EPA
TVA

United States Environmental Protection Agency
Industrial Environmental Research Laboratory
Research Triangle Park, NC 27711
EPA-600/8-85-006
March 1985

Tennessee Valley Authority
Power and Engineering
Energy Demonstrations and Technology
Muscle Shoals, AL 35660
TVA/OP/EDT-84/37

Shawnee Flue Gas Desulfurization Computer Model Users Manual

Interagency Energy/Environment R&D Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the SPECIAL REPORTS series. This series is reserved for reports which are intended to meet the technical information needs of specifically targeted user groups. Reports in this series include Problem Oriented Reports, Research Application Reports, and Executive Summary Documents. Typical of these reports include state-of-the-art analyses, technology assessments, reports on the results of major research and development efforts, design manuals, and user manuals.

EPA REVIEW NOTICE

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/8-85-006
TVA/OP/EDT-84/37
March 1985

Shawnee Flue Gas Desulfurization Computer Model Users Manual

by

F.A. Sudhoff and R.L. Torstrick

TVA, Power and Engineering
Division of Energy Demonstrations and Technology
Muscle Shoals, Alabama 35660

EPA Interagency Agreement No. 79-D-X0511

EPA Project Officer: J. David Mobley

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

DISCLAIMER

This report was prepared by the Tennessee Valley Authority and has been reviewed by the Office of Energy, Minerals, and Industry, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Tennessee Valley Authority or the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

In conjunction with the U.S. Environmental Protection Agency (EPA)-sponsored Shawnee test program, Bechtel National, Inc., and the Tennessee Valley Authority (TVA) jointly developed a computer model capable of projecting preliminary design and economics for lime- and limestone-scrubbing flue gas desulfurization (FGD) systems. The model is capable of projecting relative economics for spray tower, turbulent contact absorber (TCA), and venturi-spray tower scrubbing options. It may be used to project the effect on system design and economics of variations in required SO_2 removal, scrubber operating parameters [gas velocity, liquid-to-gas (L/G) ratio, alkali stoichiometry, liquor hold time in slurry recirculation tanks], reheat temperature, and scrubber bypass. It may also be used to evaluate alternative waste disposal methods or additives (MgO or adipic acid) on costs for the selected process. Although the model is not intended to project the economics of an individual system to a high degree of accuracy, it allows prospective users to quickly project comparative design and costs for limestone and lime case variations on a common design and cost basis.

The users manual provides a general description of the Shawnee FGD computer model and detailed instructions for its use. It describes and explains the user-supplied input data which are required such as boiler size, coal characteristics, and SO_2 removal requirements. Output includes a material balance, equipment list, and detailed capital investment and annual revenue requirements. The users manual provides information concerning the use of the overall model as well as sample runs to serve as a guide to prospective users in identifying applications. The FORTRAN-based model is maintained by TVA, from whom copies or individual runs are available.

CONTENTS

FIGURES

TABLES

ABBREVIATIONS AND CONVERSION FACTORS

ABBREVIATIONS

aft3/min	actual cubic feet per minute
Btu	British thermal unit
^{o}F	degrees Fahrenheit
dia	diameter
FGD	flue gas desulfurization
ft	feet
ft2	square feet
ft3	cubic feet
gal	gallon
Ggal	10^9 gallons
gpm	gallons per minute
gr	grain
hp	horsepower
hr	hour
in.	inch
k	thousand
kW	kilowatt
kWh	kilowatthour
lb	pound
L/G	liquid-to-gas ratio in gallons per thousand actual cubic feet of gas at outlet conditions
M	million
mi	mile
mo	month
MW	megawatt
ppm	parts per million
psig	pounds per square inch (gauge)
rpm	revolutions per minute
SCA	specific collection area
sec	second
sft3/min	standard cubic feet per minute ($60^{o}F$)
SS	stainless steel
yr	year

CONVERSION FACTORS

EPA policy is to express all measurements in Agency documents in metric units. Values in this report are given in British units for the convenience of engineers and other scientists accustomed to using the British systems. The following conversion factors may be used to provide metric equivalents.

To convert British		Multiply by	To obtain Metric	
ac	acre	0.405	hectare	ha
Btu	British thermal unit	0.252	kilocalories	kcal
°F	degrees Fahrenheit minus 32	0.5556	degrees Celsius	°C
ft	feet	30.48	centimeters	cm
ft^2	square feet	0.0929	square meters	m^2
ft^3	cubic feet	0.02832	cubic meters	m^3
ft/min	feet per minute	0.508	centimeters per second	cm/s
ft^3/min	cubic feet per minute	0.000472	cubic meters per second	m^3/s
gal	gallons (U.S.)	3.785	liters	L
gpm	gallons per minute	0.06308	liters per second	L/s
gr	grains	0.0648	grams	g
gr/ft^3	grains per cubic foot	2.288	grams per cubic meter	g/m^3
hp	horsepower	0.746	kilowatts	kW
in.	inches	2.54	centimeters	cm
lb	pounds	0.4536	kilograms	kg
lb/ft^3	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3
lb/hr	pounds per hour	0.126	grams per second	g/s
psi	pounds per square inch	6895	pascals (newton per square meter)	Pa (N/m^2)
mi	miles	1609	meters	m
rpm	revolutions per minute	0.1047	radians per second	rad/s
sft^3/min	standard cubic feet per minute (60°F)	1.6077	normal cubic meters per hour (0°C)	m^3/hr (0°C)
ton	tons (short)	0.9072	metric tons	tonne
ton/hr	tons per hour	0.252	kilograms per second	kg/s

SHAWNEE FLUE GAS DESULFURIZATION COMPUTER MODEL

USERS MANUAL

EXECUTIVE SUMMARY

The Shawnee lime-limestone computer model was developed by Bechtel National, Inc., and the Tennessee Valley Authority (TVA) to model lime-limestone wet-scrubbing flue gas desulfurization (FGD) systems and is capable of projecting comparative investment and revenue requirements for these systems. The computer model has been developed to permit the rapid estimation of relative economics of these systems for variations in process design alternatives (i.e., limestone versus lime scrubbing, alternative scrubber types, or alternative sludge disposal methods), variations in the values of independent design parameters [i.e., scrubber gas velocity and liquid-to-gas (L/G) ratio, alkali stoichiometry, slurry residence time, reheat temperature, and specific sludge disposal design], and the use of additives (MgO or adipic acid). Although the model is not intended to compute the economics of an individual system to a high degree of accuracy, it is based on sufficient detail to allow the quick projection of preliminary conceptual design and costs for various lime-limestone case variations on a common design and cost basis.

PROGRAM DEVELOPMENT

The technical development of the Shawnee lime-limestone computer model is based on actual data obtained at the Shawnee test facility. Bechtel and TVA shared the responsibility of model development. Bechtel was responsible for analyzing the test results and developing the models which calculate the overall material balance flow rates and stream compositions. Bechtel provided these models to TVA. TVA was responsible for determining the size limitations of the required equipment to establish the minimum number of parallel equipment trains, accumulating cost data for the major equipment items, and developing models for projecting equipment and field material costs as a function of equipment capacity. Utilizing these relationships, TVA developed models to project the overall investment cost breakdown and a procedure for using the output of the material balance and investment models as inputs to a previously developed TVA model for projecting annual and lifetime revenue requirements.

The model has been periodically updated to include new or improved data and process developments in FGD. The basic processes in the current model consist of limestone and lime scrubbing; spray tower, turbulent contact absorber (TCA), and venturi-spray tower absorbers; and pond or landfill disposal. Process options include three alternative modes of forced oxidation

and provisions for MgO or adipic acid addition. Several dozen additional input and output options provide further flexibility in the use of the model.

The specific mathematical treatments of material balances, including SO_2 removal efficiencies, are not fully documented in published works. Descriptions of the mathematical treatment of SO_2 removal in spray tower and TCA are given in Shawnee test facility reports (1).

The absorption of SO_2 into scrubbing liquid approximates the mass transfer situation of absorption followed by a chemical reaction, a circumstance for which no comprehensive theoretical basis exists. Such treatment requires mathematical expressions of turbulent fluid behavior and reaction orders that cannot be rigorously defined. Overall mass transfer models are usually based on modifications of general theoretical treatments that differ in concept but mathematically approach similar conclusions in some cases. Standard references (2) and texts (3) provide discussions and access to the literature.

In practice, the mass transfer functions are reduced by a number of simplifying assumptions based on a knowledge of the system and the likely or probable important and unimportant factors. The mathematical expression at once becomes manageable and specific to the situation, to which it can be further correlated empirically. The development of such expressions is discussed in detail by Wen and Fan (4), Rochelle and King (5), Chang and Rochelle (6), and Wen and others (7), for specific FGD applications.

The Shawnee model expression is simplified by the assumptions that liquid-side resistance controls the absorption rate and that liquid-phase *reactions are not limiting (that is, dissolved* SO_2 *does not significantly* affect the absorption rate). Both of these assumptions are supported by experimental results (1).

$$SO_2 = 1 - \exp\left[- \phi \, K_L^o az/Hv\right]$$

The simplified expression for the fraction of SO_2 removed contains an enhancement factor, ϕ, to represent the effects of chemical reaction and a group (consisting of a liquid-side mass transfer coefficient, K_L^o; interfacial area, a; vertical distance, z; Henry's law constant, H; and gas velocity, v) to represent physical absorption. The enhancement factor contains expressions for pH, effective magnesium, flue gas, SO_2 content, and in some cases, chloride concentration. The expression is fitted to Shawnee test facility data for each particular absorber and absorbent combination using eight coefficients. The fitted expressions have standard errors of estimate of about 4%. Pressure drop expressions for the three absorbers were developed by fitting expressions containing pertinent variables to Shawnee test facility data. The development of these expressions is discussed in the Shawnee test facility reports and symposium proceedings cited.

MODEL CAPABILITY

The Shawnee lime-limestone scrubbing model is capable of projecting a complete conceptual design package for these systems utilizing a spray tower, TCA, or venturi-spray tower absorber, each with or without use of additives; and with any of five sludge disposal options, including options with and without forced oxidation. Flow diagrams illustrating these process alternatives are shown in Appendix A. Ranges for basic design parameters are shown below.

Plant size	100-1,300 MW
Coal sulfur	2%-5% (1,500-4,000 ppm SO_2)
Scrubber gas velocity	8-12.5 ft/sec
Liquor recirculation rate	25-120 gal/aft3 (at scrubber outlet)
Slurry residence time	2-25 min
Scrubber slurry solids	5%-15%
Reheat (steam)	225°F maximum reheat temperature

Results for conditions outside these design ranges are not necessarily invalid but are subject to potential reduced accuracies.

The output of the model includes projections of annual and lifetime revenue requirements to allow comparison of the economics of the alternative system designs. The basis for these projections is described in the report appendices.

The process technology is divided into seven major areas to facilitate projection of the process design and the estimated capital investment. The facilities included in each area are identified in the process description along with the basis for design of the FGD system.

PROCESS DESCRIPTION

Processing Areas

The seven major processing areas used to define the limestone- and lime-scrubbing systems are identified below along with a description of the facilities included within the battery limits of each processing area, and the basis for design of these facilities.

Raw Material Handling--

This area provides for receiving either limestone or lime. For the limestone slurry process, the raw material-handling area includes equipment for receiving limestone by truck or rail, a storage stockpile, and live in-process limestone storage equipment.

For the lime slurry process, the raw material-handling area includes equipment for receiving lime by truck or rail and a storage silo.

The direct investment costs for the raw material-handling area includes costs for all of the lime-limestone receiving equipment and field construction materials up to and including the raw material feed bin.

Raw Material Preparation--

This area provides for preparation of a limestone or lime slurry for feed to the SO_2 scrubbing area. The raw material preparation area for the limestone slurry process includes gyratory crushers for crushing the limestone for feed to the wet ball mills. The wet ball mills grind the limestone to the desired size for feed to the scrubbers. The product slurry from the mills at a concentration of 60% solids is pumped to a slurry feed tank adjacent to the scrubbing area for distribution to the scrubbers.

The raw material preparation area for the lime slurry process includes equipment for slaking the lime at a concentration of 20% to 25% solids for feed to the scrubbers. The product slurry from each of the slakers overflows to a slurry receiving tank from which it is pumped to a common slurry feed tank. The slurry is then pumped to the scrubbing area for distribution to the scrubbers.

The direct investment costs for the feed preparation area include all preparation equipment and field construction materials from the raw material bin weigh feeder to the slurry feed tanks.

Gas Handling--

Flue gas from the power unit ducts is fed to a common plenum from which any number of scrubber trains can be fed. To minimize the problems associated with gas distribution for such a system, separate fans are included on each side of the plenum. The power plant fans are conventional induced-draft (ID) fans for balanced-draft boilers. The scrubber fans can be specified as forced-draft (FD) or ID and are designed to overcome the pressure drop of the pollution control facilities.

The direct investment costs for the gas-handling area include costs for the flue gas equipment and field materials downstream of the air heater up to, but excluding, the stack plenum. Costs for the scrubber fans are included; however, costs for the power plant fan, the stack plenum, and the stack are considered to be an integral part of the power plant and are, therefore, not included in the estimate.

SO_2 Scrubbing--

Flue gas is contacted with a lime or limestone slurry in either a spray tower, TCA, or venturi-spray tower. The absorbers are equipped with a chevron-vane mist elimination system designed for upstream and downstream wash with fresh makeup water. Makeup lime or limestone slurry from the slurry feed tank and recycled supernate or filtrate from the waste disposal area are fed to the absorber hold tanks where they are blended with the slurry draining from the absorber. The slurry recirculation loop can be designed for use of either one or two hold tanks below the absorber. For the 2-tank option, if forced oxidation is specified, air is injected into the tank which receives the effluent from the scrubber. Scrubber slurry is bled from this tank for disposal. Overflow from this tank flows by gravity to the second tank where fresh limestone slurry is added. The combined slurry is then recirculated to the absorber and either the presaturator or venturi, depending on the process selected. The bleedstream is pumped to the waste disposal area where the sludge is dewatered. The supernate or filtrate is returned to the scrubbing and raw material preparation areas. The SO_2 scrubbing area can be designed without the use of additives or with the use of either (1) MgO or (2) adipic acid to enhance SO_2 removal.

The SO_2 removal model can be run with any of the following four options for relating stoichiometry, L/G ratio in the absorber, and SO_2 removal efficiency:

Option	Input	Calculate
1	Stoichiometry, L/G	SO_2 removal
2	Stoichiometry, SO_2 removal	L/G
3	L/G, SO_2 removal	Stoichiometry
4	Stoichiometry, L/G, and SO_2 removal	Force-through alternative, no calculation

Direct investment costs for the SO_2 absorption area include all slurry and SO_2 absorption equipment and field construction materials between the slurry feed tank and the waste disposal feed tank. Costs for a mechanical collector may be included optionally.

Oxidation--

This area is an optional area which provides for oxidation of the SO_2 absorbed as calcium sulfite to calcium sulfate to facilitate subsequent dewatering and disposal of the FGD wastes. If the forced-oxidation option is not specified, the model results are based on only natural oxidation occurring in the scrubbing loop with about 5%-20% of the absorbed SO_2 being in the oxidized (calcium sulfate) form. Two forced-oxidation alternatives are available: (1) within-loop forced oxidation in which air is sparged into the absorber hold tank and scrubber slurry is recirculated to the absorber and (2) bleedstream forced oxidation in which a bleedstream from the absorber is sparged with air in a separate tank with the bleedstream subsequently processed for disposal. In both oxidation alternatives, equipment, primarily compressors and air spargers for option (1) and compressors, air spargers, tanks, agitators, and pumps for option (2), are provided.

Direct investment costs for the oxidation area, when selected, include costs for the equipment and associated field construction materials.

Reheat--

The outlet gas from the scrubber is reheated to the desired temperature by either (1) indirect steam reheat, (2) blending scrubber outlet gas with hot flue gas which bypasses the scrubber (only available if overall SO_2 removal efficiency is less than 90%), or (3) a combination of (1) and (2). The reheater gas is discharged to the stack plenum.

Direct investment costs for the reheat area include costs for the reheater equipment and field construction materials for installation.

Waste Disposal--

The model has provisions for the following five alternate waste disposal options:

1. Onsite pond

   a. Unlined pond

   b. Clay-lined pond (cost and depth of clay lining is input)

   c. Synthetic-lined pond (cost of liner is input)

2. Thickener - pond

3. Thickener - fixation fee

4. Thickener - filter - fixation fee

5. Thickener - filter - landfill

The onsite ponding options may also be run with fixation fees applied to them. For alternatives 3 and 4, the fixation fee must include costs for transportation and disposal of the fixed sludge offsite. For alternatives 1 and 2, however, only the costs for fixation need to be provided since the fixed sludge can be disposed of at the existing pond site. For alternative 5, a landfill-fixation option may be provided using model calculations. Using this option, the disposal facility is appropriately sized for the additional fixation volume requirements.

For the waste disposal alternatives, the model allows for the onsite facility to be sized larger or smaller than the normal projected lifetime capacity. This option has been incorporated (1) to account for variations in the sulfur content of fuel, (2) to evaluate design philosophy in construction of ponds or landfills for less than the total amount of sludge to be disposed (this requires assessment of additional costs for enlarging the waste disposal area later), or (3) to allow the feed preparation and scrubbing areas to be sized based on maximum sulfur contents expected while sizing the waste disposal area based on average sulfur contents.

Direct investment costs for the waste disposal area include costs for the equipment and field construction materials downstream of the waste disposal feed tank including those associated with the supernate return pumps and piping.

<u>Process Equipment Design Basis</u>

Based on results from the material balance model and some user-supplied variables, major process equipment is specified by area. The equations for predicting equipment costs were updated in 1983. The design assumptions used as a basis for projecting the size or specifications of the major process equipment are given below for each major equipment item included in the alternative FGD options.

Gyratory Crushers--

Two parallel 50% capacity gyratory-type crushers are utilized to reduce the inlet stone size from minus 1-1/2 inches to minus 3/4 inch for feed to the ball mills.

Ball Mills--

The grinding mills are rubber-lined, open-circuit, overflow wet ball mills that have a 30% ball charge and produce a 60% slurry. The number of ball mills is determined by total mill horsepower calculated from the limestone throughput rate specified in the material balance, and the fineness of grind and limestone hardness factors which are program inputs. The fineness of grind index factor is related to the desired particle size distribution of the ground limestone. One-mill systems are used for horsepower less than 200 and two parallel mill systems for horsepower between 200 and 5,000. For horsepower greater than 5,000, the number of parallel mill systems is determined assuming a maximum mill size of 2,500 horsepower.

