
  ENTER SELECTION A-C OR D-F
  TO ENTER DATA OR Z TO RETURN =====>
```

B -> A Edit Default Data (Effluent)

By model definition, the effluent is the slurry flow going to the filter press after leaving the last thickener of a flash plant. By pressing "A" all the data inputs listed earlier in section 2.1.1 appear on the screen, as shown below, and can be edited to meet user requirements.

```
                                        PRESS F1 FOR HELP

 DATA INPUT/EDIT                PLANT DATA

A. PLANT SIZE -                       50 MW
B. PLANT CAPACITY FACTOR -           .85
C. EFFLUENT FLOW                  11,000 LB/HR
D. PERCENT METALS DISSOLVED         80.0 %
E. BULK REMOVAL COEFFICIENT          .75
F. FLOW SEPARATION COEFFICIENT       .50
G. TOTAL SOLIDS                  250,000 PPM
H. TOTAL DISSOLVED SOLIDS        200,000 PPM

I. METAL CONCENTRATIONS

J. VIEW SLUDGE/SUPERNATE DATA

Z. RETURN TO MENU

 ENTER SELECTION TO
 INPUT/EDIT VALUE OR Z TO RETURN=====>
```

B -> A -> A. **Plant Size**

Key-in plant rating in MW.

B -> A -> B. **Plant Capacity Factor**

Input actual energy output (MW-hrs) divided by size of plant times total hours per year - MW-hrs/(MW x 8760).

B -> A -> C. **Effluent Flow**

Input the flow rate of the effluent in lbs/hr. If the effluent flow rate is part of a batch process, input the average hourly batch flow rate for a 24 hour period.

B -> A -> D. **Percent Metals Dissolved**

Input the average percent of metals dissolved in the effluent as a decimal. The value input will only be used for computer projections of the resulting sludge and supernate composition and may later be over-ridden by inputing individual concentrations for both sludge and supernate constituents.

B -> A -> E. **Bulk Removal Coefficient**

The Bulk Removal Coefficient (BRC) determines the amount of solid trapped by the filter press. Values must be input as a fraction of 1, with 1 meaning all solids are trapped in the resulting sludge. (0.7 means 70% are trapped.)

B -> A -> F. **Flow Separation Coefficient**

The Flow Separation Coefficient (FSC) determines the division of the initial effluent flow into sludge and supernate flows. This division is determined <u>before</u> the BRC is integrated in the model. For example, if an FSC value of 0.5 is assigned to an effluent flow rate of 11,000 lb/hr, the program automatically divides the flow between sludge (5500 lb/hr) and supernate (5500 lb/hr) before determining the metal content of either flow using the BRC or effluent metal concentration.

B -> A -> G. Total Solids

Input total solids (both dissolved and suspended) for the effluent in parts per million (ppm).

B -> A -> H. Total Dissolved Solids

Input total dissolved solids content in ppm.

B -> A -> I. Metal Concentrations

The following data input screen for the effluent appears when "I" is entered.

```
                                                          PRESS F1 FOR HELP

 DATA INPUT/EDIT                    EFFLUENT COMPOSITION

COMPONENT                 PPM      COMPONENT                 PPM
*********                 ***      *********                 ***
A.  BARIUM              540.0      M.  ZINC                  2.0
B.  BERYLLIUM             1.0      N.  ANTIMONY              0.0
C.  CADMIUM              20.0      O.  ARSENIC               0.0
D.  CHROMIUM(VI)          0.0      P.  FLOURIDE              5.0
E.  CHROMIUM(III)         0.0      Q.  SELENIUM              1.0
F.  COBALT                6.0      R.  THALLIUM              0.0
G.  COPPER                1.0      S.  VANADIUM              0.0
H.  LEAD(INORGANIC)       0.0      T.  BORON                10.0
I.  LEAD(ORGANIC)         0.0      U.  LITHIUM              10.0
J.  MERCURY               2.0      V.  GOLD                  1.0
K.  MOLYBDENUM            2.0      W.  SILVER                1.0
L.  NICKEL                5.0      Z.  RETURN TO MENU

 ENTER SELECTION TO
 INPUT/EDIT VALUE OR Z TO RETURN=====>
```

For each metal/mineral, a concentration level may be specified by keying in the line-letter and inputing a value. All values must be in total ppm i.e., suspended + dissolved levels. To view what the computer projects as resulting sludge and supernate-data press J.

The effluent portion of Plant Data Menu is now complete and ready to be saved if desired. Return to the Menu by pressing Z. To save edited defalut data, key in "C" for "Output Data to File Filename.PTA". An Output (Save) Data screen will appear. Type in a file name <u>(without the extension - i.e., PTA)</u> and press return. The data input will be saved for future use.

Saved data may be accessed by keying in "B" for "Input Data From File Filename.PTA" and typing in the appropriate filename (without the extension).

To input and save or recall sludge and supernate data proceed to D.

B -> D. Edit Default Data (Sludge/Supernate Data)

```
                                          PRESS F1 FOR HELP

  DATA INPUT/EDIT                  PLANT DATA

 A. PLANT SIZE -                        50 MW
 B. PLANT CAPACITY FACTOR -            .85

 C. SLUDGE DATA
 D. SUPERNATE DATA

 Z. RETURN TO PLANT DATA INPUT MENU


  ENTER SELECTION TO
  INPUT/EDIT VALUE OR Z TO RETURN=====>
```

B -> D -> A. Plant Size

Same as for effluent data.

B -> D -> B. Plant Capacity Factor

Same as for effluent data.

B -> D -> C. Sludge Data

After keying in C the following screen is displayed.

```
DATA INPUT/EDIT              SLUDGE DATA                PRESS F1 FOR HELP

1. TOTAL SOLIDS -             200,000 PPM
2. TOTAL DISSOLVED SOLIDS -   100,000 PPM
3. FLOW RATE -                  5,500 LB/HR

COMPONENT                  PPM      COMPONENT                  PPM
*********                  ***      *********                  ***
A.  BARIUM               432.0      M.  ZINC                   1.6
B.  BERYLLIUM              0.8      N.  ANTIMONY               0.0
C.  CADMIUM               16.0      O.  ARSENIC                0.0
D.  CHROMIUM(VI)           0.0      P.  FLOURIDE               4.0
E.  CHROMIUM(III)          0.0      Q.  SELENIUM               0.8
F.  COBALT                 4.8      R.  THALLIUM               0.0
G.  COPPER                 0.8      S.  VANADIUM               0.0
H.  LEAD(INORGANIC)        0.0      T.  BORON                  8.0
I.  LEAD(ORGANIC)          0.0      U.  LITHIUM                8.0
J.  MERCURY                1.6      V.  GOLD                   0.8
K.  MOLYBDENUM             1.6      W.  SILVER                 0.8
L.  NICKEL                 4.0      Z.  RETURN TO MENU
 ENTER SELECTION TO
 INPUT/EDIT VALUE OR Z TO RETURN=====>
```

The screen contains total and dissolved solid concentrations and the flow rate estimated based on effluent data inputs. If no effluent data was entered, all initial values will be zero. Sludge flow rate and solids concentrations can be input by keying in the corresponding numbers. Computer projected metal concentrations, will appear if accessed earlier in the effluent data section. Otherwise, individual ppm levels must be input by keying in the corresponding letter.

Return to the plant data menu only to save data or proceed to another menu. Do not save data until completing "D".

B -> D -> D. Supernate Data

After keying "D" the following screen is displayed.