Lime Storage Silo--

A 30-day dead storage capacity is used to calculate the volume of the lime storage silos. The silos are concrete, with the height of the actual storage section of the silo assumed to be one and a half times the diameter. Total height of the silo is equal to the height of the actual storage section plus the height of the carbon steel hopper plus 5 feet. Parallel storage silos are used for storage volumes greater than the capacity of the largest silo (147,200 ft^3).

Lime Slaker--

Lime is slaked at slurry concentrations of 20% to 25% solids in dual-compartment, overflow slakers which can be designed with slaking capacities of up to 33 ton/day. Parallel slaking trains are used for larger lime capacities. The number and size of parallel slakers required are determined based on the capacity of the largest size slaker available (33 ton/day).

Fans--

The fans are centrifugal (double width, double inlet) with radial impellers. The FD fans are constructed of carbon steel and the ID fans are constructed of Inconel 625. They are equipped with variable-speed fluid drives. Fan horsepower is calculated based on the inlet gas flow rate per train and the calculated pressure drop for the scrubber, mist eliminator, reheater, and duct.

Scrubbing Trains--

The following procedures are utilized for determining the size or specifications of the major process equipment in the scrubbing area. The number of parallel scrubbing trains is either an input to the program or is established as an override to the input value based on the minimum number of scrubber trains required. The minimum number of trains is calculated considering the saturated flue gas velocity and volumetric flow rate at the scrubber outlet in conjunction with the maximum cross-sectional area assumed for the scrubber (1,370 ft^2). Flue gas and slurry recirculation rates per train are calculated by dividing the total flow rates from the overall material balance model by the number of operating scrubbing trains.

Scrubbers--

Scrubber cross-sectional area is calculated considering the outlet flue gas rate per train in conjunction with the specified scrubber design gas velocity. Number of scrubber grids, beds, and height of spheres per bed are inputs to the program. The height of the scrubber is assumed to remain constant for all scrubber sizes and internal configurations. A presaturator compartment is included at the scrubber inlet for the TCA and spray tower, and chevron-type mist eliminators are included near the outlet. Materials of construction for the scrubbers and internals are listed below.

Venturi: Carbon steel with acid-resistant lining

Shell: Rubber-lined carbon steel

Grids: Type 316L stainless steel

Spheres: 1-1/2-inch-diameter, Nitrile foam

Mist eliminator, slurry header, and nozzles: Type 316L stainless steel

Tanks--

The size or specifications of tanks, agitators, and pumps for each of the areas are determined by utilizing the following procedures. Tank volume is calculated based on the residence time, which is either a program input or assumed. An additional 10% volume is added for freeboard. All tanks are constructed of carbon steel and the slurry tanks are flake glass lined. Except for the absorber bleed receiving tanks and the thickener overflow tanks, each tank is designed with diameter equal to height up to a maximum height of 60 feet. For tanks larger than 60 feet in diameter, tank height is fixed at 60 feet and diameter is calculated. Absorber bleed receiving tank height is equal to the effluent hold tank height and the diameter is calculated. Thickener overflow tank height is set equal to the height of the thickener and the diameter is calculated. As an override to the calculated diameter, a minimum diameter equal to one-half the height is fixed for all tanks. The thickener and filter feed tanks are not used unless more than one thickener or filter is required.

Agitators--

All slurry tanks are equipped with a 4-blade, pitched-blade, turbine agitator. Agitator horsepower requirements are calculated on the basis of total torque, which is a function of the degree of agitation required (expressed as torque/unit volume), total tank volume, tank diameter, and the slurry specific gravity. Unit torque (torque/unit volume) for each tank is determined as a function of the percent solids in the slurry.

Slurry Pumps--

All slurry pumps are rubber lined, centrifugal with water seals, and are equipped with either a variable- or constant-speed drive. Pumps are usually spared, with the number of operating pumps determined by the maximum available pump size of 20,000 gpm.

Water Pumps--

Vertical, multiple-stage, turbine makeup water pumps capable of providing a static head of 200 feet are provided for each 10,000 gpm of water required. The pumps are carbon steel and spared.

Compressors--

The compressors are sized to provide sufficient air (oxygen) for oxidizing the $CaSO_3 \cdot 1/2H_2O$ to $CaSO_4 \cdot 2H_2O$. The stoichiometric quantity of SO_2 absorbed is multipled by an input stoichiometry, usually 2.5, to determine the stoichiometric quantity of oxygen to be added. The quantity of air is then determined for sizing the compressors.

Reheaters--

Reheater cross-sectional area is calculated based on the superficial gas velocity (usually 20 to 25 ft/sec) which is input to the program and the volumetric gas flow rate per train at scrubber outlet conditions. Reheater surface area requirements are calculated in two steps: (1) surface area requirements for reheat to 150°F and (2) requirements for reheat to the specified reheat temperature. The portion of the reheater tubes required to reheat to 150°F are Inconel and the remaining tubes are Cor-Ten. Reheater design and costs are based on use of 1-inch tubes on a 2-inch square pitch.

Thickeners--

The thickeners are constructed of carbon steel tank walls coated with epoxy paint and 1-foot-thick concrete conical basins. Thickeners are equipped with rake mechanisms. A concrete underflow tunnel, including pumps and piping for transferring the slurry, is included. Total thickener cross-sectional area is calculated by the material balance portion of the model as a function of the settling rate and settled solids density, which are inputs into the program, and the quantity of sludge in the effluent slurry calculated in the material balance model. The number of thickeners required is determined assuming a maximum thickener diameter of 400 feet. Thickener height is calculated as a function of the diameter.

Filters--

Rotary drum vacuum filters constructed of carbon steel and equipped with a vacuum pump, a filtrate pump, and a vacuum receiver are utilized. Filter size is determined as a function of the filtration rate expressed in tons of dry solids/ft^2/day, which is a program input, in conjunction with the total quantity of sludge. The minimum and maximum sizes of filters considered have effective filtration areas of 50 and 900 ft^2, respectively. Single filters are used up to required filtration areas of 100 ft^2. For total filtration areas between 100 and 1,800 ft^2, two parallel filters are assumed. For total filtration areas greater than 1,800 ft^2, the number and size of parallel filters required are determined based on the capacity of the largest filter size.

Field Construction Materials Design Basis

Costs for field construction materials are based on the materials of construction or specifications discussed below.

Piping--

Carbon steel pipe and gate valves are used for all waterlines including pond supernate. For slurry lines less than 3-inch diameter, stainless steel pipe is used; whereas, for all larger size lines, rubber-lined carbon steel piping is used. Stainless steel strainers are used for pipes less than 4-inch diameter and rubber-lined strainers are used for 4-inch-diameter and larger pipes. For slurry lines less than 3-inch diameter, stainless steel plug valves are used. Eccentric plug valves are used for slurry lines between 3- and 20-inch diameter, and knife gate valves are used for lines greater than 20-inch diameter. Handwheel operators are used for valves less than 12-inch diameter and air cylinder actuators for larger valves. Typical piping layouts are assumed as functions of flow capacities and the number of trains and costs are correlated to flow rates in gal/min. Control valve costs are included in instrumentation. Costs are included for a rubber-lined downcomer from the scrubber to the effluent hold tank and a spare slurry disposal line to the disposal site.

Ductwork--

Costs are included for the inlet plenum and all ductwork between the inlet and stack plenums including insulation. Costs for the stack plenum are not included since this plenum is required even if an FGD system is not installed. Stack plenum elevation is set equal to effluent hold tank height with a minimum elevation of 20 feet for small hold tanks. Each scrubber train includes two guillotine dampers and costs for expansion joints.

Two partial scrubbing or emergency bypass ducts, each designed for a minimum of 25% of the total gas flow rate from the boiler, are included in the costs. Each duct includes two louver-type dampers and costs for expansion joints.

Materials of construction for all ductwork is 3/16-inch Cor-Ten with the exception of ductwork between the scrubber and reheater outlet which is 3/16-inch type 316 stainless steel. All ductwork is insulated with 2-inch rock wool. Duct size is based on a square cross section and a nominal design velocity of 3,000 ft/min at local inlet conditions.

Foundations--

Concrete foundations for each equipment item are fixed according to equipment sizes. Foundations for the structure are estimated on the basis of the weight of the structure.

Structures--

Structural estimates are based on the structure arrangement shown in the body of the report. The total quantity of structure required for each scrubber train and the corresponding costs are related to effluent hold tank volume, scrubber cross-sectional area, and number of scrubbing trains.

Electrical--

The electrical estimate is divided into four sections: (1) costs of feeder cables from the power plant transformer yard to field modules for each area; (2) transformer costs for each area; (3) costs of power supply from area field modules to individual motors; and (4) motor control costs between remote control center, field module location, and individual motors for each area. For each area, total connected motor horsepower is calculated for use in establishing costs for (1) and (2). Costs for (3) and (4) are based on individual motor sizes and number of connected motors. A typical layout is assumed for each area in reference to the power plant transformer yard, remote control center, and other areas.

Instrumentation--

Instrumentation costs are based on (1) fixed costs for instruments which do not change in size and cost with equipment and pipe size variations and (2) variable costs for instruments which increase in size and cost as equipment and pipe sizes increase. Each of these costs may be dependent upon number of scrubbing trains, number of ball mills, number of pumps, etc. Costs are included for control valves, graphic boards and panelboards, annunciator, air dryers and piping, and instrument cable and wiring systems.

Buildings--

The control room and motor control center are integrated with the power plant and prorated costs are included. Costs are included for a building to house the limestone-grinding or lime slaking facilities. Buildings to house the oxidation and/or disposal area equipment are included as appropriate. All buildings are sized as a function of the equipment size and number of equipment items and are constructed with concrete floors and corrugated aluminum siding, supported by a steel frame. They are insulated to a value of R-19 using fiberglass insulation.

Pond Construction--

Disposal pond size is calculated based on a square configuration with a diverter dike three-fourths the length of one side. A pond construction diagram is shown in Appendix B. The pond model is based on either unlined, clay-lined, or synthetic-lined design and includes the following options in running the program:

Fixed-depth pond

Optimum-depth pond based on minimum pond investment

Optimum-depth pond based on minimum pond investment with available acreage and maximum excavation depth as overriding constraints

In addition to specifying pond design, the model also itemizes the breakdown of projected pond costs.

Landfill Construction--

Disposal landfill size is calculated based on a square configuration with the cap sloping up to a point. A landfill construction diagram is shown in Appendix B.

A separate model is included to design and cost the onsite landfill. The landfill model is based on either unlined, clay-lined, or synthetic-lined design.

MODEL USAGE

The Shawnee model can be of use to utility companies or architectural and engineering firms involved in the selection and design of SO_2 removal facilities. The model also has potential for use by environmental groups or regulatory agencies. Although it is not intended to be used for projecting a final design, it can be used to assist in the evaluation of system alternatives prior to a detailed design. It should also be useful for evaluating the potential impact of various process variables on economics as a guide for planning.

Although the model was not meant to be used for comparing projected lime-limestone economics with economics for alternate processes, these comparisons should be valid as long as the bases for the alternate process economics are comparable to those included in the computer model for lime and limestone systems.

The body of this report contains information required to run the overall computer model.

SHAWNEE FLUE GAS DESULFURIZATION COMPUTER MODEL

USERS MANUAL

INTRODUCTION

The Shawnee flue gas desulfurization (FGD) computer model projects the major design and operating conditions and the detailed economics of various lime and limestone FGD process alternatives for coal-fired utility boilers from user-supplied input data. Development of the model was sponsored by the U.S. Environmental Protection Agency (EPA). The model is maintained by the Tennessee Valley Authority (TVA), from whom the complete model or individual runs are available. This manual provides a general description of the model and its uses. It includes additions and revisions to the model that have been made since publication of the previous users manual in 1981.

The model is general in nature and is capable of projecting conceptual designs and economics for a range of power plant and FGD conditions. The results are similar to those of preliminary conceptual design evaluations in which absolute accuracies are about -15% to +30% and comparative accuracies are about -10% to +10%. The model is most useful for projecting preliminary comparisons of FGD alternatives (type of absorbent, absorber design, and operating conditions, for example) and evaluation of the effects of design criteria [gas velocity, liquid-to-gas (L/G) ratio, SO_2 removal efficiency, and stoichiometry, for example]. As such, it is most useful in preliminary studies and screenings leading to detailed design studies and in planning research and development activities.

GENERAL INFORMATION

BACKGROUND

From 1968 to 1980, EPA sponsored the development of lime and limestone FGD technology at a test facility located at TVA's Shawnee Steam Plant near Paducah, Kentucky. TVA was the constructor and operator of the facility and Bechtel National, Inc., was the primary contractor. The test facility consisted of three prototype FGD systems, each with a capacity of 30,000 aft^3/min of flue gas (equivalent to 10 MW of generating capacity). One system had a venturi-spray tower absorber and one had a mobile-bed absorber [Turbulent Contact Absorber (TCA)]. The third system originally had a marble-bed absorber that was operated only briefly and eventually converted to a cocurrent absorber system.

Most of the test work involved operation of venturi, spray tower, venturi-spray tower, and TCA absorbers. Initially, an extensive series of lime and limestone FGD tests was made over a wide range of conditions. In 1976, forced-oxidation tests were begun and the use of magnesium oxide (MgO) to enhance SO_2 removal efficiency was investigated. In 1979 and 1980, an equally extensive series of tests using adipic acid to enhance SO_2 removal efficiency was made. In all, over a decade of almost continuous assessment and development of lime and limestone FGD technology was conducted, resulting in a very large and comprehensive body of information.

The main phase of the testing at Shawnee was conducted from 1974 through 1978 as the "Advanced Test Program," which has been reported in detail by Bechtel (1). The adipic acid tests were conducted after this period (8). Formal support of the test program by EPA ended in 1980. The facility is still operated by TVA for various FGD evaluations, but the results of most of these tests are not directly applicable to development of the Shawnee model.

The data developed during the tests sponsored by EPA were used to develop a computer model to project conceptual designs and economics for lime and limestone FGD processes. Bechtel developed computer procedures to project material balances, flow rates, and stream compositions. TVA developed computer procedures to project the economics of the processes. These were based on premises and procedures developed by TVA, EPA, and others for the evaluation of FGD economics. All of the computer procedures were combined into an overall model composed of two computer programs. One program projects the major equipment requirements and costs and the total capital investment. The second program projects the annual revenue requirements.

Since 1974, when development of the model began, the model has been periodically updated to reflect current technology and economic conditions. In 1979 and again in 1981 (9), users manuals were published for the model as it existed then. Since that time, further revisions and additions have been made. The major revisions consist of a refinement and expansion of the forced-oxidation and adipic acid options, inclusion of a waste fixation option and a landfill disposal option, and revision of the equipment and installation cost models to reflect base costs obtained in 1983.

DOCUMENTATION

This manual provides the information and procedures necessary to use the model but it does not describe the concepts and mathematics upon which it is based. No fully comprehensive description of this basis has been published because of the frequent revisions and additions that have been made during the course of its development. The original chemical equilibrium model which was developed by the Radian Corporation has been discussed (10), as have earlier versions of the model (11). The Advanced Test Program reports by Bechtel (1) discuss many aspects of the design and performance of the conceptual designs used. Process flowsheets and layout drawings are included in Appendix A for the alternative process and waste disposal options which are available in the model. The design and economic premises in Appendix B provide additional detail on the design basis and the economic calculations. Economic studies by TVA (12), based in whole or part on the Shawnee computer model, discuss design and economic aspects and provide examples of the economic evaluations and comparisons.

SCOPE OF THE MODEL

There are three absorber options: spray tower, TCA, and venturi, each of which can be used alone or as venturi-spray tower or venturi-TCA combinations with either limestone or lime absorbent. Forced oxidation in various configurations can be used with most of the absorber options. Adipic acid or MgO additive options are also available with most absorber configurations. Numerous design and operating condition options are available. Waste disposal options include ponding, landfill, and fixation and landfill.

The equipment size and layout configurations are based on power units between 100 MW and 1,300 MW in size and coal sulfur contents of 1% to 5%. The ranges of other critical variables are:

Absorber gas velocity	8-12.5 ft/sec
Absorbent liquid recirculation rate	25-120 gal/kaft3
Hold tank residence time	2-25 minutes
Number of absorber trains	1-10
Flue gas SO_2 concentration	600-4,000 ppm

The validity of results for conditions outside these ranges has not been determined. Results for intermediate-sized plants outside these ranges may be valid, however.

Several model runs may be required to fully analyze the combined effects of individual input conditions, especially if the ranges specified above are exceeded. The effects of variations in inputs (such as absorber gas velocity, L/G ratio, absorbent stoichiometry, SO_2 removal efficiency, and reheat temperature) can be assessed individually or the cumulative effect can be assessed by varying several conditions simultaneously.

AVAILABILITY

The model is available to the public through TVA under an information exchange agreement between EPA and TVA. Upon receipt of a written request, TVA provides a copy of the model suitable for loading onto an IBM-370-compatible computer system, along with FORTRAN program listings and the documentation required to execute the model. Under the same information exchange agreement, TVA will make model runs based on user-supplied input data. This allows users to analyze the capabilities of the model with a minimum amount of investigation and investment.

The model is based on the requirements and specifications of the G1 compiler and FORTRAN66 language. The model is executed in FORTRAN66 on the VS FORTRAN compiler using the FORTRAN66 option. It cannot be used with systems based exclusively on FORTRAN77 or VS FORTRAN.

Model options and input variables are added and modified on a regular basis. The latest version is usually supplied to users and is typically the basis for user runs made by TVA. Model and documentation availability is subject to limitations based on available funding and the costs that must be incurred in connection with a user request.

A detailed list of all of the model inputs is included in Tables C-1 and C-2 of Appendix C. These tables include a number of options for selecting process design and controlling model output. Types of options are listed below:

	Variable	Line	Page
• Print	-	1-3	9
• Particulate collection device removal	XESP	5	9
• Reheat	XRH	5	13
• Bypass and partial scrubbing	KEPASS, KPASO2	5	13-14
• Coal cleaning	KCLEAN	5	14

	Variable	Line	Page
• Input composition	INPOPT	6	17
• Particulate removal	IASH	6	18
• SO_2 removal	ISO2	7	20
• Operating parameter calculation	ISR	7	22
• Scrubbing absorbent (lime or limestone)	XIALK	7	24
• Chemical additive	IADD	7	24
• Forced oxidation	IFOX	8	29
• Fan	IFAN	8	34
• Absorber	ISCRUB	9	34
• Redundancy	NSPREP,NOREDN	9	37
• Waste disposal	ISLUDG	10	37
• Fixation	IFIXS	10	42,64
• Pond design	PSMAX,DISTPD	10	42
• Landfill design	PDEPTH,PMXEXC	10	50
• Disposal site liner	ILINER	10	54
• Process economics	IECON	11	54
• Tax-freight	ITAXFR	12	56
• Waste disposal economics	INDPND	12	62
• Overtime	IOTIME	12	56
• Pond capacity	PNDCAP	14	62
• Operating profile	IOPSCH	14	66

Requests for copies of the computer model, model runs to be made by TVA, or additional information should be made to the authors at the following address: Division of Energy Demonstrations and Technology (ED&T), Tennessee Valley Authority, Muscle Shoals, Alabama 35660, telephone number (205) 386-2814 or (205) 386-2514.