```
 DATA INPUT/EDIT                 SUPERNATE DATA             PRESS F1 FOR HEL

1. TOTAL SOLIDS -               300,000 PPM
2. TOTAL DISSOLVED SOLIDS -     300,000 PPM
3. FLOW RATE -                    5,500 LB/HR

COMPONENT                  PPM       COMPONENT                   PPM
*********                  ***       *********                   ***
A.  BARIUM               648.0       M.  ZINC                    2.4
B.  BERYLLIUM              1.2       N.  ANTIMONY                0.0
C.  CADMIUM               24.0       O.  ARSENIC                 0.0
D.  CHROMIUM(VI)           0.0       P.  FLOURIDE                6.0
E.  CHROMIUM(III)          0.0       Q.  SELENIUM                1.2
F.  COBALT                 7.2       R.  THALLIUM                0.0
G.  COPPER                 1.2       S.  VANADIUM                0.0
H.  LEAD(INORGANIC)        0.0       T.  BORON                  12.0
I.  LEAD(ORGANIC)          0.0       U.  LITHIUM                12.0
J.  MERCURY                2.4       V.  GOLD                    1.2
K.  MOLYBDENUM             2.4       W.  SILVER                  1.2
L.  NICKEL                 6.0       Z.  RETURN TO MENU
 ENTER SELECTION TO
 INPUT/EDIT VALUE OR Z TO RETURN=====>
```

The data is similar to the sludge data and may be edited/input accordingly. After completion return to the plant data menu to save the data.

The plant data menu is now complete, return to the data input driving menu by keying in Z. Input C for waste disposal data menu.

C. WASTE DISPOSAL DATA SUB-MENU

```
                                                              PRESS F1 FOR HELP
|-------------------------------------------------------------------------------|
|                               DISPOSAL MENU                                    |
|-------------------------------------------------------------------------------|
|                          INPUT/EDIT BASELINE DATA                              |
|                      A. SELECT/EDIT DEFUALT DATA                               |
|                      B. INPUT DATA FROM FILE FILENAME.DSP                      |
|                                                                               |
|                      C. SAVE DATA TO FILE FILENAME.DSP                         |
|-------------------------------------------------------------------------------|
|                            CHANGE YEARLY DATA                                  |
| HAZARDOUS WASTE                          NON-HAZARDOUS WASTE                   |
|   D. LIQUID DISPOSAL COST                  G. LIQUID DISPOSAL COST             |
|   E. SOLID DISPOSAL COST                   H. SOLID DISPOSAL COST              |
|   F. DISTANCE TO DISPOSAL SITE             I. DISTANCE TO DISPOSAL SITE        |
|                                                                               |
|                          J. TRANSPORTATION FEE                                 |
|-------------------------------------------------------------------------------|
|                          Z. RETURN TO MENU                                     |
|-------------------------------------------------------------------------------|
  ENTER SELECTION =====>
```

C -> A. Select/Edit Default Data

```
                                                              PRESS F1 FOR HELP

                          DISPOSAL BASELINE DATA
                                1987 DATA

HAZARDOUS WASTE                              NON-HAZARDOUS WASTE
  A. LIQUIDS DISPOSAL COST - 1.50 $/GAL  D. LIQUIDS DISPOSAL COST - 0.50 $/GAL
  B. SOLIDS DISPOSAL COST -   250 $/TON  E. SOLIDS DISPOSAL COST -   125 $/TON
  C. DISTANCE TO SITE -        50 MILES  F. DISTANCE TO SITE -        50 MILES

                    G. TRANSPORTATION FEE - 2.80 $/MILE

                    Z. RETURN TO MENU

   ENTER SELECTION TO CHANGE VALUE
              OR Z TO RETURN=====>
```

C -> A -> A. Liquids Disposal Cost (Hazardous)

Input the current cost ($/gal) of disposing hazardous waste that are considered liquid waste by EPA test procedures. The default has been set at $1.50/gal. Include all costs such as handling and tipping transportation fee.

C -> A -> B. Solid Disposal Cost

Input the current cost ($/ton) of disposing of hazardous wastes that are considered solids by EPA test procedures. The default value has been set at $250/ton. Include all costs such as handling and tipping transportation fee.

C -> A -> C. Distance to Site

Input distance (miles) to certified hazardous dump site. The default distance of 50 miles is used for model testing only and does not represent any actual distance to a dump site. The value can be changed by the user.

C -> A -> D. Liquid Disposal Cost (Non-Hazardous)

Input the current cost ($/gal) of disposing non-hazardous waste that are considered liquids by EPA test procedures. Do not include transportation fee. Default cost is $0.50 /gal.

C -> A -> E. Solids Disposal Cost

Input the current cost of disposing non-hazardous wastes that are considered solids. Do not include transportation fee. Default cost is $125/ton.

C -> A -> F Distance to Site

Input distance to appropriate non-hazardous waste disposal site. Default is 50 miles.

C -> A -> G. Transportation Fee

Input cost per mile for transportation of wastes to disposal site. Default for all wastes is $2.80/mile.

If baseline disposal data is completed, it can now be saved by keying in "C" Save Data to File Filename. DSP.

CHANGING YEARLY DATA

In order to accommodate changes due to disposal technology and disposal site regulations, the disposal menu allows the user to change disposal data for any given year during the period of analysis.

Input any line letter D-J. The computer prompts the user for year of change and new value. Input new value for the particular year of interest and press return (1987 = year 1).

D. <u>BIOLEACHING DATA SUB-MENU</u>

```
                                                                   PRESS F1 FOR HELP
                          BIOLEACHING DATA INPUT/EDIT
                            EDIT 1987 BASELINE DATA
                            ***********************
A. CAPITAL COST -     2,425,145. $       | METAL REMOVAL EFFICIENCIES
B. O+M COST -           117,733. $/YR    |
C. REDUCTION IN                          |  H. VIEW/EDIT DEFAULT DATA
      O+M COST -             1.0 %/YR    |  I. INPUT DATA FROM FILE FILENAME.DF2
D. EQUIPMENT LIFE -           20 YRS     |
E. NUTRIENT DOSAGE -         .09 LB/LB   |  J. SAVE DATA TO FILE FILENAME.DF2
F. NUTRIENT COST -           130 $/TON   |
G. LIQUID RESIDENCY TIME -    30 DAYS    |
--------------------------------------------------------------------------------
                               EDIT YEARLY DATA
                               ****************
                              K. ANNUAL O+M COST (EXCLUDING NUTRIENT COST)
                              L. NUTRIENT COST
--------------------------------------------------------------------------------
                        Z. RETURN TO MENU
--------------------------------------------------------------------------------
 ENTER SELECTION=====>
```

D -> A. Capital Cost

The capital cost figure displayed has been model calculated using developed cost functions (see Appendix A). The figure may be changed, however, by keying in "A" and inputing a new cost.

D -> B. O&M Cost

The annual operation and maintenance cost has also been model-calculated using a developed cost function (Appendix A). This may also be changed as required.

D -> C. Reduction in O&M Cost

The O&M cost reduction factor is an annual cost reduction factor that accounts for cost reduction due to process/technology improvements. Inputs should be in percentages.

D -> D. Equipment Life

The typical bioleaching plant has an estimated lifetime of 20 years.

D -> E. Nutrient Dosage

The nutrient dosage rate (lb of nutrient per lb of sludge) is the amount of nutrients needed for processing the sludge. The dosage rate is directly correlated to the capital and O&M cost, and will change both values on-screen if altered by the user.

D -> F. Nutrient Cost

The cost per ton of the nutrient being utilized is input here. This cost is directly correlated to the O&M cost and will change the O&M cost on-screen if altered.

D -> G. Liquid Residency Time

The bacteriological nutrients involved in a bioleaching process need a certain amount of time to "digest" the metals in the sludge. Typically this ranges from 10-50 days. The time needed is inversely related to the O&M cost because the more time there is for digestion the less nutrients are needed.

D -> H. View/Edit Default Data

PRESS F1 FOR HELP

BIOLEACHING METAL REMOVAL EFFICIENCIES

	METAL	LOW(%)	HIGH(%)		METAL	LOW(%)	HIGH(%)
	*****	******	*******		*****	******	*******
A.	BARIUM	NONE	NONE	M.	ZINC	85	89
B.	BERYLLIUM	NONE	NONE	N.	ANTIMONY	NONE	NONE
C.	CADMIUM	NONE	NONE	O.	ARSENIC	18	44
D.	CHROMIUM(VI)	22	48	P.	FLOURIDE	NONE	NONE
E.	CHROMIUM(III)	22	48	Q.	SELENIUM	NONE	NONE
F.	COBALT	NONE	NONE	R.	THALLIUM	NONE	NONE
G.	COPPER	53	91	S.	VANADIUM	NONE	NONE
H.	LEAD(INORGANIC)	NONE	NONE	T.	BORON	NONE	NONE
I.	LEAD(ORGANIC)	NONE	NONE	U.	LITHIUM	NONE	NONE
J.	MERCURY	NONE	NONE	V.	GOLD	NONE	NONE
K.	MOLYBDENUM	NONE	NONE	W.	SILVER	NONE	NONE
L.	NICKEL	NONE	NONE	Z.	RETURN TO MENU		

ENTER SELECTION TO
INPUT/EDIT VALUE OR Z TO RETURN=====>

The view/edit default data contains the metal removal efficiencies for the bioleaching process. Where the word NONE or the value "0" appears, it means no verifiable removal efficiency for that metal was found. Both the optimum (high) removal value and the low value are displayed and can be changed by keying in the corresponding letter.

If default efficiency values have been edited, they should now be saved under "I" of the Bioleaching Data Input/Edit Sub-Menu for future use. After saving the data press Z to return to the driving menu and proceed to the Metal Removal Menu.

E. METAL REMOVAL DATA