MODEL DESCRIPTION

INPUT

The model requires a minimum of 15 lines of input. Free-form format is specified and blank spaces are required between variables except for the CASEID (line 4) and the END or NEXT variable (last line of data set) which are alpha-numeric format. Individual values may be specified to the desired precision provided the total characters, including separators, do not exceed 72 per line. Additional input is required when a user-specified operating profile is chosen instead of the built-in profiles. A detailed FORTRAN variable list of the model input is shown in Table C-1 of Appendix C. The variables are defined in Table C-2 of Appendix C. Ranges for key variables to aid in establishing input data to the model are shown in Table 1.

TABLE 1. VARIABLE RANGES

Item	Description
Power plant	New, 100-1,300 MW
Fuel sulfur content	1%-5%
Fuel SO_2 content	1.7-9.0 $\frac{\text{lb } SO_2}{\text{MBtu}}$
Absorber gas velocity	8-12.5 ft/sec
Absorbent recirculation rate	25-120 gal/kft^3
Hold tank residence time	2-25 minutes
Number of scrubbing trains	1-10
Number of spare scrubbing trains	0-10
SO_2 removal efficiency	1%-100%
Fly ash removal efficiency	1%-99.9%
TCA pressure drop	$\leq$3 in. H_2O/stage
Capital investment cost year	Midpoint of construction
Annual revenue requirement cost year	First year of operation

Note: The variable ranges were established for model development purposes. Values beyond these ranges are not necessarily invalid but the potential for error is greater when these ranges are exceeded.

As new options are incorporated, the required inputs are subject to change. When this occurs, the list of variables and the associated definitions will be updated and made available as necessary.

OUTPUT

The outputs of the Shawnee lime-limestone computer model provide a complete conceptual design package for lime or limestone scrubbing. They consist of: (1) a detailed material balance, including properties of the major streams; (2) a detailed water balance itemizing water availability and water required; (3) specifications of the scrubbing system design; (4) a display of overall pond or landfill design and costs; (5) specifications and costs of the process equipment by major processing area; (6) a detailed breakdown of the capital investment; (7) an itemized breakdown of the revenue requirements for the first year of operation of the system; (8) a lifetime revenue requirement analysis showing projected costs for each year of operation, as well as lifetime cumulative and discounted costs and equivalent unit revenue requirements; and (9) a particulate removal cost table which lists operating conditions and itemizes capital investment and annual revenue requirements for a cold-side electrostatic precipitator (ESP), a hot-side ESP, a baghouse, or a particulate scrubber. However, upstream particulate removal is independent of the FGD process and costs are not included in the FGD economic projections. These outputs are illustrated in the base case printout shown in Appendix D.

In addition to the outputs listed above, a diagnostic message file is generated each time the model is executed. This file contains informative messages related to processing such as data case number and title, possible conflicts between options, variable values that may be out of range, and fatal conditions that terminate model execution. In typical model runs made by TVA, the message file is listed between the printed output from the capital investment program and the printed output from the annual revenue requirements program, but this depends on the control language procedures used for execution. An example message file is shown in the base case printout in Appendix D.

OPTIONS

A detailed list of all of the model inputs is included in Tables C-1 and C-2 of Appendix C. These tables include a number of options for selecting process design and controlling model output. Some examples of the options are shown on the pages that follow. For illustration purposes, the appropriate input data line is shown and the particular option code is indicated. An explanation of each option and sample output resulting from its use is provided where necessary. Unless a value of zero is required, nonzero values for all variables must be entered for each case even though a variable value is being calculated by the model as a result of a user-specified option. In this case, the calculated value will override the input value. A value of zero may result in a zero divide operation in some cases. Spaces cannot be used to take the place of variables which have a value equal to zero.

Some user-specified input values result in the use of default values of other variables for consistency in the calculations. For the options that allow defaults, the option code that must be input and the default values that are assumed are described. All model output listings used to illustrate individual options are derived from the base case data shown in Appendix D. Only the variables related to options being illustrated are changed from the base case unless otherwise noted.

Print Options

Line No.	Input data
1	1 1 1 1 1
2	1 1 1 1 1 1 1 1 1 1 1 1
3	1 1 1 1 1

IRPT (first value on line 3) IEQPR (third value on line 3)

The options on the first three lines of the input data control printed output from the model. The first print option on line 3 (IRPT) requires further explanation. This option controls the printout of the capital investment and annual revenue requirements. The short form printout is shown in Table 2 and may be compared with the long printout of the base case example in Appendix D. The other print option requiring further explanation is the third option on line 3 (IEQPR). This option controls the printing of all or selected portions of the equipment list. These options are described in the input definition list in Table C-2 of Appendix C.

Particulate Collection Device Option

Line No.	Input data
5	2 500 9500 11700 39 300 2 1 0 90 0 84.1 12.1 .3 175 470 751

XESP (first value on line 5)

The particulate collection device option is controlled by the XESP variable. The value of XESP may be 0, 1, or 2. A zero value is used if no particulate removal device is to be considered. A value of 1 is used if a mechanical collector (33% efficient) is selected, and the code for upstream removal (line 6, ASHUPS, see Table C-2) should have an input value of 33% (% removal). If an XESP value of 2 is selected, a separate particulate removal cost model (13) projects the capital investment and annual revenue requirements for particulate removal. The results are listed in the output but are not included in the FGD costs. The percentage of particulate removal required for this option is specified by the ASHUPS variable. Example output showing the results of specifying mechanical collectors (XESP = 1) is shown in Table 3. Example output showing the results of using the built-in particulate removal cost model is shown in the base case printout in Appendix D.

TABLE 2. EXAMPLE RESULTS ILLUSTRATING SHORT-FORM PRINTOUT

LANDFILL DESIGN

LANDFILL COSTS (THOUSANDS OF DOLLARS)

LANDFILL EQUIPMENT			1189.
TAX AND FREIGHT			87.
LANDFILL EQUIPMENT TOTAL			1277.
	LABOR	MATERIAL	TOTAL
SUBTOTAL DIRECT	2830.	347.	3177.
TAX AND FREIGHT		26.	26.
TOTAL DIRECT LANDFILL INVESTMENT	2830.	373.	3203.
LAND COST			679.
LANDFILL SITE			5990.

REVENUE QUANTITIES

LANDFILL LABOR	29120.	MAN-HRS
DIESEL FUEL	103595.	GALLONS
ELECTRICITY	145178.	KWH
WATER	3867.	K-GALLONS
ANALYSIS	42.	MAN-HRS

(Continued)

TABLE 2. (Continued)

PROJECTED CAPITAL INVESTMENT REQUIREMENTS

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								
	MAT HAND	FEED PREP	GAS HAND	SO2 SCRUB	OXID	REHEAT	SOLID SEP	TOTAL	PER KW
SUBTOTAL DIRECT INVESTMENT	2927.	5316.	11723.	23564.	2797.	5077.	8120.	59525.	119.05
TOTAL CAPITAL INVESTMENT	5381.	9745.	21490.	43193.	5128.	9307.	14575.	108818.	217.64

PROJECTED FIRST YEAR REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL

ANNUAL OPERATION KW-HR/KW = 5500

	REVENUE REQUIREMENT, $
SUBTOTAL RAW MATERIAL	2220400
SUBTOTAL CONVERSION COSTS	11699200
SUBTOTAL INDIRECT COSTS	3720000
FIRST YEAR OPERATING AND MAINTENANCE COSTS	17639600
LEVELIZED CAPITAL COSTS	15996300
FIRST YEAR ANNUAL REVENUE REQUIREMENTS	33635900

EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH (TOTAL MW) 12.23

TABLE 3. EXAMPLE RESULTS ILLUSTRATING

MECHANICAL COLLECTOR PARTICULATE REMOVAL

SO2 SCRUBBING

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
MECHANICAL ASH COLLECTOR	33% PARTICULATE REMOVAL	1	634081.	129699.
SHELL			2341328.	
NEOPRENE LINING			1928600.	
MIST ELIMINATOR			383686.	
SLURRY HEADER AND NOZZLES			938730.	
GRIDS			627930.	
TOTAL SPRAY SCRUBBER COSTS		5	6220272.	507083.
SOOTBLOWERS	AIR-FIXED	40	174667.	27123.
EFFLUENT HOLD TANK	323974.GAL, 38.0FT DIA, 38.0FT HT, FLAKEGLASS-LINED CS	5	410706.	347464.
EFFLUENT HOLD TANK AGITATOR	66 HP	5	457885.	189610.
COOLING SPRAY PUMPS	1389.GPM 100 FT HEAD, 61.HP, 4 OPERATING AND 6 SPARE	10	113911.	36076.
RECIRCULATION PUMPS	18408.GPM, 100 FT HEAD, 814.HP, 8 OPERATING AND 7 SPARE	15	2085846.	167399.
MAKEUP WATER PUMPS	3473.GPM, 200.FT HEAD, 293.HP, 1 OPERATING AND 1 SPARE	2	26754.	4155.
TOTAL SO2 SCRUBBING EQUIPMENT COST			10133118.	1408606.

Reheat Option

Line No.	Input data
5	2 500 9500 11700 39 300 2 1 0 90 0 84.1 12.1 .3 175 470 751

XRH (2) — TSTEAM (470) — HVS (751)

The reheat option (XRH) allows for either an inline steam reheater for the scrubbed gas or for no reheating of the scrubbed gas. The inline steam reheater is the only type of reheater available in the current version of the model. When a reheater is specified (XRH = 2), the TSTEAM variable is used to specify the temperature of the reheater steam and the HVS variable is used to specify the heat of vaporization of the reheater steam. For the base case, steam at 470°F and 500 psia is used; a steam table should be used to determine the latent heat of steam for other steam conditions. Example output showing the results of specifying an inline steam reheater is shown in the base case in Appendix D. When no reheating is specified (XRH = 0), the reheater section is omitted from the printout. If partial scrubbing/bypass is used (variable KPASO2, line 5 below), the reheat requirements are determined by the final temperature of the recombined flue gas, which includes the heat contribution of the bypassed flue gas.

Emergency Bypass Option

Line No.	Input data
5	2 500 9500 11700 39 300 2 1 0 90 0 84.1 12.1 .3 175 470 751

KEPASS (1)

The emergency bypass option (KEPASS) allows an emergency bypass around the FGD system for one-half of the flue gas normally scrubbed as specified in the premises (Appendix B). If only one operating scrubbing train is specified (line 9, NOTRAN) then the emergency bypass is sized for all of the gas normally scrubbed instead of only one-half. When both emergency bypass and partial scrubbing/bypass (line 5, KPASO2 and PSSO2X) are specified, the emergency bypass is sized for 50% of the gas normally scrubbed (100% of the gas normally scrubbed if only one operating train) plus the partial bypass normally used for the unscrubbed gas (the total cannot exceed 100%). The following values are used for the KEPASS option:

0 - No emergency bypass

1 - Emergency bypass

An example showing output when an emergency bypass is specified is shown in the base case printout in Appendix D.

Partial Scrubbing/Bypass Option

Line No.	Input data
5	2 500 9500 11700 39 300 2 1 1 90 0 84.1 12.1 .3 175 470 751
	(1 → KPASO2; 90 → PSSO2X)

The partial scrubbing/bypass option (KPASO2) allows FGD systems to be projected for conditions in which all of the flue gas does not have to be scrubbed to meet specified emission levels. The percent removal in the absorber is specified with the PSSO2X variable and the model will calculate the percentage of flue gas that can be bypassed (if any) while still meeting the emission limit or overall removal percentage specified (line 7, ISO2 and XSO2). The appropriate ductwork and reheater adjustments are made as required, depending on the amount of bypassed gas. When the partial scrubbing/bypass option is specified, the emergency bypass duct is also used for the gas normally bypassed, as discussed above. Partial scrubbing/bypass is not allowed when SO_2 removal is calculated from scrubber operating conditions (line 7, ISR = 3). The following values are used for the KPASO2 option:

0 - No partial scrubbing/bypass

1 - Partial scrubbing/bypass

Example output showing partial scrubbing/bypass specified is shown in Table 4 based on an emission limit of 1.2 lb SO_2/MBtu.

Coal-Cleaning Option

Line No.	Input data
5	2 500 9500 11700 39 300 2 1 1 90 1 84.1 12.1 .3 175 470 751
	(1 → KCLEAN; 84.1 → PREC; 12.1 → SPASH; .3 → WPRITE)
5B	1.0 5.5 6.0 13000
	(1.0 → SMRW; 5.5 → SMCL; 6.0 → ASHCLN; 13000 → HVCLN)

The coal-cleaning option (KCLEAN) allows the model to be used in conjunction with a coal-cleaning process. The model calculates the composition and firing rate of cleaned coal based on the raw coal characteristics, the coal-cleaning conditions, and the boiler megawatt rating and heat rate. The corresponding flue gas composition is used to determine the SO_2 removal required in the FGD system.

In line 5, the variable PREC specifies the weight percent recovery in pounds of cleaned coal per 100 pounds of raw coal, SPASH specifies the weight

TABLE 4. EXAMPLE RESULTS ILLUSTRATING

PARTIAL SCRUBBING/BYPASS

EMERGENCY BY-PASS

EMERGENCY BY-PASS DESIGNED FOR 53.2 %

HOT GAS FROM BOILER

	MOLE PERCENT	LB-MOLE/HR	LB/HR
CO2	12.317	0.2255E+05	0.9923E+06
HCL	0.006	0.1145E+02	0.4175E+03
SO2	0.221	0.4042E+03	0.2589E+05
O2	5.553	0.1017E+05	0.3253E+06
N2	75.199	0.1377E+06	0.3857E+07
H2O	6.703	0.1227E+05	0.2211E+06

FLYASH EMISSION = 10.325 LBS/MILLION BTU TO BOILER
= 49043. LB/HR

HOT GAS FLOW RATE = .1156E+07 SCFM (60. DEG F, 14.7 PSIA)
= .1690E+07 ACFM (300. DEG F, 14.7 PSIA)

CORRESPONDING COAL FIRING RATE = .4060E+06 LB/HR

HOT GAS HUMIDITY = 0.043 LB H2O/LB DRY GAS

WET BULB TEMPERATURE = 124. DEG F

HOT GAS TO BY-PASS

	MOLE PERCENT	LB-MOLE/HR	LB/HR
CO2	12.317	0.1426E+04	0.6274E+05
HCL	0.006	0.7241E+00	0.2640E+02
SO2	0.221	0.2556E+02	0.1637E+04
O2	5.553	0.6427E+03	0.2057E+05
N2	75.199	0.8703E+04	0.2439E+06
H2O	6.703	0.7758E+03	0.1398E+05

HOT GAS BY-PASSED 6.3 %

FLYASH EMISSION = 0.004 LBS/MILLION BTU TO BOILER
= 17. LB/HR

HOT GAS FLOW RATE = .7311E+05 SCFM (60. DEG F, 14.7 PSIA)
= .1068E+06 ACFM (300. DEG F, 14.7 PSIA)

CORRESPONDING COAL FIRING RATE = .2567E+05 LB/HR

(Continued)

TABLE 4. (Continued)

HOT GAS TO SCRUBBER

	MOLE PERCENT	LB-MOLE/HR	LB/HR
CO2	12.317	0.2112E+05	0.9296E+06
HCL	0.006	0.1073E+02	0.3911E+03
SO2	0.221	0.3787E+03	0.2426E+05
O2	5.553	0.9522E+04	0.3047E+06
N2	75.199	0.1289E+06	0.3613E+07
H2O	6.703	0.1149E+05	0.2071E+06

SO2 CONCENTRATION IN SCRUBBER INLET GAS = 2208. PPM
= 5.45 LBS / MILLION BTU

FLYASH EMISSION = 0.053 LBS/MILLION BTU TO BOILER
= 251. LB/HR

SOLUBLE CAO IN FLY ASH = 0. LB/HR
SOLUBLE MGO IN FLY ASH = 0.

HOT GAS FLOW RATE = .1083E+07 SCFM (60. DEG F, 14.7 PSIA)
= .1583E+07 ACFM (300. DEG F, 14.7 PSIA)

MW EQUIVALENT OF SCRUBBER = 468 MEGAWATTS

CORRESPONDING COAL FIRING RATE = .3803E+06 LB/HR

HOT GAS HUMIDITY = 0.043 LB H2O/LB DRY GAS

WET BULB TEMPERATURE = 124. DEG F

WET GAS FROM SCRUBBER

	MOLE PERCENT	LB-MOLE/HR	LB/HR
CO2	11.722	0.2149E+05	0.9459E+06
HCL	0.000	0.5364E+00	0.1956E+02
SO2	0.010	0.1893E+02	0.1213E+04
O2	5.101	0.9351E+04	0.2992E+06
N2	70.332	0.1289E+06	0.3613E+07
H2O	12.835	0.2353E+05	0.4240E+06

SO2 CONCENTRATION IN SCRUBBER OUTLET GAS = 103. PPM

FLYASH EMISSION = 0.026 LBS/MILLION BTU TO BOILER
= 126. LB/HR

TOTAL WATER PICKUP = 444. GPM
INCLUDING 10.6 GPM ENTRAINMENT

WET GAS FLOW RATE = .1158E+07 SCFM (60. DEG F, 14.7 PSIA)
= .1301E+07 ACFM (124. DEG F, 14.7 PSIA)

WET GAS SATURATION HUMIDITY = 0.087 LB H2O/LB DRY GAS percent of sulfur in the cleaned coal, and WPRITE specifies the weight percent of pyritic sulfur in the raw coal. In line 5B, which is required only if the coal-cleaning option (KCLEAN = 1) is specified, SMRW specifies the surface moisture of the raw coal, SMCL specifies the surface moisture of the cleaned coal, ASHCLN specifies the ash content of the cleaned coal, and HVCLN specifies the heating value of the cleaned coal.