```
                                                              PRESS F1 FOR HELP

|-----------------------------------------------------------------------------|
|                           METAL REMOVAL MENU                                |
|-----------------------------------------------------------------------------|
|                                      |                                      |
| METAL REMOVAL PROCESS                | METAL MARKET PRICE DATA              |
|   A. LIME PRECIPITATION              |   D. VIEW/DEFAULT PRICE DATA         |
|   B. ALUMINUM BASED PRECIPITATION    |   E. INPUT DATA FROM FILENAME.MTL    |
|   C. IRON BASED PRECIPITATION        |   F. SAVE DATA TO FILENAME.MTL       |
|--------------------------------------|--------------------------------------|
|                           Z. RETURN TO MENU                                 |
|-----------------------------------------------------------------------------|
                      ENTER SELECTION =====>
```

Metal Removal Process

The data inputs and screen set ups for the three removal processes (Lime Precipitation, Aluminum-Based Precipitation, and Iron-Based Precipitation) are the same with the exception of differing chemicals, dosage rates and costs. To avoid repetition only the Lime Precipitation screen will be explained below.

E -> A. Lime Precipitation

```
                                                          PRESS F1 FOR HELP
   METAL REMOVAL DATA INPUT/EDIT              LIME ADDITION DATA
                            EDIT 1987 BASELINE DATA
                            ***********************
A. CAPITAL COST -      415,774. $      | METAL REMOVAL EFFICIENCIES
B. O+M COST -          278,756. $/YR   |
C. REDUCTION IN                        |   G. VIEW/EDIT DEFAULT DATA
         O+M COST -         1.0 %/YR   |   H. INPUT DATA FROM FILE FILENAME.DF2
D. EQUIPMENT LIFE -          20 YRS    |
E. LIME DOSAGE -            300 MG/L   |   I. SAVE DATA TO FILE FILENAME.DF2
F. LIME COST -               30 $/TON  |
--------------------------------------------------------------------------------
                             EDIT YEARLY DATA
                             ****************
                            J. ANNUAL O+M COST (EXCLUDING LIME COST)
                            K. LIME COST
--------------------------------------------------------------------------------
                       Z. RETURN/SELECT ANOTHER PROCESS
--------------------------------------------------------------------------------
 ENTER SELECTION=====>
```

E -> A -> A through E -> A -> F

The line inputs for lime precipitation are similar to the previously described bioleaching process. The main difference is that nutrient dosage rate, residency time, and cost are replaced with lime dosage rate and cost which are directly related to capital and O&M cost.

Metal Removal Efficiency

E -> A -> G. View/Edit Default Data

PRESS F1 FOR HELP

LIME ADDITION METAL REMOVAL EFFICIENCIES

	METAL	LOW(%)	HIGH(%)		METAL	LOW(%)	HIGH(%)
	*****	******	*******		*****	******	*******
A.	BARIUM	30	90	M.	ZINC	30	60
B.	BERYLLIUM	NONE	NONE	N.	ANTIMONY	NONE	NONE
C.	CADMIUM	30	90	O.	ARSENIC	30	85
D.	CHROMIUM(VI)	60	90	P.	FLOURIDE	85	95
E.	CHROMIUM(III)	60	90	Q.	SELENIUM	10	40
F.	COBALT	NONE	NONE	R.	THALLIUM	NONE	NONE
G.	COPPER	30	90	S.	VANADIUM	NONE	NONE
H.	LEAD(INORGANIC)	30	90	T.	BORON	5	20
I.	LEAD(ORGANIC)	NONE	NONE	U.	LITHIUM	NONE	NONE
J.	MERCURY	30	60	V.	GOLD	NONE	NONE
K.	MOLYBDENUM	NONE	NONE	W.	SILVER	10	90
L.	NICKEL	55	95	Z.	RETURN TO MENU		

ENTER SELECTION TO
INPUT/EDIT VALUE OR Z TO RETURN=====>

Lime process removal efficiencies for twenty-three metals/minerals may be input in the above screen. The default values that appear on-screen are average values for existing process plants in the United States as determined by a review of the literature (Appendix B). The value of "NONE" or "0" does not necessarily mean that the lime process cannot remove that metal/mineral but rather than no comprehensive data has been found to indicate such. Both a high removal value and a low removal value (separated by a comma, i.e., 60, 90) should be input for the appropriate metals.

After completing G, the metal removal efficiencies may be saved under "I" for future use. Data may be retrieved by pressing "H".

E -> A -> J. Annual O&M cost

By keying in "J", users may specify individual annual O&M cost figures (excluding reagent cost) for lime treatment during any year of the analysis. This is accomplished by typing in a specific year and a new O&M value after the current value, (estimated by the computer based on baseline data), appears on the screen, as follows:

```
YEAR (1- 30)  ? 1  CURRENT VALUE -    278,668. $/YR        NEW VALUE - ?
```

E -> A -> K. Lime Cost

Lime cost for a particular year may also be separately specified using a similar procedure to the O&M cost procedure outline above.

Metal Market Price Data

E -> D. View/Edit Default Price Data

```
                                                      PRESS F1 FOR HELP
                                          METAL SPOT PRICES (05-05-1987)
 DATA INPUT/EDIT