When the 1979 new source performance standards (NSPS) emission limit is automatically calculated by the model (line 7, ISO2 = 4), the appropriate credit for coal cleaning will also be automatically calculated by the model on a raw coal basis. In all other cases, the emission limit or removal percentage (line 7, ISO2 and XSO2) must be specified on a cleaned coal basis or must be calculated by the model from FGD operating conditions (line 7, ISR = 3). Coal cleaning is not allowed when the flue gas composition is specified directly (line 6, INPOPT = 2). The following values are used for the KCLEAN option:

0 - No coal cleaning

1 - Coal cleaning

Input Composition Option

Line No.	Input data
	INPOPT ↓
6A	1 66.7 3.8 5.6 1.3 3.36 .1 15.1 4.0 95 80 2 .06 .03
or	
6B	2 12.338 .006 .214 5.560 75.227 6.654 1154000 47500 100 100 2 .06 .03
	↑ INPOPT

The input composition option (INPOPT) allows the flue gas composition to be specified directly instead of being calculated by the model from a coal composition. This allows the model to be used to project FGD systems for other than coal-fired boilers. The variables described for line 6A (C, H, O, N, S, Cl, ash, H_2O, etc.; see Table C-2) should be used when the coal composition is specified; the variables described for line 6B (CO_2, HCl, SO_2, O_2, N_2, H_2O, etc.; see Table C-2) should be used when the flue gas composition is specified directly. Coal cleaning (line 5, KCLEAN = 1) and the automatic calculation of 1979 NSPS emission levels (line 7, ISO2 = 4) are not allowed when the flue gas composition is specified directly. The following values are used for the INPOPT option:

1 - Coal composition is specified (line 6A)

2 - Flue gas composition is specified (line 6B)

When a coal composition is specified, a "BOILER CHARACTERISTICS" section is included in the output. Example output showing the results of specifying a coal composition as input (INPOPT = 1) is shown in the base case printout in Appendix D. When a flue gas composition is specified, a "HOT GAS ANALYSIS" section is provided. Example output showing the results of specifying a flue gas composition as input is shown in Table 5.

Particulate Removal Option

Line No.	Input data
6	1 66.7 3.8 5.6 1.3 3.36 .1 15.1 4.0 95 80 2 .06 .03
	IASH ASHUPS ASHSCR

The particulate removal variables are IASH, ASHUPS, and ASHSCR. The IASH option identifies the method for specifying particulate removal, i.e., as percent removal or as outlet emission in lb/MBtu. IASH may take values of 0, 1, 2, or 3. If IASH is equal to 0, upstream particulate removal (ASHUPS) and absorber particulate removal (ASHSCR) take default values of 33% and 99.2% removal, respectively. If IASH equals 1, ASHUPS and ASHSCR are input as percent removal. If IASH equals 2, ASHUPS and ASHSCR are input particulate loadings in lb/MBtu at the outlet of the upstream particulate collector and the absorber, respectively. If IASH equals 3, ASHUPS is input as percent removal and ASHSCR takes a default value of 75%. Regardless of the option chosen, the output listing provides the equivalent particulate emission as both percent removal and lb/MBtu. A summary of the options is shown below.

IASH = 0	ASHUPS default value = 33% removal ASHSCR default value = 99.2% removal
IASH = 1	ASHUPS input value as percent removal ASHSCR input value as percent removal
IASH = 2	ASHUPS input value as lb/MBtu to absorber ASHSCR input value as lb/MBtu from absorber
IASH = 3	ASHUPS input value as percent removal ASHSCR default value equals 75% removal

Example output showing the results of specifying particulate removal based on lb/MBtu (IASH = 2) is shown in the base case printout in Appendix D.

TABLE 5. EXAMPLE RESULTS ILLUSTRATING USER INPUT FLUE GAS COMPOSITION

*** INPUTS ***

HOT GAS ANALYSIS, MOLE PERCENT:

CO2	CL	SO2	O2	N2	H2O
12.3170	0.0060	0.2210	5.5530	75.1990	6.7030

SULFUR OVERHEAD = 100.0 PERCENT

ASH OVERHEAD = 100.0 PERCENT

HEATING VALUE OF COAL = 11700. BTU/LB

FLYASH REMOVAL	EFFICIENCY, %	EMISSION, LBS/M BTU
UPSTREAM OF SCRUBBER	99.4	0.06
WITHIN SCRUBBER	50.0	0.03

EMISSION STANDARD

SIP: 0.60 LBS SO2/M BTU TO THE BOILER
COST OF UPSTREAM FLYASH REMOVAL EXCLUDED

SO2 Removal Option

Line No.	Input data
7	90 10 5 10 25 4 1.2 10 1 1.3 1 0 .15 0.0 1500 3 4.85 5 0 0

(4 = ISO2, 1.2 = XSO2)

The model has five methods for specifying SO_2 outlet concentrations or removal. The controlling variables are the ISO2 option and the actual value to be removed, XSO2. If ISO2 = 1, XSO2 is input as the percentage of SO_2 to be removed. (The percentage of SO_2 to be removed is used as the percent removal by the absorber except when partial scrubbing is specified with the KPASO2 option on line 5.) If ISO2 = 2, XSO2 is input as the absorber outlet emission expressed as pounds SO_2/MBtu. If ISO2 = 3, XSO2 is input as ppm SO_2 in the absorber outlet stream. If ISO2 = 4, SO_2 removal is automatically calculated by the model from the input coal composition based on the 1979 NSPS (14). Figure 1 illustrates the relationship between the SO_2 content of the raw coal and the controlled outlet emission levels used in the model for the 1979 NSPS. The fifth method for specifying SO_2 removal, SO_2 removal calculated, is described in the operating condition options section (line 7, ISR = 3). Regardless of the option chosen, the equivalent SO_2 removal in all three units is displayed in the model output. The input value is shown as having been specified and the other values are shown as having been calculated. A summary of the input options is shown below.

ISO2 = 1 XSO2 is input as percent removal

ISO2 = 2 XSO2 is input as pounds SO_2/MBtu at the absorber outlet

ISO2 = 3 XSO2 is input as ppm SO_2 in the absorber outlet stream

ISO2 = 4 XSO2 will be automatically calculated by the model based on the 1979 NSPS

Example output showing the results of specifying emission limits based on the 1979 NSPS is shown in the base case printout in Appendix D.

An important concept related to SO_2 removal calculations in the model should be emphasized here. The SO_2 removal options are based on long-term average sulfur content of the coal and are not necessarily representative of 3-hour or 24-hour averages. When sizing an FGD facility, the raw material-handling, feed preparation, and scrubbing areas should be based on the maximum sulfur content of the coal rather than the long-term average. The waste disposal area, however, should be sized on the long-term average sulfur content. This can be done by entering the weight percent sulfur as the maximum expected and then entering the waste disposal capacity factor (line 14, PNDCAP) to adjust the total amount of waste generated back to the equivalent long-term average amount.

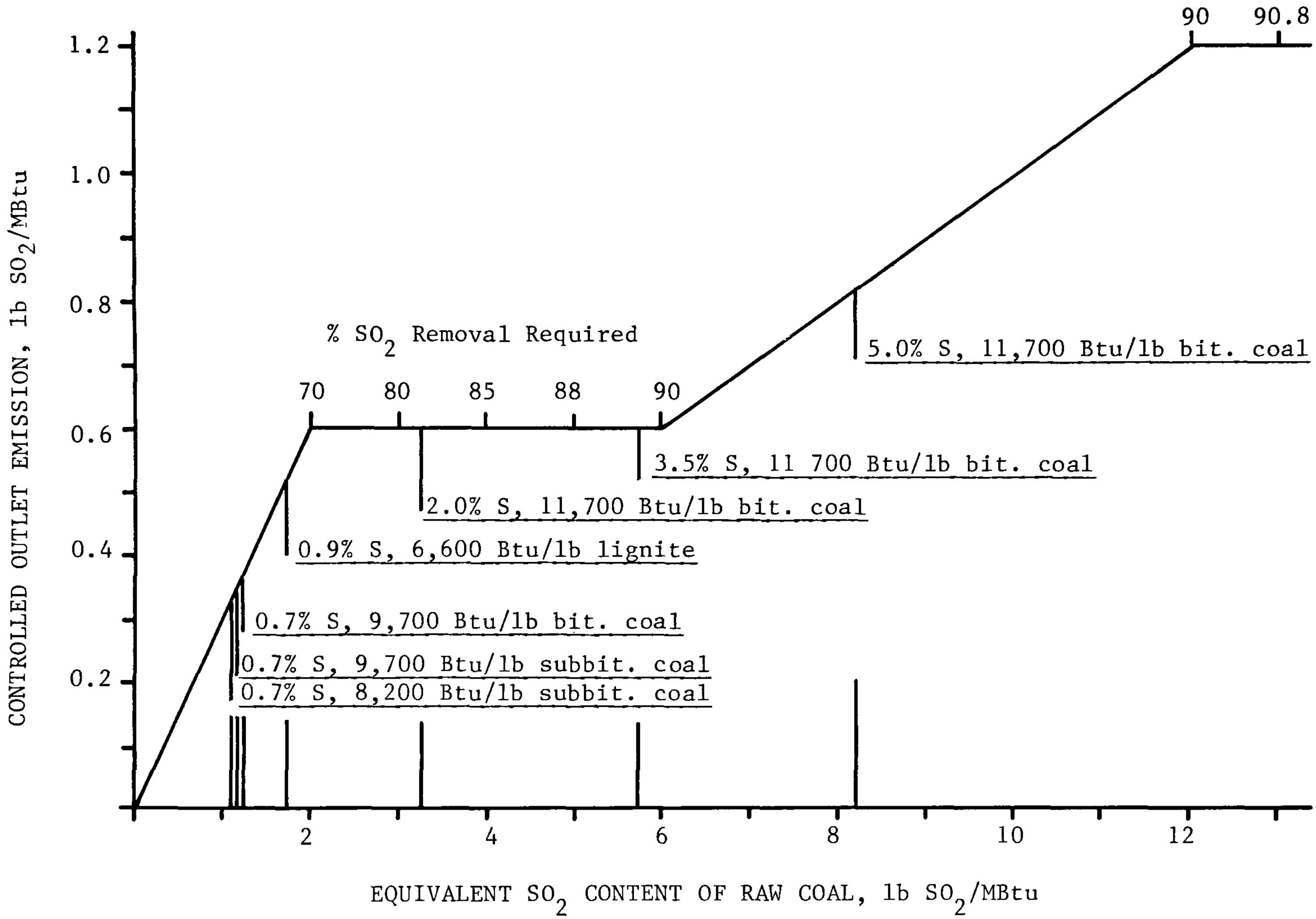


Figure 1. Controlled SO_2 emission requirements for 1979 NSPS. Premise coals, shown underlined, are based on premise boiler conditions.

Operating Condition Calculation Option

Line No.	Input data
	XLG ↓ 90, XSO2 ↓ 1.2, ISR ↓ 1, SRIN ↓ 1.3, XIALK ↓ 1, IADD ↓ 0, AD ↓ 1500
7	90 10 5 10 25 4 1.2 10 1 1.3 1 0 .15 0.0 1500 3 4.85 5 0 0
8	15 40 .2 40 0 30 2.5 85 1.2 7.0 0 9 0 14.7 1
	PHLIME ↑ 7.0

Four options are available in the model to allow either user input or model calculation of the major operating conditions which include L/G (expressed as absorber liquid recirculation rate in gallons per 1,000 aft^3 of flue gas at the absorber outlet), stoichiometry (expressed as mols $CaCO_3$ or CaO added per mol of SO_2 + 2HCl absorbed), and SO_2 removal. The options differ slightly for the limestone system, the additive-enhanced limestone system, and the lime-scrubbing system so the description is divided into three sections.

For limestone scrubbing (line 7, XIALK = 1), the variables used are ISR, XLG, SRIN, and XSO2. ISR is the controlling option and takes values from 0 to 3. If ISR has an input value of 0, the L/G (XLG), stoichiometry (SRIN), and SO_2 removal (XSO2, units depend on ISO2) are all user input values. Specifying ISR = 0 is referred to as "force-through" because no program checks are made for validity or consistency among the three input variables to ensure that specified L/G and stoichiometry can result in the input degree of removal. If ISR is equal to 1, XLG and XSO2 are input and the model calculates stoichiometry. If ISR is equal to 2, SRIN and XSO2 are input and the model calculates the L/G ratio. When ISR is equal to 3, XLG and SRIN are input and the model calculates SO_2 removal. Values of 1.03 or greater should be used for SRIN when it is specified as input because of logarithm mathematical requirements. A summary of the various options for a limestone-scrubbing system is shown below.

ISR = 0 XLG is input
XSO2 is input
SRIN is input

ISR = 1 XLG is input
XSO2 is input
SRIN is calculated

ISR = 2 XLG is calculated
XSO2 is input
SRIN is input

ISR = 3 XLG is input
XSO2 is calculated
SRIN is input

Example output showing the results of specifying ISR = 1 is shown in the base case printout in Appendix D.

Similar options are available for the adipic acid-enhanced limestone system (line 7, IADD = 2). The variable PHLIME is used to input the pH of absorber recirculating liquid. The pH has a critical effect on the calculation of L/G ratio and SO_2 removal and the user must understand the system so that anomalous results are not produced. The adipic acid option is discussed in more detail in Appendix E. A summary of the options is shown below. The PHLIME option specifies pH. The AD option specifies the quantity of adipic acid in the system in ppm.

ISR = 0 XLG is input
XSO2 is input
PHLIME is input
AD is input

ISR = 1 XLG is input
XSO2 is input
PHLIME is input
AD is calculated

ISR = 2 XLG is calculated
XSO2 is input
PHLIME is input
AD is input

ISR = 3 XLG is input
XSO2 is calculated
PHLIME is input
AD is input

Similar options are available in the lime-scrubbing option (line 7, XIALK = 2). The variable PHLIME replaces SRIN except when ISR = 0 because for lime scrubbing the model calculates the pH of the recirculation liquid instead of the lime stoichiometry. (When limestone is specified, the value of PHLIME is ignored. When lime is specified, SRIN is ignored except when ISR = 0, in which case PHLIME is ignored.) A summary of the options for a lime system is shown below.

ISR = 0 XLG is input
XSO2 is input
SRIN is input

ISR = 1 XLG is input
XS02 is input
PHLIME is calculated

ISR = 2 XLG is calculated
XS02 is input
PHLIME is input

ISR = 3 XLG is input
XS02 is calculated
PHLIME is input

The output listing for the lime option is similar to that for the limestone option shown in Appendix D except that the stoichiometry is printed out for CaO instead of $CaCO_3$, as shown in Table 6. (An input value of 7.85 is used for PHLIME in this example.) For both the lime and limestone options, if input values are specified for the variables that are to be calculated by the model, the input values are ignored.

Scrubbing Absorbent Option (Lime or Limestone)

Line No.	Input data
7	90 10 5 10 25 4 1.2 10 1 1.3 1 0 .15 0.0 1500 3 4.85 5 0 0

(XIALK → 1)

The absorbent option (XIALK) allows a choice of either lime or limestone. If XIALK = 1, limestone slurry is selected as the scrubbing medium. If XIALK = 2, lime slurry is selected. Example output showing the results of specifying limestone scrubbing (XIALK = 1) is shown in the base case printout in Appendix D. The scrubbing output and the raw material preparation area equipment list from the lime option output are shown in Tables 7 and 8, respectively.

Chemical Additive Option

Line No.	Input data
7	90 10 5 10 25 4 1.2 10 1 1.3 1 0 .15 0.0 1500 3 4.85 5 0 0

(IADD → 0, XMGOAD → 0.0, AD → 1500, ADDC → 3)

The chemical additive option (IADD) provides for the addition of either MgO or adipic acid to the slurry stream to improve scrubber efficiency and SO_2 removal rates. The following values are used for the IADD option:

TABLE 6. EXAMPLE RESULTS ILLUSTRATING

LIME-SCRUBBING INPUT

BOILER CHARACTERISTICS
------ ---------------

MEGAWATTS = 500.

BOILER HEAT RATE = 9500. BTU/KWH

EXCESS AIR = 39. PERCENT, INCLUDING LEAKAGE

HOT GAS TEMPERATURE = 300. DEG F

COAL ANALYSIS, WT % AS FIRED :

C	H	O	N	S	CL	ASH	H2O
66.70	3.80	5.60	1.30	3.36	0.10	15.10	4.00

SULFUR OVERHEAD = 95.0 PERCENT

ASH OVERHEAD = 80.0 PERCENT

HEATING VALUE OF COAL = 11700. BTU/LB

FLYASH REMOVAL	EFFICIENCY, %	EMISSION, LBS/M BTU
UPSTREAM OF SCRUBBER	99.4	0.06
WITHIN SCRUBBER	50.0	0.03

EMISSION STANDARD
-------- --------

1979 NSPS
COST OF UPSTREAM FLYASH REMOVAL EXCLUDED

ALKALI

LIME :

CAO = 95.00 WT % DRY BASIS
SOLUBLE MGO = 0.15
INERTS = 4.85
MOISTURE CONTENT : 5.00 LB H2O/100 LBS DRY LIME

FLY ASH :

SOLUBLE CAO = 0.0 WT %
SOLUBLE MGO = 0.0
INERTS = 100.00

RAW MATERIAL HANDLING AREA
--- -------- -------- ----

NUMBER OF REDUNDANT ALKALI PREPARATION UNITS = 1

TABLE 7. EXAMPLE RESULTS ILLUSTRATING LIME-SCRUBBING OUTPUT

```
SCRUBBER SYSTEM
-------- ------

TOTAL NUMBER OF SCRUBBING TRAINS (OPERATING+REDUNDANT) =  5

SO2 REMOVAL =  89.0 PERCENT

PARTICULATE REMOVAL IN SCRUBBER SYSTEM =  50.0 PERCENT

SPRAY TOWER PRESSURE DROP =  1.8 IN. H2O

TOTAL SYSTEM PRESSURE DROP =  7.0 IN. H2O

SPECIFIED  SPRAY TOWER L/G RATIO  =  70. GAL/1000 ACF(SATD)

LIME ADDITION = 0.2370E+05 LB/HR DRY LIME

SPECIFIED  LIME STOICHIOMETRY      =  1.10 MOLE CAO ADDED AS LIME
                                          PER MOLE (SO2+2HCL) ABSORBED

SOLUBLE CAO FROM FLY ASH =  0.00 MOLE PER MOLE (SO2+2HCL) ABSORBED

TOTAL SOLUBLE MGO          =  0.00 MOLE PER MOLE (SO2+2HCL) ABSORBED

TOTAL STOICHIOMETRY        =  1.10 MOLE SOLUBLE (CA+MG)
                                   PER MOLE (SO2+2HCL) ABSORBED

MAKE UP WATER  =  563. GPM

OXIDATION AIR RATE = 0.4972E+05LB/HR
                   = 0.1083E+05 SCFM (60 DEG F,14.7 PSIA)

CROSS-SECTIONAL AREA PER SCRUBBER =   577. SQ FT


SOLIDS DISPOSAL SYSTEM
------ -------- ------

TOTAL CLARIFIER(S) CROSS-SECTIONAL AREA =   1551. SQ FT


SYSTEM SLUDGE DISCHARGE
------ ------ ---------
```

SPECIES	LB-MOLE/HR	LB/HR	SOLID COMP, WT %	LIQUID COMP, PPM
CASO3 .1/2 H2O	0.1797E+02	0.2321E+04	3.50	
CASO4 .2H2O	0.3417E+03	0.5880E+05	88.79	
CACO3	0.3809E+02	0.3812E+04	5.76	
INSOLUBLES	----------	0.1292E+04	1.95	
H2O	0.6148E+03	0.1108E+05		
CA++	0.4198E+01	0.1682E+03		14395.
MG++	0.1635E+01	0.3975E+02		3401.
SO3--	0.1873E-01	0.1499E+01		128.
SO4--	0.1624E+00	0.1560E+02		1334.
CL-	0.1088E+02	0.3857E+03		33001.

```
TOTAL DISCHARGE FLOW RATE = 0.7791E+05 LB/HR
                          =    74.      GPM
```

TABLE 8. EXAMPLE RESULTS ILLUSTRATING LIME-SCRUBBING, RAW MATERIAL-HANDLING, AND PREPARATION AREAS

RAW MATERIAL HANDLING

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
CAR SHAKER AND HOIST	20HP SHAKER 7.5HP HOIST	1	85232.	14392.
CAR PULLER	25HP PULLER, 5HP RETURN	1	70391.	21586.
UNLOADING HOPPER	16FT DIA, 10FT STRAIGHT INCLUDES 6 IN SQ GRATING	1	16539.	6758.
UNLOADING VIBRATING FEEDER	3.5 HP	1	4880.	299.
UNLOADING BELT CONVEYOR	20 FT HORIZONTAL, 5 HP	1	11986.	1639.
UNLOADING PIT DUST COLLECTOR	POLYPROPYLENE BAGTYPE, INCLUDES DUST HOOD	1	10835.	5967.
STORAGE SILO ELEVATOR	125.FT HIGH 40 HP	1	58702.	4862.
STORAGE BELT CONVEYOR	133.FT HORIZONTAL. 5 HP	1	47903.	11436.
STORAGE CONVEYOR TRIPPER	30FPM, 1 HP	1	19077.	7459.
CONCRETE STORAGE SILO	103404.FT3,44.4 FT DIA, 66.7FT STRAIGHT SIDE STORAGE HT	3	379493.	685939.
STORAGE SILO HOPPER BOTTOM	60 DEGREE, CS	3	59345.	44987.
RECLAIM VIBRATING FEEDER	3.5 HP	3	14639.	1356.
RECLAIM BELT CONVEYOR	208.FT HORIZONTAL, 5 HP	1	38962.	5822.
FEED BIN ELEVATOR	50 FT HIGH, 20 HP	1	35452.	2543.
FEED BELT CONVEYOR	60 FT HORIZONTAL, 5 HP	1	16648.	1212.
FEED CONVEYOR TRIPPER	30 FPM, 1 HP	1	19841.	7459.
FEED BIN	10FT DIA, 15FT STRAIGHT SIDE HT, COVERED, CS	3	15425.	11494.
LIME SYSTEM DUST COLLECTORS	POLYPROPYLENE BAG TYPE 2200 CFM,7.5 HP	1	7423.	2961.
TOTAL RAW MATERIAL HANDLING EQUIPMENT COST			912781.	839061.

(Continued)

TABLE 8. (Continued)

RAW MATERIAL PREPARATION

INCLUDING 2 OPERATING AND 1 SPARE PREPARATION UNITS

ITEM	DESCRIPTION	NO.	MATEPIAL	LABOP
BIN VIBRATING FEEDER	3.5 HP	3	39038.	4441.
BIN WEIGH FEEDER	12FT, 12 IN SCREW, 1 HP	3	20010.	2661.
SLAKER	6. TPH, 11. HP	3	193160.	35661.
SLAKER PRODUCT TANK	6000 GAL 10FT DIA, 10FT HT, FLAKEGLASS LINED CS	3	20207.	15155.
SLAKER PRODUCT TANK AGITATOR	7.5 HP	3	26200.	2712.
SLAKER PRODUCT TANK SLURRY PUMPS	139.GPM, 60 FT HEAD, 4 HP, 2 OPERATING AND 1 SPARE	3	11190.	3956.
SLURRY FEED TANK	146699.GAL, 29.2 FT DIA, 29.2 FT HT, FLAKEGLASS-LINED CS	1	43742.	36615.
SLURRY FEED TANK AGITATOR	52 HP	1	63961.	5297.
SLURRY FEED TANK PUMPS	69.GPM, 60 FT HEAD, 2.HP, 4 OPERATING ANC 4 SPARE	8	19211.	8137.
			---------	---------
TOTAL FEED PREPARATION EQUIPMENT COST			436718.	114638.

0 - No chemical additive

1 - MgO added

2 - Adipic acid added

If IADD = 1, variable XMGOAD is used to specify the quantity of MgO added to the system (expressed as pounds of soluble MgO added per 100 pounds of alkali feed). When IADD = 2, variable AD is used to specify the concentration of adipic acid in the scrubber slurry [expressed as ppm (by weight) adipic acid] and variable ADDC specifies the degradation constant for adipic acid in the scrubber slurry (expressed as pounds of adipic acid to be added per pound of adipic acid remaining in the slurry after degradation).

Example output showing the results of adding adipic acid is shown in Table 9.

Forced-Oxidation Option

Line No.	Input data
8	15 40 .2 40 0 30 2.5 85 1.2 7.0 0 9 0 14.7 1

(In the input data, .2 = RS, 0 = IFOX, 30 = OX.)

The forced-oxidation option (IFOX) provides for oxidation of the sulfite slurry to gypsum by sparging air into one of the slurry tanks. Gypsum offers better disposal options such as easier dewatering, a higher settling rate, and a higher density. Variable RS is the thickener solids settling rate (ft/hr) and may be user specified or will be automatically calculated based on the percent oxidation of the scrubbing slurry by specifying a value of 0.0. The following values are used for the IFOX option:

0 - No forced oxidation

1 - Forced oxidation in a single effluent tank (within the absorber loop)

2 - Forced oxidation in the first of two effluent tanks (within the absorber loop)

3 - Forced oxidation in the disposal feed tank (bleedstream from the absorber loop); the number of effluent tanks depends on the ISCRUB variable (line 9)

The percent oxidation efficiency (0-99, in mol percent) in the system is specified with the OX variable and should be specified in agreement with the IFOX option. The number of tanks specified by the forced-oxidation option must not conflict with the number of tanks indicated by the absorber option

TABLE 9. EXAMPLE RESULTS ILLUSTRATING THE ADDITION OF ADIPIC ACID

SCRUBBER SYSTEM

TOTAL NUMBER OF SCRUBBING TRAINS (OPERATING+REDUNDANT) = 5

SO2 REMOVAL = 95.0 PERCENT

PARTICULATE REMOVAL IN SCRUBBER SYSTEM = 50.0 PERCENT

SPRAY TOWER PRESSURE DROP = 2.0 IN. H2O

TOTAL SYSTEM PRESSURE DROP = 7.1 IN. H2O

SPECIFIED SPRAY TOWER L/G RATIO = 80. GAL/1000 ACF(SATD)

LIMESTONE ADDITION = 0.4106E+05 LB/HR DRY LIMESTONE

SPECIFIED LIMESTONE STOICHIOMETRY = 1.07 MOLE CACO3 ADDED AS LIMESTONE PER MOLE (SO2+2HCL) ABSORBED

SOLUBLE CAO FROM FLY ASH = 0.00 MOLE PER MOLE (SO2+2HCL) ABSORBED

TOTAL SOLUBLE MGO = 0.00 MOLE PER MOLE (SO2+2HCL) ABSORBED

TOTAL STOICHIOMETRY = 1.07 MOLE SOLUBLE (CA+MG) PER MOLE (SO2+2HCL) ABSORBED

SCRUBBER LIQUOR ADIPIC ACID CONCENTRATION = 1500. PPM

MAKE UP WATER = 534. GPM

MAKE-UP ADIPIC ACID = 0.5234E+02 LB/HR

OXIDATION AIR RATE = 0.4972E+05LB/HR
= 0.1083E+05 SCFM (60 DEG F,14.7 PSIA)

CROSS-SECTIONAL AREA PER SCRUBBER = 542. SQ FT

SOLIDS DISPOSAL SYSTEM

TOTAL CLARIFIER(S) CROSS-SECTIONAL AREA = 1543. SQ FT

SYSTEM SLUDGE DISCHARGE

SPECIES	LB-MOLE/HR	LB/HR	SOLID COMP, WT %	LIQUID COMP, PPM
CASO3 .1/2 H2O	0.1798E+02	0.2321E+04	3.52	
CASO4 .2H2O	0.3417E+03	0.5880E+05	89.21	
CACO3	0.2662E+02	0.2665E+04	4.04	
INSOLUBLES	----------	0.2126E+04	3.22	
H2O	0.6129E+03	0.1104E+05		
CA++	0.3981E+01	0.1596E+03		13718.
MG++	0.1487E+01	0.3614E+02		3107.
SO3--	0.1851E-01	0.1482E+01		127.
SO4--	0.1582E+00	0.1520E+02		1307.
CL-	0.1019E+02	0.3613E+03		31061.
AD--	0.1195E+00	0.1745E+02		1500.

(Continued)

TABLE 9. (Continued)

RAW MATERIAL HANDLING

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
CAR SHAKER AND HOIST	20HP SHAKER 7.5HP HOIST	1	85232.	14392.
CAR PULLER	25HP PULLER, 5HP RETURN	1	70391.	21586.
UNLOADING HOPPER	16FT DIA, 10FT STRAIGHT INCLUDES 6 IN SQ GRATING	1	16566.	6837.
UNLOADING VIBRATING FEEDER	3.5 HP	1	6987.	588.
UNLOADING BELT CONVEYOR	20 FT HORIZONTAL, 5 HP	1	11490.	1639.
UNLOADING INCLINE BELT CONVEYOR	310 FT, 50 HP	1	85641.	5922.
UNLOADING PIT DUST COLLECTOR	POLYPROPYLENE BAGTYPE. INCLUDES DUST HOOD	1	10835.	5922.
UNLOADING PIT SUMP PUMP	60 GPM, 70 FT HEAD, 5 HP	1	4476.	870.
STORAGE BELT CONVEYOR	200 FT, 5 HP	1	73387.	4521.
STORAGE CONVEYOR TRIPPER	30 FPM, 1 HP	1	27264.	10443.
MOBILE EQUIPMENT	SCRAPPER TRACTOR	1	166916.	0.
RECLAIM HOPPER	7FT WIDE, 4.25FT HT, 2FT WIDE BOTTOM, CS	2	2576.	1876.
RECLAIM VIBRATING FEEDER	3.5 HP	2	13973.	1175.
RECLAIM BELT CONVEYOR	200 FT, 5 HP	1	42182.	3277.
RECLAIM INCLINE BELT CONVEYOR	193 FT, 40 HP	1	60587.	3842.
RECLAIM PIT DUST COLLECTOR	POLYPROPYLENE BAG TYPE	1	7511.	2961.
RECLAIM PIT SUMP PUMP	60 GPM, 70 FT HEAD, 5 HP	1	4476.	870.
RECLAIM BUCKET ELEVATOR	90 FT HIGH, 25 HP	1	54294.	7606.
FEED BELT CONVEYOR	60.FT HORIZONTAL 7.5 HP	1	21091.	1639.
FEED CONVEYOR TRIPPER	30 FPM, 1 HP	1	27264.	10443.
FEED BIN	13FT DIA, 21FT STRAIGHT SIDE HT, COVERED, CS	3	46096.	27734.
ADIPIC ACID ADD STORAGE SILO	733.FT3, 8.5FT DIA 19.9 FT HT 60 DEG CONE	1	7727.	5440.
PNEUMATIC CONVEYOR SYSTEM	10. HP	1	9006.	6024.
ADDITION FEED BIN	RUBBER LINED	1	2238.	1165.
ADDITIVE DUST COLLECTOR	POLYPROPLENE BAG TYPE 450 CFM, 1.5 HP	1	3204.	299.
TOTAL RAW MATERIAL HANDLING EQUIPMENT COST			861409.	146668.

(Continued)

TABLE 9. (Continued)

RAW MATERIAL PREPARATION

INCLUDING 2 OPERATING AND 1 SPARE PREPARATION UNITS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
BIN WEIGH FEEDER	14 FT PULLEY CENTERS, 2HP	3	63437.	2661.
GYRATORY CRUSHERS	75 HP	3	402825.	7374.
BALL MILL DUST COLLECTORS	POLYPROPYLENE BAG TYPE 2200 CFM, 7.5HP	3	28820.	8883.
BALL MILL	CYLINDRICAL 10.3TPH, 585.HP	3	1363254.	104992.
MILLS PRODUCT TANK	5500 GAL 10FT DIA, 10FT HT, FLAKEGLASS LINED CS	3	17963.	13257.
MILLS PRODUCT TANK AGITATOR	7.5 HP	3	38317.	4069.
MILLS PRODUCT TANK SLURRY PUMP	43. GPM,60 FT HEAD, 2.HP, 2 OPERATING AND 1 SPARE	3	7170.	3051.
SCREW FEEDER	30 FT LONG, 6 IN D, SS	1	6004.	593.
SLURRY FEED TANK	45623. GAL, 19.8 FT DIA, 19.8 FT HT, FLAKEGLASS-LINED CS	1	20080.	16809.
SLURRY FEED TANK AGITATOR	42 HP	1	42100.	3487.
SLURRY FEED TANK PUMPS	22. GPM, 60 FT HEAD, 1 HP, 4 OPERATING AND 4 SPARES	8	18709.	8137.
TOTAL FEED PREPARATION EQUIPMENT COST			2008677.	173243.

(Continued)

TABLE 9. (Continued)

LIMESTONE SLURRY PROCESS -- BASIS: 468 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL
DISPLAY SHEET FOR YEAR= 1
ANNUAL OPERATION KW-HR/KW = 5500

32.99 TONS PER HOUR DRY SLUDGE
TOTAL CAPITAL INVESTMENT 97625000

	ANNUAL QUANTITY	UNIT COST,$	TOTAL ANNUAL COST,$
DIRECT COSTS			
RAW MATERIAL			
LIMESTONE	112.9 K TONS	15.00/TON	1693900
ADIPIC ACID	143.9 TONS	1500.00/TON	215900
SUBTOTAL RAW MATERIAL			1909800
CONVERSION COSTS			
OPERATING LABOR AND SUPERVISION	42970.0 MAN-HR	19.00/MAN-HR	816400
LANDFILL LABOR AND SUPERVISION	29120.0 MAN-HR	24.00/MAN-HR	698900
UTILITIES			
STEAM	432220.0 K LB	4.00/K LB	1728900
PROCESS WATER	179400.0 K GAL	0.16/K GAL	28700
ELECTRICITY	44469840.0 KWH	0.055/KWH	2445800
DIESEL FUEL	75480.0 GAL	1.60/GAL	120800
MAINTENANCE			
LABOR AND MATERIAL			4079500
ANALYSES	3330.0 HR	26.00/HR	86600
SUBTOTAL CONVERSION COSTS			10005600
SUBTOTAL DIRECT COSTS			11915400
INDIRECT COSTS			
OVERHEADS			
PLANT AND ADMINISTRATIVE (60.0% OF CONVERSION COSTS LESS UTILITIES)			3408800
FIRST YEAR OPERATING AND MAINTENANCE COSTS			15324200
LEVELIZED CAPITAL CHARGES(14.70% OF TOTAL CAPITAL INVESTMENT)			14351000
FIRST YEAR ANNUAL REVENUE REQUIREMENTS			29675200
EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)			11.53
EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH (TOTAL MW)			10.79
LEVELIZED OPERATING AND MAINTENANCE (1.886 TIMES FIRST YEAR OPER. & MAIN.)			28901400
LEVELIZED CAPITAL CHARGES(14.70% OF TOTAL CAPITAL INVESTMENT)			14351000
LEVELIZED ANNUAL REVENUE REQUIREMENTS			43252400
EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)			16.80
EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (TOTAL MW)			15.73

HEAT RATE 9500. BTU/KWH HEAT VALUE OF COAL 11700 BTU/LB COAL RATE 1116500 TONS/YR

(ISCRUB, line 9). Example output showing the results of specifying forced oxidation in the first of two effluent tanks (IFOX = 2) is shown in Table 10. An example of one tank (IFOX = 1) is shown in Table 11.

Booster Fan Option

Line No.	Input data
8	15 40 .2 40 0 30 2.5 85 1.2 7.0 0 9 0 14.7 1 (↑ IFAN)

The fan option (IFAN) allows either induced-draft (ID) fans or forced-draft (FD) fans to be specified to compensate for the pressure drop in the FGD system. The following values are used.

0 - Forced-draft fans

1 - Induced-draft fans

Example output showing the results of specifying ID fans is shown in the base case printout in Appendix D. The format of the output is similar for the FD fan option; however, the fan costs are different.

Scrubbing Option

Line No.	Input data
9	1 0 0 0 35 .0000005 32 10 5.70 1 4 1 .1 (↑ ISCRUB at first value)

The scrubbing option (ISCRUB) identifies one of the six absorber systems that can be used. The ISCRUB values and the corresponding systems are as follows:

ISCRUB = 1 Spray tower (one effluent tank unless two tanks are specified by the forced-oxidation option, IFOX, on line 8)

ISCRUB = 2 TCA (one effluent tank unless two tanks are specified by the forced-oxidation option, IFOX, on line 8)

ISCRUB = 3 Venturi-spray tower with two effluent tanks (if forced oxidation is specified by IFOX on line 8, IFOX must be 2)

ISCRUB = 4 Venturi-spray tower with one effluent tank (if forced oxidation is specified by IFOX on line 8, IFOX must be 1)

TABLE 10. EXAMPLE RESULTS ILLUSTRATING FORCED OXIDATION, TWO EFFLUENT TANKS

SO2 SCRUBBING

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
SHELL			2341328.	
NEOPRENE LINING			1928600.	
MIST ELIMINATOR			383686.	
SLURRY HEADER AND NOZZLES			938730.	
GRIDS			627930.	
TOTAL SPRAY SCRUBBER COSTS		5	6220272.	507083.
SOOTBLOWERS	AIR-FIXED	40	174667.	27123.
EFFLUENT HOLD TANK	323974.GAL, 38.0FT DIA, 38.0 FT HT, FLAKEGLASS-LINED CS	5	419706.	347464.
EFFLUENT HOLD TANK AGITATOR	66.HP	5	457885.	189610.
COOLING SPRAY PUMPS	1389. GPM 100 FT HEAD, 61.HP, 4 OPERATING AND 6 SPARE	10	113911.	36076.
RECIRCULATION PUMPS	18408.GPM, 100 FT HEAD, 814.HP, 8 OPERATING AND 7 SPARE	15	2085846.	167399.
MAKEUP WATER PUMPS	3473.GPM, 200.FT HEAD, 293.HP, 1 OPERATING AND 1 SPARE	2	26754.	4155.
TOTAL SO2 SCRUBBING EQUIPMENT COST			9499038.	1278907.