METAL                      $/LB ORE     METAL                       $/LB ORE
*****                      ********     *****                       ********
A.  BARIUM                  20.00       M.  ZINC                      0.45
B.  BERYLLIUM              150.00       N.  ANTIMONY                 10.00
C.  CADMIUM                 12.00       O.  ARSENIC                   0.35
D.  CHROMIUM(VI)             0.07       P.  FLOURIDE                  0.05
E.  CHROMIUM(III)            0.07       Q.  SELENIUM                 50.00
F.  COBALT                  25.00       R.  THALLIUM                  8.00
G.  COPPER                   0.67       S.  VANADIUM                 20.00
H.  LEAD(INORGANIC)          0.03       T.  BORON                     5.00
I.  LEAD(ORGANIC)            0.03       U.  LITHIUM                  15.00
J.  MERCURY                  5.25       V.  GOLD                   4800.00
K.  MOLYBDENUM               6.00       W.  SILVER                  102.00
L.  NICKEL                   2.00       Z.  RETURN TO MENU

 ENTER SELECTION TO
 INPUT/EDIT VALUE OR Z TO RETURN=====>
```

The above prices are spotmarket prices of minerals ($/lb ore) as of May 5, 1987. Commodity prices are usually based in futures which can have large fluctuations. Users should update the prices whenever possible to reflect current trends.

After inputing the specific prices save the data under "F"-Same Data to Filename.MTL. Return to the driving menu and access the Threshold Concentration Limits Menu.

F. THRESHOLD CONCENTRATION LIMITS MENU

```
                                                              PRESS F1 FOR HELI

|-------------------------------------------------------------|
|              THRESHOLD CONCENTRATION LIMITS                 |
|-------------------------------------------------------------|
|                              |                              |
| STLC                         | TTLC                         |
|   A. SELECT/EDIT CALIFORNIA  |   D. SELECT/EDIT CALIFORNIA  |
|      LIMITS                  |      LIMITS                  |
|   B. INPUT LIMITS FROM       |   E. INPUT LIMITS FROM       |
|      FILE FILENAME.STL       |      FILE FILENAME.TTL       |
|   C. SAVE LIMITS TO          |   F. SAVE LIMITS TO          |
|      FILE FILENAME.STL       |      FILE FILENAME.TTL       |
|                              |                              |
|-------------------------------------------------------------|
|                    Z. RETURN TO MENU                        |
|-------------------------------------------------------------|
     ENTER SELECTION A-C OR D-F
     TO ENTER DATA OR Z TO RETURN =====>
```

STLC

```
                                                              PRESS F1 FOR HELP
  DATA INPUT/EDIT                               CALIFORNIA LIMITS
           SOLUBLE THRESHOLD LIMIT CONCENTRATIONS

 COMPONENT                 PPM       COMPONENT                   PPM
 *********                 ***       *********                   ***
 A.  BARIUM               100.0      M.  ZINC                   250.0
 B.  BERYLLIUM              0.8      N.  ANTIMONY                15.0
 C.  CADMIUM                1.0      O.  ARSENIC                  5.0
 D.  CHROMIUM(VI)           5.0      P.  FLOURIDE               180.0
 E.  CHROMIUM(III)        560.0      Q.  SELENIUM                 1.0
 F.  COBALT                80.0      R.  THALLIUM                 7.0
 G.  COPPER                25.0      S.  VANADIUM                24.0
 H.  LEAD(INORGANIC)        5.0      T.  BORON                   NONE
 I.  LEAD(ORGANIC)         NONE      U.  LITHIUM                 NONE
 J.  MERCURY                0.2      V.  GOLD                    NONE
 K.  MOLYBDENUM           350.0      W.  SILVER                   5.0
 L.  NICKEL                20.0      Z.  RETURN TO MENU

  ENTER SELECTION TO
  INPUT/EDIT VALUE OR Z TO RETURN=====>
```

The Soluble Threshold Limits Concentration (STLC) is the more stringent of the two standards employed to determine if a waste is hazardous or not. For the most part, STLC is applied to liquid wastes near aquifers. The default data above is for the State of California. All levels are in ppm. Users may change the default values to reflect other regions of the country by keying in the desired line-letter.

If editing any value, save the data under line-letter C.

TTLC

```
                                                  PRESS F1 FOR HELP
DATA INPUT/EDIT                       CALIFORNIA LIMITS
          TOTAL THRESHOLD LIMIT CONCENTRATIONS

COMPONENT                   PPM        COMPONENT                 PPM
*********                   ***        *********                 ***
A.  BARIUM              10000.0        M.  ZINC               5000.0
B.  BERYLLIUM              75.0        N.  ANTIMONY            500.0
C.  CADMIUM               100.0        O.  ARSENIC             500.0
D.  CHROMIUM(VI)          500.0        P.  FLOURIDE          18000.0
E.  CHROMIUM(III)        2500.0        Q.  SELENIUM            100.0
F.  COBALT               8000.0        R.  THALLIUM            700.0
G.  COPPER               2500.0        S.  VANADIUM           2400.0
H.  LEAD(INORGANIC)      1000.0        T.  BORON                NONE
I.  LEAD(ORGANIC)          13.0        U.  LITHIUM              NONE
J.  MERCURY                20.0        V.  GOLD                 NONE
K.  MOLYBDENUM           3500.0        W.  SILVER              500.0
L.  NICKEL               2000.0        Z.  RETURN TO MENU

 ENTER SELECTION TO
 INPUT/EDIT VALUE OR Z TO RETURN=====>
```

The Total Threshold Limits Concentration is applied mostly to non-leachable wastes. The default data shown above is for the State of California. User may change the data to reflect other areas of the United States.

If editing any of the values, save the data under "F"-Save Limits To File Filename.TTL.

Once data input is complete, the Process Options Menu may be accessed.

B. PROCESS OPTIONS MENU

Unlike the Data Driving Menu, keying in B does not immediately result in a Process Option Screen being displayed. Instead the computer first compares the constituent metals in the sludge to the STLC limits (because it is normally a liquid based on EPA procedures) and displays those that are above the limit as shown in the example below.

```
              INITIAL SLUDGE IS HAZARDOUS
THE FOLLOWING SLUDGE CONSTITUENTS ARE ABOVE SPECIFIED STLC LIMITS
AND MUST BE REDUCED BY THE FOLLOWING LEVELS TO MEET STANDARDS

MERCURY                -   15.8 PPM
```

If none are at or above hazardous levels the screen displays the message:

```
INITIAL SLUDGE IS NOT HAZARDOUS

   NO TREATMENT NECESSARY
```

By pressing return, similar statements may be found for the supernate:

```
              INITIAL SUPERNATE IS HAZARDOUS
THE FOLLOWING SUPERNATE CONSTITUENTS ARE ABOVE SPECIFIED STLC LIMITS
AND MUST BE REDUCED BY THE FOLLOWING LEVELS TO MEET STANDARDS

MERCURY                -   23.8 PPM
```

or

```
INITIAL SUPERNATE IS NOT HAZARDOUS

   NO TREATMENT NECESSARY
```

If the waste in either case is non-hazardous no treatment will be needed since unnecessary treatment will more than likely increase costs. Current disposal cost will instead be printed on screen as shown below:

```
                    PROCESS RESULTS

                 NON-HAZARDOUS SLUDGE
                NO TREATMENT NECESSARY

PERIOD OF ANALYSIS - 30 YRS

                                    LEVELIZED COST
                                  $000/YR     $/KWH
                                  *******     *****
CURRENT DISPOSAL                    376       1.0092

NON-HAZARDOUS DISPOSAL              125       0.3364
```

Hazardous Sludge Case

If the sludge is hazardous the user may choose from process options A-D by hitting "return" to display the Process Option Screen, as shown below:

B Process Options Menu