OXIDATION

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
RECIRCULATION TANK	202484.GAL 30.1 FT DIA, 38.0 FT HT, FLAKEGLASS-LINED CS	5	319840.	264831.
RECIRCULATION TANK AGITATOR	59.HP	5	342708.	141915.
OXIDATION BLEED PUMPS	468.GPM, 60 FT HEAD 12.HP, 4 OPERATING AND 4 SPARE	8	47202.	17942.
OXIDATION AIR BLOWER	2708 SCFM, 267.HP	6	204276.	5425.
OXIDATION SPARGER	19.0 FT DIA RING	5	66414.	42697.
TOTAL FORCED OXIDATION EQUIPMENT COST			980440.	472809.

TABLE 11. EXAMPLE RESULTS ILLUSTRATING

FORCED OXIDATION, ONE EFFLUENT TANK

SO2 SCRUBBING

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
SHELL			2341328.	
NEOPRENE LINING			1928600.	
MIST ELIMINATOR			383686.	
SLURRY HEADER AND NOZZLES			938730.	
GRIDS			627930.	
TOTAL SPRAY SCRUBBER COSTS		5	6220272.	507083.
SOOTBLOWERS	AIR-FIXED	40	174667.	27123.
EFFLUENT-OXIDATION HOLD TANK	374595.GAL, 39.9FT DIA, 39.9 FT HT, FLAKEG LASS-LINED CS	5	462355.	382772.
EFFLUENT-OXIDATION HOLD TANK AGITATOR	73 HP	5	500755.	207362.
COOLING SPRAY PUMPS	1389.GPM 100 FT HEAD, 61.HP, 4 OPERATING AND 6 SPARE	10	113911.	36076.
ABSORBER RECYCLE PUMPS	18408.GPM, 100 FT HEAD, 814.HP, 8 OPERATING AND 7 SPARE	15	2085846.	167399.
MAKEUP WATER PUMPS	3473.GPM, 200 FT HEAD, 293.HP, 1 OPERATING AND 1 SPARE	2	26754.	4155.
			---------	---------
TOTAL SO2 SCRUBBING EQUIPMENT COST			9584557.	1331967.

OXIDATION

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
OXIDATION BLEED PUMPS	468.GPM, 60 FT HEAD 12.HP, 4 OPERATING AND 4 SPARE	8	47202.	17942.
OXIDATION AIR BLOWER	2708.SCFM, 281.HP	6	204276.	5425.
OXIDATION SPARGER	20.0 FT DIA RING	5	69014.	42697.
			---------	---------
TOTAL FORCED OXIDATION EQUIPMENT COST			320492.	66064.

ISCRUB = 5 Venturi-TCA with two effluent tanks (if forced oxidation is specified by IFOX on line 8, IFOX must be 2)

ISCRUB = 6 Venturi-TCA with one effluent tank (if forced oxidation is specified by IFOX on line 8, IFOX must be 1)

There are no specific material balance models for the venturi-TCA scrubbing combination specified by options 5 and 6. These options are provided to allow comparative cost estimates for analysis and should normally be used only in "force-through" mode (see the operating condition calculation option, ISR, on line 7). Example output showing the results of specifying a spray tower is shown in the base case printout in Appendix D. Example output showing the results of specifying a venturi-spray tower with two effluent tanks is shown in Table 12.

<u>Spare Equipment Options</u>

Line No.	Input data
9	1 0 0 0 35 .0000005 32 10 5.70 1 4 1 .1

(1 → NSPREP, 4 → NOTRAN, 1 → NOREDN)

Options for spare equipment in the model apply to the raw material preparation area and the scrubbing area. The controlling input variables are NSPREP, NOTRAN, and NOREDN. NSPREP specifies the number of spare preparation units (ball mills for limestone or slakers for lime) and may be given any realistic value, 0, 1, 2, 3, ... NOTRAN specifies the number of operating absorbers. The model automatically overrides the value of NOTRAN if the specified number requires an absorber larger than the maximum available size. NOREDN indicates the number of spare absorber trains. The base case equipment list in Appendix D shows the output for a limestone-scrubbing system designed with spare ball mills and absorbers. For comparison, Table 13 shows similar output for a limestone system with no spare absorbers.

<u>Waste Disposal Option</u>

Line No.	Input data
10	5 0 0.0 9999 5000 25 25 5280 1 12 4.75

(5 → ISLUDG, 0 → IFIXS, 0.0 → SDFEE, 5280 → DISTPD)

Six basic waste disposal options are available in the model (usually these are based on a disposal site one mile from the FGD facility, as specified in feet by the variable DISTPD). The input variables are ISLUDG, IFIXS, and SDFEE and are illustrated below. ISLUDG takes values of 1, 2, 3, 4, or 5. Options 1 through 4 specify variations of pond disposal. Option 5 specifies dewatering and landfill disposal. IFIXS takes values of 0 or 1. IFIXS = 1 can be used only with ISLUDG = 5 and specifies an additional

TABLE 12. EXAMPLE RESULTS ILLUSTRATING

A VENTURI-SPRAY TOWER ABSORBER

SO2 SCRUBBING

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
VENTURI		5	797677.	111617.
SHELL			2341328.	
NEOPRENE LINING			1928600.	
MIST ELIMINATOR			383686.	
SLURRY HEADER AND NOZZLES			922698.	
GRIDS			627930.	
TOTAL SPRAY SCRUBBER COSTS		5	6204240.	507083.
SOOTBLOWERS	AIR-FIXED	55	240167.	37295.
VENTURI-OXIDATION HOLD TANK	78615. GAL 18.8 FT DIA, 37.7FT HT,FLAKEGLASS-LINED CS	5	166075.	139076.
VENTURI-OXIDATION TANK AGITATORS	46 HP	5	191263.	79201.
VENTURI-OXIDATION PUMPS	6946.GPM 100 FT HEAD, 307.HP 4 OPERATING AND 6 SPARE	10	733826.	72893.
EFFLUENT HOLD TANK	314805.GAL, 37.7FT DIA, 37.7FT HT, FLAKEGLASS-LINED CS	5	411750.	340878.
EFFLUENT HOLD TANK AGITATOR	65 HP	5	449853.	186283.
ABSORBER RECYCLE PUMPS	17887.GPM, 100 FT HEAD, 791.HP, 8 OPERATING AND 7 SPARE	15	2050555.	165311.
MAKEUP WATER PUMPS	3473.GPM, 200.FT HEAD, 293.HP, 1 OPERATING AND 1 SPARE	2	26754.	4155.
			---------	---------
TOTAL SO2 SCRUBBING EQUIPMENT COST			11272128.	1643790.

TABLE 13. EXAMPLE RESULTS ILLUSTRATING NO SPARE EQUIPMENT

RAW MATERIAL HANDLING

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
CAR SHAKER AND HOIST	20HP SHAKER 7.5HP HOIST	1	85232.	14392.
CAR PULLER	25HP PULLER, 5HP RETURN	1	70391.	21586.
UNLOADING HOPPER	16FT DIA, 10FT STRAIGHT INCLUDES 6 IN SQ GRATING	1	16566.	6837.
UNLOADING VIBRATING FEEDER	3.5 HP	1	6987.	588.
UNLOADING BELT CONVEYOR	20 FT HORIZONTAL, 5 HP	1	11490.	1639.
UNLOADING INCLINE BELT CONVEYOR	310 FT, 50 HP	1	85641.	5521.
UNLOADING PIT DUST COLLECTOR	POLYPROPYLENE BAGTYPE, INCLUDES DUST HOOD	1	10835.	5922.
UNLOADING PIT SUMP PUMP	60 GPM, 70 FT HEAD, 5 HP	1	4476.	870.
STORAGE BELT CONVEYOR	200 FT, 5 HP	1	73387.	4521.
STORAGE CONVEYOR TRIPPER	30 FPM, 1 HP	1	27264.	10443.
MOBILE EQUIPMENT	SCRAPPER TRACTOR	1	166916.	0.
RECLAIM HOPPER	7FT WIDE, 4.25FT HT, 2FT WIDE BOTTOM, CS	2	2576.	1876.
RECLAIM VIBRATING FEEDER	3.5 HP	2	13973.	1175.
RECLAIM BELT CONVEYOR	200 FT, 5 HP	1	42182.	3277.
RECLAIM INCLINE BELT CONVEYOR	193 FT, 40 HP	1	60587.	3842.
RECLAIM PIT DUST COLLECTOR	POLYPROPYLENE BAG TYPE	1	7511.	2961.
RECLAIM PIT SUMP PUMP	60 GPM, 70 FT HEAD, 5 HP	1	4476.	870.
RECLAIM BUCKET ELEVATOR	90 FT HIGH, 25 HP	1	63508.	7606.
FEED BIN	13FT DIA, 21FT STRAIGHT SIDE HT, COVERED, CS	2	30730.	18489.
TOTAL RAW MATERIAL HANDLING EQUIPMENT COST			784727.	112415.

(Continued)

TABLE 13. (Continued)

GAS HANDLING

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
I.D. FANS	7.9IN H20, WITH 664. HP MOTOR AND DRIVE	4	2792047.	50980.
			---------	---------
TOTAL GAS HANDLING EQUIPMENT COST			2792047.	50980.

SO2 SCRUBBING

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
SHELL			1873062.	
NEOPRENE LINING			1542880.	
MIST ELIMINATOR			306949.	
SLURRY HEADER AND NOZZLES			750984.	
GRIDS			502344.	
TOTAL SPRAY SCRUBBER COSTS		4	4976217.	405667.
SOOTBLOWERS	AIR-FIXED	32	139733.	21699.
EFFLUENT HOLD TANK	323974.GAL, 38.0 FT DIA, 38.0 FT HT, FLAKEGLASS-LINED CS	4	335765.	277971.
EFFLUENT HOLD TANK AGITATOR	66 HP	4	366308.	121350.
COOLING SPRAY PUMPS	1389.GPM 100 FT HEAD, 61 HP, 4 OPERATING AND 4 SPARE	8	91129.	28861.
RECIRCULATION PUMPS	18408.GPM, 100 FT HEAD, 814 HP, 8 OPERATING AND 4 SPARE	12	1668677.	133919.
MAKEUP WATER PUMPS	3473.GPM, 200 FT HEAD, 293.HP, 1 OPERATING AND 1 SPARE	2	26754.	4155.
			---------	---------
TOTAL SO2 SCRUBBING EQUIPMENT COST			7604579.	993621.

(Continued)

TABLE 13. (Continued)

OXIDATION

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
RECIRCULATION TANK	202484.GAL 30.1FT DIA, 38.0 FT HT, FLAKEGLASS-LINED CS	4	255872.	211865.
RECIRCULATION TANK AGITATOR	59 HP	4	274166.	90825.
OXIDATION BLEED PUMPS	468. GPM, 60 FT HEAD 12.HP, 4 OPERATING AND 2 SPARE	6	35402.	13457.
OXIDATION AIR BLOWER	2708 SCFM, 267 HP	6	204276.	5425.
OXIDATION SPARGER	19.0 FT DIA RING	4	53131.	34157.
TOTAL FORCED OXIDATION EQUIPMENT COST			822847.	355729.

REHEAT

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
REHEATERS		4	2371214.	147297.
SOOTBLOWERS	AIR-RETRACTABLE	16	262000.	18082.
TOTAL REHEAT EQUIPMENT COST			2633213.	166009.

fixation process which is described below. SDFEE is a user-specified fee in $/ton of dry waste that can be used to specify a fee for additional costs not included in the model. It is normally used with ISLUDG values of 3 and 4 but it can also be used with the other ISLUDG options. In all options that involve dewatering, user-specified solids contents are used. These must be within practical limits to attain accurate results. The use of ISLUDG = 5 normally requires either the use of IFIXS = 1 or one of the forced-oxidation options because unoxidized sludge is not normally landfilled without fixation. A summary of the basic options is shown below.

ISLUDG = 1	Onsite pond disposal of untreated waste.
ISLUDG = 2	Dewatering in a gravity thickener followed by onsite pond disposal.
ISLUDG = 3	Dewatering in a gravity thickener with additional costs based on SDFEE to cover fixation and/or disposal cost.
ISLUDG = 4	Dewatering in a gravity thickener and a rotary vacuum filter with additional costs based on SDFEE to cover fixation and/or disposal costs.
ISLUDG = 5	Dewatering in a gravity thickener and a rotary vacuum filter followed by disposal in an onsite landfill.
ISLUDG = 5 and IFIXS = 1	Dewatering with a gravity thickener and a rotary vacuum filter, followed by fixation by blending the filter cake with an equal quantity of dry fly ash and 3.5% lime (both based on dry waste) for disposal in an onsite landfill.

The base case printout in Appendix D is an example of the forced-oxidation, landfill option (ISLUDG = 5, IFIXS = 0). Sample equipment lists corresponding to the output for the other waste disposal options are shown in Tables 14-16. Annual revenue requirements corresponding to fixation using the model and landfill disposal (ISLUDG = 5, IFIXS = 1) are shown in Table 17.

Pond Disposal Option

Line No.	Input data
10	1 0 0.0 9999 5000 25 25 5280 1 12 6.00
	PSAMAX PDEPTH PMXEXC DISTPD

The design of the disposal ponds used in the model is described in Appendix B. The model has three options for defining the relationships between pond land area, excavation depth, and depth of waste in the filled pond.

TABLE 14. EXAMPLE RESULTS ILLUSTRATING POND WASTE DISPOSAL

SOLIDS SEPARATION

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
ABSORBER BLEED RECEIVING TANK	80905.GAL, 19.0 FT DIA, 38.0 FT HT, FLAKGLASS-LINED CS	1	33857.	28353.
ABSORBER BLEED TANK AGITATOR	41.HP	1	37036.	3067.
POND FEED SLURRY PUMPS	1874.GPM, 130. FT HEAD 107.HP, 1 OPERATING AND 1 SPARE	2	30704.	8223.
POND SUPERNATE PUMPS	1672.GPM, 192. FT HEAD, 135.HP, 1 OPERATING AND 1 SPARE	2	16244.	2522.
			----------	----------
TOTAL EQUIPMENT COST			117841.	42165.

TABLE 15. EXAMPLE RESULTS ILLUSTRATING THICKENER - FILTER - POND WASTE DISPOSAL

SOLIDS SEPARATION

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
ABSORBER BLEED RECEIVING TANK	80905.GAL, 19.0 FT DIA, 38.0FT HT, FLAKGLASS-LINED CS	1	33857.	28353.
ABSORBER BLEED TANK AGITATOR	41 HP	1	37036.	3067.
THICKENER FEED PUMP	1873.GPM, 60 FT HEAD, 50 HP, 1 OPERATING AND 1 SPARE	2	23293.	8221.
THICKENER	1843.SQ.FT., 48. FT DIA, 5.5FT HT TANK 1. HP RAKE	1	88611.	69845.
THICKENER UNDERFLOW SLURRY PUMPS	293.GPM, 9.4 FT HEAD, 2.HP , 1 OPERATING AND 1 SPARE	2	9657.	3654.
THICKENER OVERFLOW PUMPS	1525.GPM, 75.0 FT HEAD, 48.HP, 1 OPERATING AND 1 SPARE	2	10517.	1633.
THICKENER OVERFLOW TANK	25169.GAL, 28.0 FT DIA, 5.5 FT HT	1	7223.	5475.
FILTER FEED TANK	4832. GAL, 9.4 FT DIA, 9.4 FT HT, FLAKEGLASS-LINED CS	1	4496.	3763.
FILTER FEED TANK AGITATOR	7 HP	1	8443.	699.
FILTER FEED SLURRY PUMP	146.GPM, 50 FT HEAD, 4. HP, 2 OPERATING AND 1 SPARE	3	11201.	4049.
FILTER	393.SQ FT FILTRATION AREA, 49. VACUUM HP 2 OPERATING AND 1 SPARE	3	511867.	77905.
FILTRATE PUMP (PER FILTER)	101.GPM, 20.0 FT HEAD, 1.HP, 2 OPERATING AND 2 SPARE	4	13939.	2165.
FILTRATE SURGE TANK	3331. GAL, 8.3 FT DIA, 8.3 FT HT	1	1848.	1400.
FILTRATE SURGE TANK PUMP	202. GPM, 85.0 FT HEAD, 7. HP, 1 OPERATING AND 1 SPARE	2	7496.	1164.
FILTER CAKE CONVEYOR	75 FT. HORIZONTAL 100 FT. INCLINE 1.5 HP	1	42066.	3592.
TOTAL EQUIPMENT COST			811550.	214986.

SOLIDS DISPOSAL FIXATION - LANDFILL

SOLIDS SEPARATION

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
ABSORBER BLEED RECEIVING TANK	80905. GAL, 19.0 FT DIA, 38.0 HT HT, FLAKGLASS-LINED CS	1	33857.	28353.
ABSORBER BLEED TANK AGITATOR	41.HP	1	37036.	3067.
THICKENER FEED PUMP	1873. GPM, 60 FT HEAD, 50. HP, 1 OPERATING AND 1 SPARE	2	23293.	8221.
THICKENER	1843.SQ.FT., 48.FT DIA, 5.5 FT HT TANK 1. HP RAKE	1	88611.	69845.
THICKENER UNDERFLOW SLURRY PUMPS	293.GPM, 9.4 FT HEAD, 2. HP , 1 OPERATING AND 1 SPARE	2	9657.	3645.
THICKENER OVERFLOW PUMPS	1525.GPM, 75.0 FT HEAD, 48.HP, 1 OPERATING AND 1 SPARE	2	10517.	1633.
THICKENER OVERFLOW TANK	25169.GAL, 28.0 FT DIA, 5.5 FT HT	1	7223.	5475.
FILTER FEED TANK	4832.GAL. 9.4 FT DIA, 9.4 FT HT, FLAKEGLASS-LINED CS	1	4496.	3763.
FILTER FEED TANK AGITATOR	7 HP	1	8443.	699.
FILTER FEED SLURRY PUMP	146.GPM, 50 FT HEAD, 4.HP, 2 OPERATING AND 1 SPARE	3	11201.	4049.
FILTER	393.SQ FT FILTRATION AREA, 49. VACUUM HP 2 OPERATING AND 1 SPARE	3	511867.	77905.
FILTRATE PUMP (PER FILTER)	101.GPM, 20.0 FT HEAD, 1.HP, 2 OPERATING AND 2 SPARE	4	13939.	2165.
FILTRATE SURGE TANK	3331. GAL, 8.3 FT DIA, 8.3 FT HT	1	1848.	1400.
FILTRATE SURGE TANK PUMP	202.GPM, 85.0 FT HEAD, 7.HP, 1 OPERATING AND 1 SPARE	2	7496.	1164.
FILTER CAKE CONVEYOR	75 FT. HORIZONTAL 100 FT. INCLINE 1.5 HP	1	42066.	3592.
TOTAL EQUIPMENT COST			811550.	214986.