```
                                                  PRESS F1 FOR HELP
|----------------------------------------------------------------|
|                    PROCESS OPTIONS MENU                        |
|----------------------------------------------------------------|
| A. BIOLEACHING                                                 |
| B. SLUDGE DETOXIFICATION                                       |
| C. SLUDGE SOLIDIFICATION                                       |
| D. SUPERNATE METAL REMOVAL                                     |
|                                                                |
|----------------------------------------------------------------|
|                    Z. RETURN TO MAIN MENU                      |
|----------------------------------------------------------------|
  ENTER SELECTION =====>
```

A. Bioleaching

If bioleaching is chosen, the sludge is processed using the high and low bioleaching metal removal efficiencies. The processed sludge's flow rate is then used to determine ppm levels for any remaining metals. If the ppm levels of these metals are still above STLC standards, the hazardous metals and their concentrations are displayed as shown in the example below:

```
      PROCESSED SLUDGE IS HAZARDOUS - HIGH METAL REMOVAL SCENARIO
   THE FOLLOWING SLUDGE CONSTITUENTS ARE ABOVE SPECIFIED STLC LIMITS
   AND MUST BE REDUCED BY THE FOLLOWING LEVELS TO MEET STANDARDS

MERCURY                  -    15.8 PPM
```

A remaining hazardous metals screen similar to the one above is then generated for the low removal efficiency.

```
      PROCESSED SLUDGE IS HAZARDOUS - LOW METAL REMOVAL SCENARIO
   THE FOLLOWING SLUDGE CONSTITUENTS ARE ABOVE SPECIFIED STLC LIMITS
   AND MUST BE REDUCED BY THE FOLLOWING LEVELS TO MEET STANDARDS

MERCURY                  -    15.8 PPM
```

After hitting return, the model outputs will be displayed under the heading Process Results.

```
                        PROCESS RESULTS

                          BIOLEACHING
                          ***********

   PERIOD OF ANALYSIS - 30 YRS
                                            LEVELIZED COST
                                   $000/YR                    $/KWH
                                   *******                    *****
   CURRENT DISPOSAL                    376                   1.0092

   PROCESS COSTS
     CAPITAL($ 2,425,145)          192,235                 516.3442
     O+M                             1,832                   4.9220
     CHEMICALS                         833                   2.2374

   DISPOSAL COSTS
     NON-HAZARDOUS            0 TO     125      0.0000 TO    0.3364
     HAZARDOUS               38 TO     413      0.1009 TO    1.1101

                     HIT <RETURN> TO CONTINUE
```

Bioleaching process O&M and disposal costs based on flow rates, low and high metal removal efficiencies and ppm levels of the sludge are compared with current disposal costs. It is assumed the bioleachate will be trucked to a hazardous waste disposal site.

User should print the screen to obtain hard copies of model results.

B. Sludge Detoxification

The maximum levelized cost and metal removal efficiencies of the sludge detoxification process, required to render the sludge as non-hazardous based on STLC limits, are calculated based on sludge metal concentrations and specified threshold limits. The maximum levelized cost, determined by the program, is the annual cost, consisting of amortized capital and O&M costs, which would allow a detoxification process to compete with current disposal practices.

PROCESS RESULTS

DETOXIFICATION
****

PERIOD OF ANALYSIS - 30 YRS

	LEVELIZED COST	
	$000/YR	$/KWH
	*******	*****
CURRENT DISPOSAL	376	1.0092
PROCESS COSTS		
MAXIMUM	250	0.6718
DISPOSAL COSTS		
NON-HAZARDOUS DISPOSAL	125	0.3359
HAZARDOUS DISPOSAL	1	0.0015

REMOVAL EFFICIENCIES PRESENTED ON NEXT SCREEN

HIT <RETURN> TO CONTINUE

On the first screen shown above the maximum process cost for non-hazardous disposal is displayed along with current disposal costs.

On the second screen, displayed after hitting return, the minimum removal efficiencies needed to reduce hazardous metal concentrations to 10% below standards are shown.

PROCESS RESULTS

MINIMUM DETOXIFICATION PROCESS REMOVAL EFFICIENCIES

METAL	(%)	METAL	(%)
*****	******	*****	******
BARIUM	0.0	ZINC	0.0
BERYLLIUM	0.0	ANTIMONY	0.0
CADMIUM	0.0	ARSENIC	0.0
CHROMIUM(VI)	0.0	FLOURIDE	0.0
CHROMIUM(III)	0.0	SELENIUM	0.0
COBALT	0.0	THALLIUM	0.0
COPPER	0.0	VANADIUM	0.0
LEAD(INORGANIC)	0.0	BORON	NONE
LEAD(ORGANIC)	NONE	LITHIUM	NONE
MERCURY	1.1	GOLD	NONE
MOLYBDENUM	0.0	SILVER	0.0
NICKEL	0.0		

C. Sludge Solidification

The solidification process calculates maximum levelized cost, including amortized capital and O&M costs, for a 50%, 75% and 100% increase in percent weight solids. The maximum process costs are the costs which would make a solidification process competitive with current disposal practices, and are determining by comparing the cost of disposing a hazardous solid (TTLC limits) with current disposal costs. Exactly at what percent solids content a waste can be considered a solid cannot be determined.

PROCESS RESULTS

SOLIDIFICATION
****

PERIOD OF ANALYSIS - 30 YRS

LEVELIZED COST

PROCESS	MAXIMUM PROCESS COST $000/YR	MAXIMUM PROCESS COST $/KWH	DISPOSAL COSTS $000/YR	DISPOSAL COSTS $/KWH
*******	*******	*****	*******	*****
CURRENT LIQUID DISPOSAL (0.2 % WGT SOLIDS)			376	1.0092
SOLIDS DISPOSAL				
(50.1 % WGT SOLIDS)	38	0.1027	7	0.0183
(75.1 % WGT SOLIDS)	40	0.1083	5	0.0127
(100.0 % WGT SOLIDS)	41	0.1111	4	0.0099

User should print the screen for a hard copy of model results.

D. Hazardous Supernate Case

If Supernate Metal Removal is chosen, the supernate is processed using the chosen metal treatment (lime, alum or iron solution) processes' high metal removal efficiencies. If any of the remaining metals in the processed supernate are still above STLC limits, their over-limits levels are individually displayed as shown in the example below.

```
PROCESSED SUPERNATE IS HAZARDOUS - HIGH METAL REMOVAL SCENARIO
THE FOLLOWING SUPERNATE CONSTITUENTS ARE ABOVE SPECIFIED STLC LIMITS
AND MUST BE REDUCED BY THE FOLLOWING LEVELS TO MEET STANDARDS

MERCURY                    -    9.4 PPM
```

The initial supernate is also processed using the metal treatment processes' low metal removal efficiencies. A screen showing the remaining hazardous metals similar to the one above is then generated as shown below.