(Continued)

TABLE 16. (Continued)

FIXATION

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
PNEUMATIC CONVEYOR SYSTEM	10.HP	1	1965.	746.
LIME CONCRETE STORAGE SILO	29196. FT3 29.2 FT DIA, 43.7 FT STRAIGHT SIDE STORAGE HT	1	56780.	102354.
LIME SILO HOPPER BOTTOM	60 DEGREE, CS	1	8760.	6640.
ASH CONCRETE STORAGE SILO	23404. FT3 27.1 FT DIA, 40.6 FT STRAIGHT SIDE STORAGE HT	1	49367.	88948.
ASH SILO HOPPER BOTTOM	60 DEGREE, CS	1	7579.	5744.
LIME SCREW CONVEYOR	30 FEET LONG, 6 IN D,CS	1	1747.	147.
ASH SCREW CONVEYOR	30 FEET LONG, 14 IN D,CS	1	4885.	452.
LIME/ASH SCREW CONVEYOR	47 FEET LONG, 16 IN D,CS	1	8133.	746.
PUG MILL	72.9 TPH 75. HP 1 OPERATEING AND 1 SPARE	2	73447.	8702.
PUG MILL DUST COLLECTORS	POLYPROPLENE BAG TYPE 2200 CFM, 7.5 HP	2	14847.	5922.
PUG MILL DISCHARGE CONVEYOR	50 FEET HORTIZONAL 36 INCH BELT, 2.5 HP	1	14279.	1492.
RADIAL STACKER	185.FT LENGTH,36 INCH BELT 50. HP, MOTOR TRAVEL	1	48039.	11366.
			---------	---------
TOTAL FIXATION EQUIPMENT COST			289827.	233258.

(Continued)

TABLE 16. (Continued)

LANDFILL DISPOSAL

LANDFILL EQUIPMENT ESTIMATED INCLUDING FIXATION PROCESS VOLUME

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
TRUCKS	26.0 CU YD, 1 SPARE	3	232689.	0.
WHEEL LOADER	5.3 CU YDS-BUCKET	2	461864.	0.
TRACK-DOZER	167.HP,STRAIGHT-BLADE	1	197307.	0.
COMPACTOR	SHEEP-FOOT	1	283082.	0.
WHEEL LOADER	2.6 CU YDS BUCKET,CLEANUP	1	107169.	0.
WATER TRUCK	1500 GALLON TANK AND SPRAY HEADERS	1	37990.	0.
SERVICE TRUCK	WRECKER RIG, TOOLS	1	70511.	0.
TRAILER	12 FT X 30 FT, OFFICE, BREAKROOM,FACILITIES	1	10917.	1130.
WATER TREATMENT SYSTEM	PUMPS, TANKS		40033.	31610.
			----------	---------
TOTAL EQUIPMENT COST			1441560.	32740.

TABLE 17. EXAMPLE REVENUE REQUIREMENTS TABLE ILLUSTRATING FIXATION COSTS

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL
DISPLAY SHEET FOR YEAR= 1
ANNUAL OPERATION KW-HR/KW = 5500

39.38 TONS PER HOUR DRY SLUDGE
TOTAL CAPITAL INVESTMENT 113053000

	ANNUAL QUANTITY	UNIT COST,$	TOTAL ANNUAL COST,$
DIRECT COSTS			
RAW MATERIAL			
LIMESTONE	148.0 K TONS	15.00/TON	2220400
LIME	12.3 K TONS	90.00/TON	1104000
SUBTOTAL RAW MATERIAL			3324400
CONVERSION COSTS			
OPERATING LABOR AND SUPERVISION	54810.0 MAN-HR	19.00/MAN-HR	1041400
LANDFILL LABOR AND SUPERVISION	33280.0 MAN-HR	24.00/MAN-HR	798700
UTILITIES			
STEAM	542640.0 K LB	4.00/K LB	2170500
PROCESS WATER	195920.0 K GAL	0.16/K GAL	31300
ELECTRICITY	57629390.0 KWH	0.055/KWH	3169600
DIESEL FUEL	121020.0 GAL	1.60/GAL	193600
MAINTENANCE LABOR AND MATERIAL			4657000
ANALYSES	5750.0 HR	26.00/HR	149600
SUBTOTAL CONVERSION COSTS			12211700
SUBTOTAL DIRECT COSTS			15536100
INDIRECT COSTS			
OVERHEADS			
PLANT AND ADMINISTRATIVE (60.0% OF CONVERSION COSTS LESS UTILITIES)			3988000
FIRST YEAR OPERATING AND MAINTENANCE COSTS			19524100
LEVELIZED CAPITAL CHARGES(14.70% OF TOTAL CAPITAL INVESTMENT)			16618800
FIRST YEAR ANNUAL REVENUE REQUIREMENTS			36142900
EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)			13.14
LEVELIZED OPERATING AND MAINTENANCE (1.886 TIMES FIRST YEAR OPER. & MAIN.)			36822500
LEVELIZED CAPITAL CHARGES(14.70% OF TOTAL CAPITAL INVESTMENT)			16618800
LEVELIZED ANNUAL REVENUE REQUIREMENTS			53441300
EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)			19.43

HEAT RATE 9500. BTU/KWH - HEAT VALUE OF COAL 11700 BTU/LB - COAL RATE 1116500 TONS/YR

Three variables, PSAMAX, PDEPTH, and PMXEXC are required inputs. The PSAMAX variable specifies the maximum land area in acres available for the pond, the PDEPTH variable specifies the final depth of waste in the filled pond, and the PMXEXC variable specifies the maximum depth of topsoil and subsoil (clay) that can be excavated and used for dike construction (excavation and dike construction calculations are based on the assumption that the excavated material compacts to 85% of the original volume). For a fixed depth pond, PSAMAX should be zero, PDEPTH should be set to the desired depth, and PMXEXC should be set to zero. For a pond based on minimum capital investment costs but subject to area and excavation limits, PSAMAX should be set to the maximum area in acres available for pond construction, PDEPTH should be set to zero, and PMXEXC should be set to the maximum excavation depth allowed. The pond based on minimum capital investment costs (with no area and excavation limits) is essentially the same as the second option except that the values specified for the area and excavation limits should be high enough not to realistically limit the optimized values; for example, PSAMAX = 9999 and PMXEXC = 25.

In all three options below, the pond is designed to minimize the sum of construction cost and land cost.

Fixed depth pond

PSAMAX = 0.0

PDEPTH = desired depth, feet

PMXEXC = 0.0

Optimum pond cost, subject to limits of area and excavation depth

PSAMAX = Maximum area available for disposal site, acres

PDEPTH = 0.0

PMXEXC = Maximum allowable excavation depth, feet

Optimized capital investment, assuming unlimited area and excavation depth

PSAMAX = Maximum area available for pond construction (maximum = 9999 acres)

PDEPTH = Maximum pond depth, feet

PMXEXC = Maximum excavation depth, feet

When the restricted area pond design option is used and calculations indicate that the total waste volume cannot be contained within the specified area and excavation limits, an error message is issued and the case is terminated. Example output showing the results of specifying a pond based on minimum capital investment costs and the available area constant is shown in Table 18.

The pond portion of the model can also be executed separately in an interactive mode. Execution of the pond portion of the model in this manner is discussed in Appendix F.

Landfill Disposal Option

Line No.	Input data
10	5 0 0.0 9999 75 85 5280 1 12 6.00

75 → PDEPTH, 85 → PMXEXC

The design of the landfill used in the model is described in Appendix B. Based on this design and the volume of waste to be disposed of, the transportation and landfill requirements are determined. The variable names used in executing the landfill model are the same as those used in executing the pond model, but are defined differently. In the landfill model, PDEPTH specifies the uncompacted waste bulk density in lb/ft^3 (for transportation requirements) and PMXEXC specifies the compacted bulk density in lb/ft^3 (for landfill volume determination). If bulk density values are unknown, the model will choose default values for FGD wastes as shown below. Example output showing the results of specifying a landfill based on minimum capital investment costs with a synthetic liner is shown in Table 19. As with the pond option, the liner is specified separately, as discussed below.

DEFAULT VALUES OF WASTE BULK DENSITIES

	Bulk density, lb/ft3	
	In-process waste	Compacted
Waste Sludge		
Sulfite (filtered)	70	85
Gypsum (filtered)	75	95
Fixed sulfite (filtered)	90	106
Fixed sulfate (filtered)	85	100

The landfill portion of the model can also be executed separately in an interactive mode. Execution of the landfill portion of the model in this manner is discussed in Appendix G.

TABLE 18. EXAMPLE RESULTS ILLUSTRATING POND SITE ACREAGE CONSTRAINT

POND DESIGN

OPTIMIZED TO MINIMIZE TOTAL COST PLUS OVERHEAD

WITH POND SITE ACREAGE CONSTRAINT

POND DIMENSIONS

DEPTH OF POND	21.86	FT
DEPTH OF EXCAVATION	4.80	FT
LENGTH OF DIVIDER DIKE	1735.	FT
LENGTH OF POND PERIMETER DIKE	9655.	FT
LENGTH OF POND PERIMETER FENCE	10605.	FT
SURFACE AREA OF BOTTOM	545.	THOUSAND YD2
SURFACE AREA OF INSIDE WALLS	98.	THOUSAND YD2
SURFACE AREA OF OUTSIDE WALLS	71.	THOUSAND YD2
SURFACE AREA OF RECLAIM STORAGE	66.	THOUSAND YD2
LAND AREA OF POND	637.	THOUSAND YD2
LAND AREA OF POND SITE	847.	THOUSAND YD2
LAND AREA OF POND SITE	175.	ACRES
VOLUME OF EXCAVATION	968.	THOUSAND YD3
VOLUME OF RECLAIM STORAGE	362.	THOUSAND YD3
VOLUME OF SLUDGE TO BE	4333.	THOUSAND YD3
DISPOSED OVER LIFE OF PLANT	2686.	ACRE FT

POND COSTS (THOUSANDS OF DOLLARS)

	LABOR	MATERIAL	TOTAL
CLEARING LAND	386.		386.
EXCAVATION	1914.		1914.
DIKE CONSTRUCTION	2090.		2090.
LINING(12. IN. CLAY)	1287.		1287.
SEEDING DIKE WALLS	130.	77.	207.
ROAD CONSTRUCTION	15.	21.	36.
PERIMETER COSTS. FENCE	64.	74.	138.
RECLAMATION EXPENSE	519.		519.
MONITOR WELLS	5.	5.	10.
SUBTOTAL DIRECT	6411.	177.	6588.
TAX AND FREIGHT		13.	13.
TOTAL DIRECT POND INVESTMENT	6411.	190.	6601.
ENGINEERING DESIGN AND SUPERVISION (2.0)			132.
ARCHITECT AND ENGINEERING CONTRACTOR(1.0)			66.
CONSTRUCTION EXPENSES (8.0)			528.
CONTRACTOR FEES (5.0)			330.
CONTINGENCY (10.0)			766.
TOTAL FIXED INVESTMENT			9189.
LAND COST			1050.

TABLE 19. EXAMPLE RESULTS ILLUSTRATING

LANDFILL DISPOSAL BASED MINIMUM COSTS WITH SYNTHETIC LINER

LANDFILL DESIGN

LANDFILL DIMENSIONS

HEIGHT OF LANDFILL	112.27	FT
HEIGHT OF LANDFILL CAP	92.27	FT
SLOPE OF LANDFILL CAP	6.	DEGREES
LENGTH OF LANDFILL DISPOSAL SIDE	1856.	FT
LENGTH OF LANDFILL TRENCH	7569.	FT
LENGTH OF PERIMETER FENCE	9657.	FT
SURFACE AREA OF LANDFILL	3495.	THOUSAND FT2
FILL AREA LAND EXPOSED TO RAIN	3673.	THOUSAND FT2
SURFACE AREA OF RECLAIM STORAGE	515.	THOUSAND FT2
DISPOSAL LAND AREA OF LANDFILL	3444.	THOUSAND FT2
LAND AREA OF LANDFILL SITE	4930.	THOUSAND FT2
LAND AREA OF LANDFILL SITE	113.	ACRES
VOLUME OF EXCAVATION	301.	THOUSAND YD3
VOLUME OF RECLAIM STORAGE	297.	THOUSAND YD3
VOLUME OF SLUDGE TO BE	5955.	THOUSAND YD3
DISPOSED OVER LIFE OF PLANT	3691.	ACRE FT
DENSITY OF DISCHARGE CAKE	75.00	LBS/FT3
DENSITY OF COMPACTED CAKE	95.00	LBS/FT3
DEPTH OF CATCHMENT POND	24.44	FT
LENGTH OF CATCHMENT POND	373.33	FT
VOLUME OF CATCHMENT POND	96.	THOUSAND YD3

(Continued)

TABLE 19. (Continued)

LANDFILL COSTS (THOUSANDS OF DOLLARS)

LANDFILL EQUIPMENT			1189.
TAX AND FREIGHT			87.
LANDFILL EQUIPMENT TOTAL			1277.

	LABOR	MATERIAL	TOTAL
CLEARING LAND	249.		249.
EXCAVATION	596.		596.
DISCHARGE TRENCH	25.		25.
LINING(SYNTHETIC)	746.	2184.	2929.
DRAINAGE LANDFILL	0.	0.	0.
SEEDING LANDFILL SITE	89.	53.	142.
ROAD CONSTRUCTION	81.	47.	128.
PERIMETER COSTS, FENCE	66.	74.	140.
RECLAMATION EXPENSE	281.		281.
RECLAMATION SYNTHETIC COVER	752.	1526.	2278.
MONITOR WELLS	6.	5.	11.
SUBTOTAL DIRECT	2891.	3889.	6780.
TAX AND FREIGHT		292.	292.
TOTAL DIRECT LANDFILL INVESTMENT	2891.	4181.	7071.
ENGINEERING DESIGN AND SUPERVISION (2.0)			141.
ARCHITECT AND ENGINEERING CONTRACTOR(1.0)			71.
CONSTRUCTION EXPENSES (8.0)			566.
CONTRACTOR FEES (5.0)			354.
CONTINGENCY (20.0)			1896.
TOTAL FIXED INVESTMENT			11375.
LAND COST			679.

REVENUE QUANTITIES

LANDFILL LABOR	29120.	MAN-HRS
DIESEL FUEL	103596.	GALLONS
ELECTRICITY	145178.	KWH
WATER	3867.	K-GALLONS
ANALYSIS	42.	MAN-HRS

Disposal Site Liner Option

Line No.	Input data
10	1 0 0.0 9999 5000 0 25 5280 1 12 6.00

ILINER XLINA XLINB

The liner option allows a choice of an unlined, clay-lined, or synthetic-lined disposal site. The input variables are ILINER, XLINA, and XLINB. ILINER specifies the type of lining as illustrated below.

1 = Clay liner

2 = Synthetic liner

3 = No liner

For a clay lining (ILINER = 1), XLINA specifies the depth of clay in inches and XLINB specifies the clay lining installation cost (or the costs for reworking the clay subsoil into a lining) in $\$/yd^3$. For a synthetic lining (ILINER = 2), XLINA specifies the liner material cost in $\$/yd^2$ and XLINB specifies the installation cost in $\$/yd^2$. For no liner (ILINER = 3), XLINA and XLINB should be set to zero. Example output showing the results of specifying a synthetic liner is shown in Table 20.

Economic Premises Option

Line No.	Input data
11	7 2 16 5 10 8 15.6 10 8 3 6 1 60 1.886 14.7 0.0

IECON PCTOVR XLEVEL CAPCHG PCTMKT

or or or

PCTADM UNDCAP PCTINS

The economic premises option (IECON) allows cost projections based on either the current EPA-TVA economic premises adopted December 5, 1979 (and expanded and amplified in March 1981), or the old premises that were used before December 5, 1979. Appendix B contains a description of the current premises. Four variables are used in conjunction with the economic premises option. The meaning of these variables depends on which set of premises is selected. If the current premises are specified (IECON = 1), the PCTOVR variable specifies the plant administrative overhead rate, applied as a percent of conversion costs less utilities; the XLEVEL variable specifies the levelizing factor to be applied to first-year operating and maintenance costs to develop levelized operating and maintenance costs for the total life of the

TABLE 20. EXAMPLE RESULTS ILLUSTRATING SYNTHETIC POND LINER OUTPUT

POND DESIGN

OPTIMIZED TO MINIMIZE TOTAL COST PLUS OVERHEAD

POND DIMENSIONS

DEPTH OF POND	29.83	FT
DEPTH OF EXCAVATION	7.57	FT
LENGTH OF DIVIDER DIKE	1485.	FT
LENGTH OF POND PERIMETER DIKE	8435.	FT
LENGTH OF POND PERIMETER FENCE	9505.	FT
SURFACE AREA OF BOTTOM	385.	THOUSAND YD2
SURFACE AREA OF INSIDE WALLS	108.	THOUSAND YD2
SURFACE AREA OF OUTSIDE WALLS	78.	THOUSAND YD2
SURFACE AREA OF RECLAIM STORAGE	56.	THOUSAND YD2
LAND AREA OF POND	485.	THOUSAND YD2
LAND AREA OF POND SITE	683.	THOUSAND YD2
LAND AREA OF POND SITE	141.	ACRES
VOLUME OF EXCAVATION	1082.	THOUSAND YD3
VOLUME OF RECLAIM STORAGE	288.	THOUSAND YD3
VOLUME OF SLUDGE TO BE	4333.	THOUSAND YD3
DISPOSED OVER LIFE OF PLANT	2686.	ACRE FT

POND COSTS (THOUSANDS OF DOLLARS)

	LABOR	MATERIAL	TOTAL
CLEARING LAND	311.		311.
EXCAVATION	2141.		2141.
DIKE CONSTRUCTION	2739.		2739.
LINING(SYNTHETIC)	790.	2394.	3184.
SEEDING DIKE WALLS	74.	44.	118.
ROAD CONSTRUCTION	13.	18.	31.
PERIMETER COSTS, FENCE	58.	67.	124.
RECLAMATION EXPENSE	401.		401.
MONITOR WELLS	5.	5.	10.
SUBTOTAL DIRECT	6532.	2527.	9059.
TAX AND FREIGHT		190.	190.
TOTAL DIRECT POND INVESTMENT	6532.	2717.	9249.
ENGINEERING DESIGN AND SUPERVISION (2.0)			185.
ARCHITECT AND ENGINEERING CONTRACTOR(1.0)			92.
CONSTRUCTION EXPENSES (8.0)			740.
CONTRACTOR FEES (5.0)			462.
CONTINGENCY (10.0)			1073.
TOTAL FIXED INVESTMENT			11801.
LAND COST			847.

plant; the CAPCHG variable specifies levelized annual capital charges applied as a percent of total capital investment; and the PCTMKT variable specifies marketing costs applied as a percent of byproduct credit (applies only to processes with a salable byproduct). If the levelizing factor (XLEVEL) is set to zero then a lifetime revenue sheet is printed showing annual revenue requirements for each year of plant operation.