```
PROCESSED SUPERNATE IS HAZARDOUS - LOW METAL REMOVAL SCENARIO
THE FOLLOWING SUPERNATE CONSTITUENTS ARE ABOVE SPECIFIED STLC LIMITS
AND MUST BE REDUCED BY THE FOLLOWING LEVELS TO MEET STANDARDS

MERCURY                    -   16.6 PPM
```

Model results are then displayed under the heading Supernate Metal Removal.

PROCESS RESULTS

SUPERNATE METAL REMOVAL
****

PERIOD OF ANALYSIS - 30 YRS

	LEVELIZED COST $000/YR *******	$/KWH *****
CURRENT DISPOSAL	376	1.0092
PROCESS COSTS (LIME ADDITION)		
CAPITAL($ 415,774.)	32,957	88.5236
O+M	14,145	37.9943
CHEMICALS	9	0.0253
MAXIMUM METAL SALES REVENUE		
LOW REMOVAL EFFICIENCY	8	0.0224
HIGH REMOVAL EFFICIENCY	25	0.0677

HIT <RETURN> TO CONTINUE

Current disposal costs are compared with process costs and maximum metal sales revenue that may be generated by the recovered metals. The calculated metals' revenues are theoretical maximums based on metal ores with no impurities.

User should print screen the results for further analysis.

3.0 CONCLUSION

As outlined in the statement of work, the objective of this project was to develop a decision-making model which assessed the relative economics of alternative sludge/supernate waste treatment options versus those of direct disposal. Throughout the development of this model, the project team encountered numerous obstacles in formulating the algorithims needed for this assessment. Two main obstacles in particular were:

- Lack of Real-time Geothermal Based Treatment Options. After conducting an extensive literature search, no working example of a treatment option system tailored for geothermal plants was found. In light of this fact, bench-scale experiments conducted by Brookhaven National Laboratory on the bioleaching of sludge were used as the cost-basis for the bioleaching option in EDM-GSD. Additionally, precipitation/coagulation methods widely used in heavy industry and previously employed in pilot plant-scale experiments on geothermal brine were used as the cost-basis of the supernate treatment option.

- The Complexity of Chemical Reactions. Because of the varying nature of the chemistry of geothermal waste, it was - and still is - impossible to accurately predict if the precipitation method employed at one site will be equally effective or cost the same at another site. Uniformity had to be assumed in this model.

Model assumptions aside, built-in versatility helped by-pass these and other obstacles by contributing to the structure of the model as shown in Figure 2. At most points of the flow chart, for example, users are given the option to input pertinent, accurate and often proprietary information on the sludge, supernate and treatment option in question; thereby reducing the inaccuracies of the default data being utilized. EDM-GSD's versatility is further highlighted by the fact that while it's design is based on a 50 MW flash plant, it focuses on the end-product of the plant thereby becoming applicable to most end-products of open-cycle plants.

By taking advantage of this versatility, a geothermal manager can conduct useful preliminary studies on alternative waste disposal techniques for geothermal end-products using the results generated by EDM-GSD. Successive runs of the model using different regulatory and economic scenarios will further enable the manager to analyze the cost-effectiveness of the various treatment alternatives while determining the cost associated with conventional hauling practices.

Test runs of the model, conducted by the project team indicate that bioleaching is not cost effective at the present time. (See, for example, on page 23 a capital cost figure of over 2 million dollars for a sludge flow rate of 5,500 lb/hr). However, supernate removal techniques do appear marginally cost effective even assuming only a small segment of the metal market is available for the recovered metals. (Results on page 35 assume a 100 percent market acceptance of the recovered metals at market price. Even 1/2 of 1 percent of this total, however, appears to more than offset the cost of either processing the supernate or hauling it to a disposal site).

APPENDIX A

COST FUNCTIONS

COST FUNCTIONS

Cost functions for treatment processes in the EDM-GSD's model were developed using geothermal and conventional waste treatment references (Appendix B). Conventional treatment references were included when it became apparent that while several geothermal refernces had attempted to develop individual cost functions for certain components of a treatment system, none had attempted to compile complete plant figures.

Supernate Treatment Cost Functions

The complete supernate treatment plant system employed by the model is shown in Figure A.1. The complex liquid (supernate) first enters the rapid mixer where the required chemicals (lime, alum, or iron solution) are added from the chemical feed system. The supernate stays in the rapid mixer until the practical limits of metal precipitation and coagulation have been reached. Many significant assumptions on reaction temperature, pH level and metal compounds formed during the reaction have been made at this point to keep the model from being too complex.

The reacted supernate is next fed to the flocculator, where the precipitants and coagulants are "bubbled" to the top of the liquid stream for removal by the clarifier. The remaining liquid stream, with its reduced constituents level, is discharged to the reinjection well already in place at most geothermal locations.

After being removed by the clarifier, the precipitant and coagulant stream is passed on to the thickener to further reduce its liquid content. The stream then leaves the thickener to enter the filtration system.

The type of filtration system used is very much dependent on the entering stream's characteristics. Generally, a filter press may be installed but for

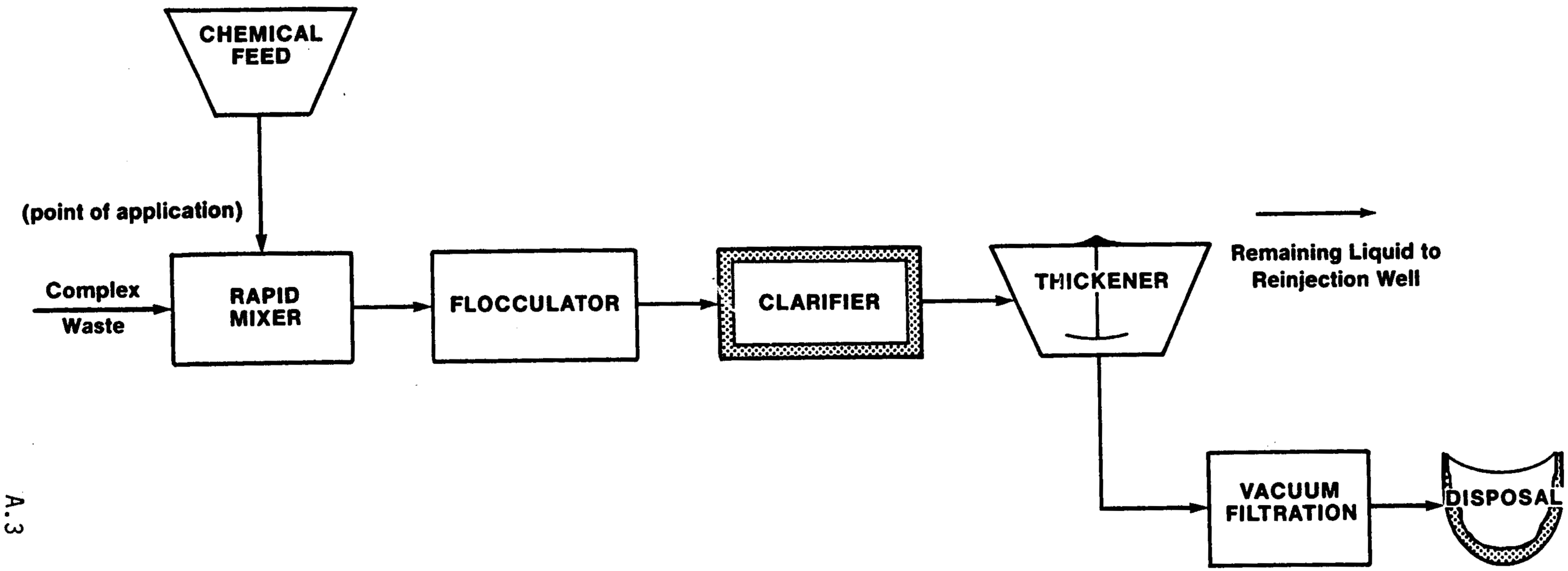

Figure A.1
STANDARD COMPLEX WASTE TREATMENT PROCEDURE

maximum effectiveness a vacuum filter may be used. A precipitant and coagulant stream leaving a vacuum filter is usually a 60-90% solids content cake ready for easy disposal or for use at a metal ore processing plant.

Costs for the various components of the system are outlined in Table A.1 and A.2 together with the main sources used. Very often, separate sources have been used to verify cost figures. Specific diagrams for lime, alum and iron based chemical feed systems (which are required before the waste treatment procedures) are shown in Figures A.2 through A.5.

Bioleaching Process Cost Functions

The complete bioleaching treatment process, as developed by Brookhaven National Laboratory is shown in Figure A.6. Thickener costs are the same as those developed for the supernate treatment process. Pump costs are fixed at $10,000/pump. Filter presses are also assumed to be fixed at $300,000/press.

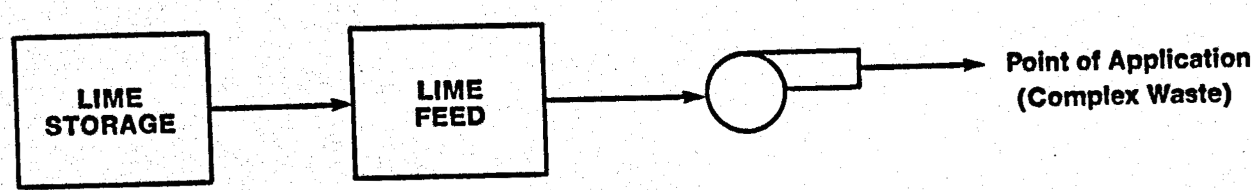

Figure A.2
LIME STORAGE AND FEED SYSTEM

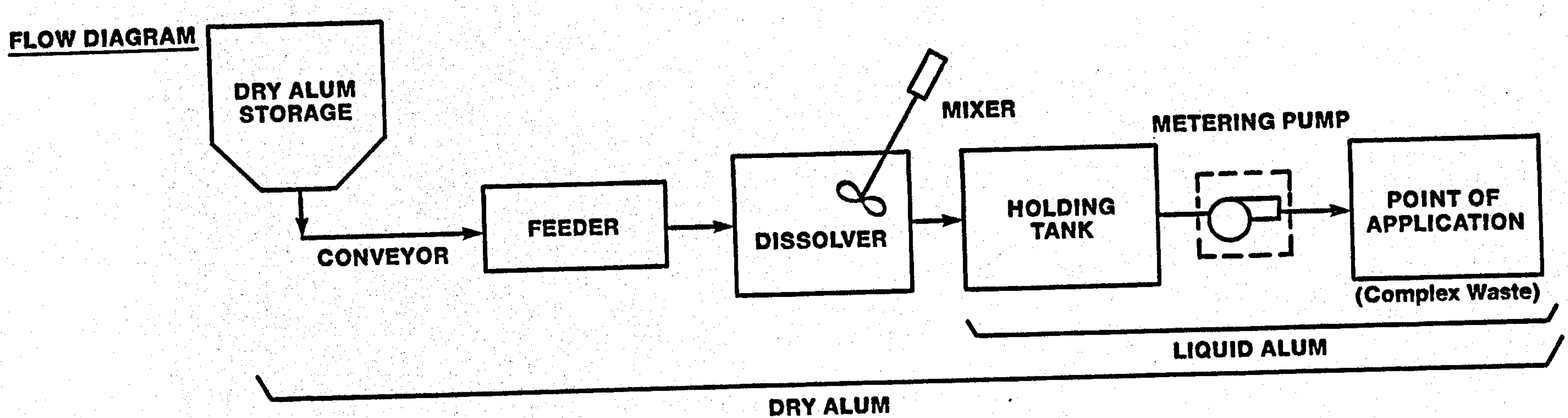

Figure A.3
ALUM STORAGE AND FEED SYSTEM

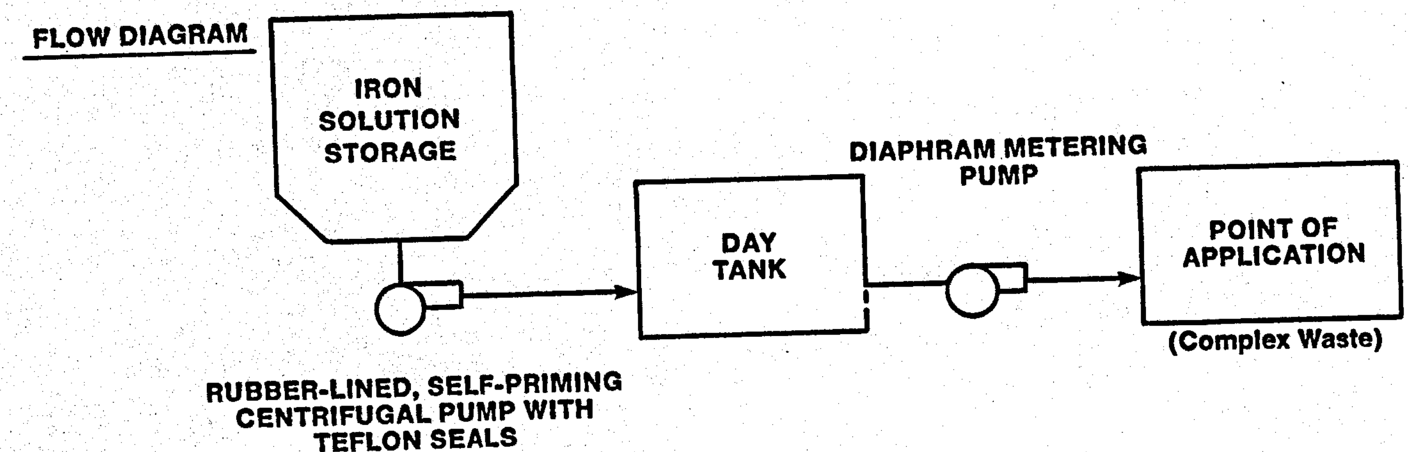

Figure A.4
IRON BASED STORAGE AND FEED SYSTEM

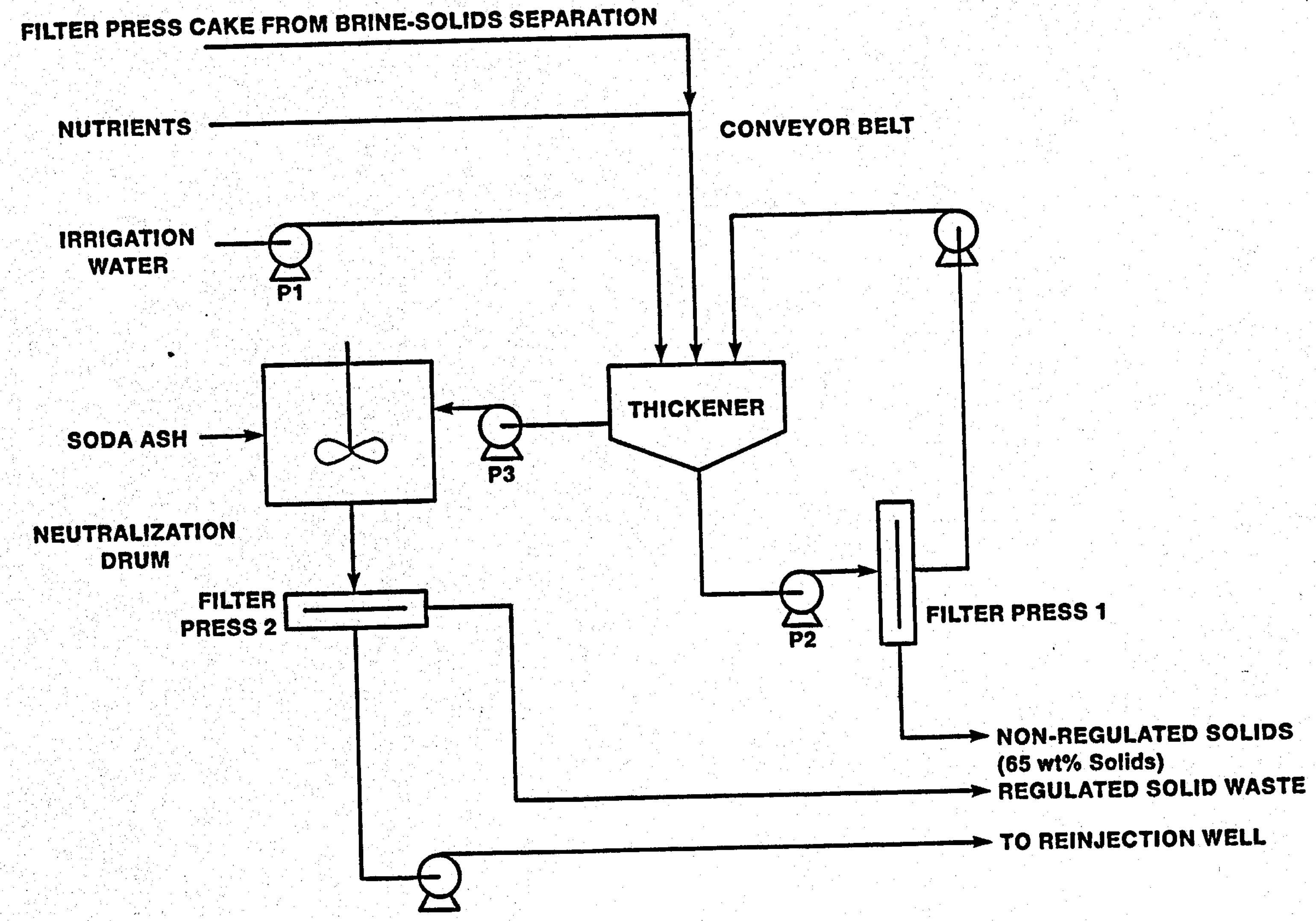

Figure A.5
BIOLEACHING WASTE-TREATMENT PLANT

Chemical Feed System	PRIMARY COST BASIS				Main Source(s) (Developer - Title)
	Formula-Based	Updated From	Cost Graph Extrapolated (By Medium)	Updated From	
Lime	X	1980			The Cost of Meeting Geo. Liquid Effluent Disposal Regulations[1]
Lime			X	1980	EPA Innovative and Alternative Technology Assessment Manual[2]
Lime	X	1980			TRW/EPA-Preliminary Cost Estimates of Pollution Control Technologies for Geothermal Development[3]
Alum	X	1980			(1)[A]
Alum			X		(2)
Alum	X	1980			(3)
Iron	X				(1)
Iron			X	1980	(2)
Iron	X	1980			(3)

TABLE A.1 CHEMICAL FEED COST FUCTIONS

(A. Numbers in brackets refer to superscripts of titles above)

Component	Formula-Based	Updated From	Cost Graph Extrapolated (By Medium)	Updated From	Main Source(s) (Developer - Title)
Rapid Mixer			X	1973	Patterson-Industrial Wastewater Treatment Technology(1)
Floculator			X		(1)
			X	1980	EPA-Innovative and Alternative Technology Assessment Manual(2)
			X	1979	Cushnie-Removal of Metals from Waste Water(3)
			X	1978	Culp-Handbook of Advanced Wastewater Treatment(4)
Clarifier			X	1973	(1)
			X	1980	(2)
			X	1979	(3)
	X	1980			PNL 2991-The Cost of Meeting Geothermal Liquid Effluent Disposal Regulations(5)

TABLE A.2 COMPONENT COST FUNCTION

Component	Formula-Based	Updated From	Cost Graph Extrapolated (By Medium)	Updated From	Main Source(s) (Developer - Title)
Thickener			X	1973	(1)
			X	1980	(2)
			X	1979	(3)
	X	1980			(4)
			X	1978	(5)
Filtration			X	1973	(1)
			X	1980	(2)
			X	1979	(3)
	X	1980			(5)
			X	1978	(4)

TABLE A.2 COMPONENT COST FUNCTIONS (Continued)

APPENDIX B

REFERENCES

Reference List of Books and Reports
Reviewed for the Model

Books:

Carberry, J.B.; Englande, A.; (eds.), Sludge Characteristics and Behavior. Boston: Martinus Nijhoff Publishers, 1983.

Culp, R.L.; Wesner, G.M.; Culp, G.L., Handbook of Advanced Wastewater Treatment, 2nd Edition. New York: Van Nostrand Reinhold Company, 1978.

Cushnie, G.C. Jr. (ed.), Removal of Metals from Wastewater - Neutralization and Precipitation, Pollution Technology Review., No. 107. New Jersey: Noyes Publications, 1984.

Eckenfelder, W.W. Jr. and Santhanam, C.J. (eds.), Sludge Treatment. New York: Marcel Dekker, Inc., 1981.

Patterson, J.W., Industrial Wastewater Treatment Technology, 2nd edition. Boston: Butterworth Publishers, 1985.

Russell, S.H., Resource Recovery Economics - Methods for Feasibility Analysis. New York: Marcel Dekker, Inc., 1982.

Shuckrow, A.J.; Pajak, A.P. and Touhill, C.J., Hazardous Waste Leachate Management Manual, Pollution Technology Review, No. 92. New Jersey: Noyes Publications, 1982.

Sitting, M., Landfill Disposal of Hazardous Wastes and Sludges, Pollution Technology Review, No 62. New Jersey: Noyes Publications, 1979.

Vesilind, P.A.; Hartman, G.C. and Skene, E.T., Sludge Management and Disposal for the Practicising Engineer. Michigan: Lewis Publishers, Inc., 1986.

Papers:

Bell, J. (ed.), Proceedings of the 36th Industrial Waste Conference, May 12, 13 and 14, 1981, Purdue University. Michigan: Ann Arbor Science Publishers, 1982.

Ibid., 34th Conference, 1980.

Reports:

Preliminary Cost Estimates of the Pollution Control Technologies for Geothermal Developments. Prepared by TRW for EPA-600/7-79-2-25.

National Forecast for Geothermal Resource Exploration and Development. Prepared by TAR for DOE AC02-79ET2742.

The Cost of Meeting Geothermal Effluent Control Standards. Prepared by PNL for DOE AC06-76RLO 1830.

Solid Wastes from Geothermal Energy Operation. Prepared by EER for DOE AC07-ID-12183.

An Analysis of Environmental Regulations Governing the Disposal of Geothermal Wastes in California. Prepared by BNL for DOE AC02-76CH0016.

Bioleaching of Toxic Metals from Geothermal Waste; a Preliminary Engineering Analysis. Prepared by BNL for DOE AC02-76CH0016.

State-of-the-Art of Liquid Waste Disposal for Geothermal Energy Systems. Prepared by DOE.

Updated Cost Estimates of Meeting Geothermal Hydrogen Sulfide Emission Regulation. Prepared by PNL for DOE AC06-76RLO-1830.

Process Technology for Recovering Geothermal Brine Materials. Prepared by Hazen Research for Bureau of Mines OFR 35-75.

The Recovery and Separation of Mineral Values from Geothermal Brines. Prepared by Hazen Research for Bureau of Mines OFR 81-75.

Innovative and Alternative Technology Assessment Manual. Prepared by the Office of Research and Development's Municipal Environmental Research Laboratory for the EPA.

Estimating Water Treatment Costs, Volume 3, Cost Curves Applicable to 2500 gpd to 1 mgd Treatment Plant. EPA 600/2-79-162c, USEPA, Cincinnati, Ohio, 1979.