If the old premises are specified (IECON = 0), the PCTOVR variable specifies the plant overhead rate applied as a percent of conversion costs less utilities, the PCTADM variable specifies the administrative research and service overhead rate applied as a percent of operating labor and supervision, the UNDCAP variable specifies the annual capital charge basis for undepreciated investment, and the PCTINS variable specifies the rate for insurance and interim replacements applied as a percent of total capital investment.

Example output showing the results of specifying the current economic premises (IECON = 1) and a nonzero levelizing factor (XLEVEL = 1.886) is shown in the base case printout in Appendix D. The results of specifying a zero levelizing factor are shown in the example revenue requirements in Table 21. The results of specifying the old economic premises are shown in the example revenue requirements in Table 22.

Sales Tax and Freight Option

Line No.	Input data
12	1 4 3.5 6 0 1 1.5 1 2 1 8 5 10 0

```
1 4 3.5 6 0 1 1.5 1 2 1 8 5 10 0
↓  ↘  ↘
ITAXFR TXRAT FRRAT
```

The sales tax and freight option (ITAXFR) allows capital investment sales tax and freight to be applied as a percentage of material costs. The sales tax rate is specified with the variable TXRAT and the freight rate is specified with the FRRAT variable. When ITAXFR is 1, the specified rates are applied to material costs and included in the capital investment summary printout; when ITAXFR is zero, sales tax and freight are excluded. Example output showing the results of specifying sales tax and freight is shown on the capital investment summary sheet in the base case printout in Appendix D. An example investment summary sheet showing sales tax and freight excluded is shown in Table 23.

Overtime Option

Line No.	Input data
12	1 4 3.5 6 0 1 1.5 1 2 1 8 5 10 0

```
          0 1 1.5
           ↙   ↓
     IOTIME OTRATE
```

TABLE 21. EXAMPLE REVENUE REQUIREMENTS USING

THE ECONOMIC PREMISES WITH NO LEVELIZING FACTORS

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL

DISPLAY SHEET FOR YEAR= 1

ANNUAL OPERATION KW-HR/KW = 5500

39.38 TONS PER HOUR DRY SLUDGE

TOTAL CAPITAL INVESTMENT 108818000

	ANNUAL QUANTITY	UNIT COST,$	TOTAL ANNUAL COST,$
DIRECT COSTS			
RAW MATERIAL			
LIMESTONE	148.0 K TONS	15.00/TON	2220400
SUBTOTAL RAW MATERIAL			2220400
CONVERSION COSTS			
OPERATING LABOR AND SUPERVISION	43860.0 MAN-HR	19.00/MAN-HR	833400
LANDFILL LABOR AND SUPERVISION	29120.0 MAN-HR	24.00/MAN-HR	698900
UTILITIES			
STEAM	542640.0 K LB	4.00/K LB	2170500
PROCESS WATER	194000.0 K GAL	0.16/K GAL	31000
ELECTRICITY	56943180.0 KWH	0.055/KWH	3131900
DIESEL FUEL	103600.0 GAL	1.60/GAL	165800
MAINTENANCE			
LABOR AND MATERIAL			4538000
ANALYSES	4990.0 HR	26.00/HR	129700
SUBTOTAL CONVERSION COSTS			11699200
SUBTOTAL DIRECT COSTS			13919600
INDIRECT COSTS			
OVERHEADS			
PLANT AND ADMINISTRATIVE (60.0% OF CONVERSION COSTS LESS UTILITIES)			3720000
FIRST YEAR OPERATING AND MAINTENANCE COSTS			17639600
LEVELIZED CAPITAL CHARGES(14.70% OF TOTAL CAPITAL INVESTMENT)			15996300
FIRST YEAR ANNUAL REVENUE REQUIREMENTS			33635900
EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)			12.23

HEAT RATE 9500. BTU/KWH - HEAT VALUE OF COAL 11700 BTU/LB - COAL RATE 1116500 TONS/YR

(Continued)

TABLE 21. (Continued)

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED LIFETIME REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL

TOTAL CAPITAL INVESTMENT: $ 108819000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR /KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BYPRODUCT RATE, EQUIVALENT TONS/YEAR DRY SLUDGE	SLUDGE FIXATION FEE $/TON DRY SLUDGE	ADJUSTED GROSS ANNUAL REVENUE REQUIREMENT EXCLUDING SLUDGE FIXATION COST, $/YEAR	TOTAL ANNUAL SLUDGE FIXATION COST, $/YEAR	NET ANNUAL INCREASE IN TOTAL REVENUE REQUIREMENT, $	CUMULATIVE NET INCREASE IN TOTAL REVENUE REQUIREMENT, $
1	5500	26125000	1116500	31700	216600	0.0	33635900	0	33635900	33635900
2	5500	26125000	1116500	31700	216600	0.0	34694100	0	34694100	68330000
3	5500	26125000	1116500	31700	216600	0.0	35816100	0	35816100	104146100
4	5500	26125000	1116500	31700	216600	0.0	37005400	0	37005400	141151500
5	5500	26125000	1116500	31700	216600	0.0	38265900	0	38265900	179417400
6	5500	26125000	1116500	31700	216600	0.0	39601900	0	39601900	219019300
7	5500	26125000	1116500	31700	216600	0.0	41018400	0	41018400	260037700
8	5500	26125000	1116500	31700	216600	0.0	42519700	0	42519700	302557400
9	5500	26125000	1116500	31700	216600	0.0	44111100	0	44111100	346668500
10	5500	26125000	1116500	31700	216600	0.0	45797800	0	45797800	392466300
11	5500	26125000	1116500	31700	216600	0.0	47585900	0	47585900	440052200
12	5500	26125000	1116500	31700	216600	0.0	49481200	0	49481200	489533400
13	5500	26125000	1116500	31700	216600	0.0	51490500	0	51490500	541023900
14	5500	26125000	1116500	31700	216600	0.0	53620200	0	53620200	594644100
15	5500	26125000	1116500	31700	216600	0.0	55877700	0	55877700	650521800
16	5500	26125000	1116500	31700	216600	0.0	58270300	0	58270300	708792100
17	5500	26125000	1116500	31700	216600	0.0	60807200	0	60807200	769599300
18	5500	26125000	1116500	31700	216600	0.0	63495400	0	63495400	833094700
19	5500	26125000	1116500	31700	216600	0.0	66345300	0	66345300	899440000
20	5500	26125000	1116500	31700	216600	0.0	69366500	0	69366500	968806500
21	5500	26125000	1116500	31700	216600	0.0	72568400	0	72568400	1041374900
22	5500	26125000	1116500	31700	216600	0.0	75963000	0	75963000	1117339400
23	5500	26125000	1116500	31700	216600	0.0	79561000	0	79561000	1196898900
24	5500	26125000	1116500	31700	216600	0.0	83374700	0	83374700	1280273600
25	5500	26125000	1116500	31700	216600	0.0	87417600	0	87417600	1367691200
26	5500	26125000	1116500	31700	216600	0.0	91702700	0	91702700	1459393900
27	5500	26125000	1116500	31700	216600	0.0	96245200	0	96245200	1555639100
28	5500	26125000	1116500	31700	216600	0.0	101060200	0	101060200	1656699300
29	5500	26125000	1116500	31700	216600	0.0	106164100	0	106164100	1762863400
30	5500	26125000	1116500	31700	216600	0.0	111573900	0	111573900	1874437300
TOT	165000	783750000	33495000	951000	6498000		1874437300	0	1874437300	

LIFETIME AVERAGE INCREASE IN UNIT REVENUE REQUIREMENT			
DOLLARS PER TON OF COAL BURNED	55.96	0.0	55.96
MILLS PER KILOWATT-HOUR	22.72	0.0	22.72
CENTS PER MILLION BTU HEAT INPUT	239.16	0.0	239.16
DOLLARS PER TON OF SULFUR REMOVED	1971.02	0.0	1971.02
REVENUE REQUIREMENT DISCOUNTED AT 10.0% TO INITIAL YEAR, DOLLARS	446631900	0	446631900
LEVELIZED INCREASE IN UNIT REVENUE REQUIREMENT EQUIVALENT TO DISCOUNTED REQUIREMENT OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	42.43	0.0	42.43
MILLS PER KILOWATT-HOUR	17.23	0.0	17.23
CENTS PER MILLION BTU HEAT INPUT	181.35	0.0	181.35
DOLLARS PER TON OF SULFUR REMOVED	1494.75	0.0	1494.75

UNIT COSTS INFLATED AT 6.00% PER YEAR

TABLE 22. EXAMPLE REVENUE REQUIREMENTS USING THE OLD ECONOMIC PREMISES

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL
DISPLAY SHEET FOR YEAR= 1
ANNUAL OPERATION KW-HR/KW = 5500

39.38 TONS PER HOUR DRY SLUDGE
TOTAL CAPITAL INVESTMENT 105529000

	ANNUAL QUANTITY	UNIT COST,$	TOTAL ANNUAL COST,$
DIRECT COSTS			
RAW MATERIAL			
LIMESTONE	148.0 K TONS	15.00/TON	2220400
SUBTOTAL RAW MATERIAL			2220400
CONVERSION COSTS			
OPERATING LABOR AND SUPERVISION	43860.0 MAN-HR	19.00/MAN-HR	833400
LANDFILL LABOR AND SUPERVISION	25810.0 MAN-HR	24.00/MAN-HR	619500
UTILITIES			
STEAM	542640.0 K LB	4.00/K LB	2170500
PROCESS WATER	193170.0 K GAL	0.16/K GAL	30900
ELECTRICITY	56912080.0 KWH	0.055/KWH	3130200
DIESEL FUEL	81400.0 GAL	1.60/GAL	130200
MAINTENANCE			
LABOR AND MATERIAL			3926700
ANALYSES	4420.0 HR	26.00/HR	114800
SUBTOTAL CONVERSION COSTS			10956200
SUBTOTAL DIRECT COSTS			13176600
INDIRECT COSTS			
DEPRECIATION			3401900
COST OF CAPITAL AND TAXES, 17.20% OF UNDEPRECIATED INVESTMENT			18151000
INSURANCE & INTERIM REPLACEMENTS, 1.17% OF TOTAL CAPITAL INVESTMENT			1234700
OVERHEAD			
PLANT, 50.0% OF CONVERSION COSTS LESS UTILITIES			2747200
ADMINISTRATIVE, RESEARCH, AND SERVICE, 10.0% OF OPERATING LABOR AND SUPERVISION			62000
SUBTOTAL INDIRECT COSTS			25596800
TOTAL ANNUAL REVENUE REQUIREMENT			38773400
EQUIVALENT UNIT REVENUE REQUIREMENT, MILLS/KWH			14.10

HEAT RATE 9500. BTU/KWH - HEAT VALUE OF COAL 11700 BTU/LB - COAL RATE 1116500 TONS/YR

(Continued)

TABLE 22. (Continued)

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED LIFETIME REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL

TOTAL CAPITAL INVESTMENT: $ 105529000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR /KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BYPRODUCT RATE, EQUIVALENT TONS/YEAR DRY SLUDGE	SLUDGE FIXATION FEE $/TON DRY SLUDGE	ADJUSTED GROSS ANNUAL REVENUE REQUIREMENT EXCLUDING SLUDGE FIXATION COST, $/YEAR	TOTAL ANNUAL SLUDGE FIXATION COST, $/YEAR	NET ANNUAL INCREASE IN TOTAL REVENUE REQUIREMENT, $	CUMULATIVE NET INCREASE IN TOTAL REVENUE REQUIREMENT, $
1	5500	26125000	1116500	31700	216600	0.0	38773400	0	38773400	38773400
2	5500	26125000	1116500	31700	216600	0.0	39147600	0	39147600	77921000
3	5500	26125000	1116500	31700	216600	0.0	39579000	0	39579000	117500000
4	5500	26125000	1116500	31700	216600	0.0	40071700	0	40071700	157571700
5	5500	26125000	1116500	31700	216600	0.0	40628900	0	40628900	198200600
6	5500	26125000	1116500	31700	216600	0.0	41254700	0	41254700	239455300
7	5500	26125000	1116500	31700	216600	0.0	41953200	0	41953200	281408500
8	5500	26125000	1116500	31700	216600	0.0	42728400	0	42728400	324136900
9	5500	26125000	1116500	31700	216600	0.0	43585500	0	43585500	367722400
10	5500	26125000	1116500	31700	216600	0.0	44529200	0	44529200	412251600
11	5500	26125000	1116500	31700	216600	0.0	45564300	0	45564300	457815900
12	5500	26125000	1116500	31700	216600	0.0	46697000	0	46697000	504512900
13	5500	26125000	1116500	31700	216600	0.0	47932700	0	47932700	552445600
14	5500	26125000	1116500	31700	216600	0.0	49277200	0	49277200	601722800
15	5500	26125000	1116500	31700	216600	0.0	50738300	0	50738300	652461100
16	5500	26125000	1116500	31700	216600	0.0	52321400	0	52321400	704782500
17	5500	26125000	1116500	31700	216600	0.0	54035200	0	54035200	758817700
18	5500	26125000	1116500	31700	216600	0.0	55886500	0	55886500	814704200
19	5500	26125000	1116500	31700	216600	0.0	57884000	0	57884000	872588200
20	5500	26125000	1116500	31700	216600	0.0	60036600	0	60036600	932624800
21	5500	26125000	1116500	31700	216600	0.0	62353500	0	62353500	994978300
22	5500	26125000	1116500	31700	216600	0.0	64844500	0	64844500	1059822800
23	5500	26125000	1116500	31700	216600	0.0	67520400	0	67520400	1127343200
24	5500	26125000	1116500	31700	216600	0.0	70391400	0	70391400	1197734200
25	5500	26125000	1116500	31700	216600	0.0	73469800	0	73469800	1271204400
26	5500	26125000	1116500	31700	216600	0.0	76768300	0	76768300	1347972700
27	5500	26125000	1116500	31700	216600	0.0	80299600	0	80299600	1428272300
28	5500	26125000	1116500	31700	216600	0.0	84077800	0	84077800	1512350100
29	5500	26125000	1116500	31700	216600	0.0	88118100	0	88118100	1600468200
30	5500	26125000	1116500	31700	216600	0.0	92435900	0	92435900	1692904100
TOT	165000	783750000	33495000	951000	6498000		1692904100	0	1692904100	

LIFETIME AVERAGE INCREASE IN UNIT REVENUE REQUIREMENT			
DOLLARS PER TON OF COAL BURNED	50.54	0.0	50.54
MILLS PER KILOWATT-HOUR	20.52	0.0	20.52
CENTS PER MILLION BTU HEAT INPUT	216.00	0.0	216.00
DOLLARS PER TON OF SULFUR REMOVED	1780.13	0.0	1780.13
REVENUE REQUIREMENT DISCOUNTED AT 10.0% TO INITIAL YEAR, DOLLARS	437818600	0	437818600
LEVELIZED INCREASE IN UNIT REVENUE REQUIREMENT EQUIVALENT TO DISCOUNTED REQUIREMENT OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	41.60	0.0	41.60
MILLS PER KILOWATT-HOUR	16.89	0.0	16.89
CENTS PER MILLION BTU HEAT INPUT	177.77	0.0	177.77
DOLLARS PER TON OF SULFUR REMOVED	1465.26	0.0	1465.26

UNIT COSTS INFLATED AT 6.00% PER YEAR

TABLE 23. EXAMPLE INVESTMENT SUMMARY TABLE WITH SALES TAX AND FREIGHT EXCLUDED

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED CAPITAL INVESTMENT REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 SCRUB	OXID	REHEAT	SOLID SEP	TOTAL	DOLLARS PER KWH
EQUIPMENT									
MATERIAL	839.	2376.	3490.	9499.	580.	3292.	812.	21287.	42.57
LABOR	134.	187.	64.	1279.	473.	208.	215.	2558.	5.12
PIPING									
MATERIAL	37.	416.	0.	5723.	25.	559.	851.	7611.	15.22
LABOR	17.	192.	0.	735.	57.	263.	271.	1536.	3.07
DUCTWORK									
MATERIAL	0.	0.	2918.	0.	102.	0.	0.	3020.	6.04
LABOR	0.	0.	2424.	0.	182.	0.	0.	2606.	5.21
FOUNDATIONS									
MATERIAL	215.	114.	49.	103.	45.	0.	35.	561.	1.12
LABOR	524.	219.	88.	208.	90.	0.	69.	1197.	2.39
STRUCTURAL									
MATERIAL	142.	67.	0.	393.	0.	0.	0.	602.	1.20
LABOR	36.	124.	0.	722.	0.	0.	0.	882.	1.76
ELECTRICAL									
MATERIAL	177.	178.	338.	437.	202.	66.	250.	1641.	3.28
LABOR	540.	365.	1103.	780.	226.	67.	529.	3610.	7.22
INSTRUMENTATION									
MATERIAL	1.	167.	60.	942.	69.	32.	55.	1325.	2.65
LABOR	0.	24.	12.	127.	10.	7.	72.	252.	0.50
BUILDINGS									
MATERIAL	0.	161.	0.	0.	34.	0.	61.	256.	0.51
LABOR	0.	166.	0.	0.	34.	0.	61.	260.	0.52
TOTAL PROCESS CAPITAL	2656.	4754.	10545.	20948.	2530.	4494.	3280.	49207.	98.41
SERVICES AND MISCELLANEOUS (6.0 %)	159.	285.	633.	1257.	152.	270.	197.	2952.	5.90
TOTAL DIRECT PROCESS INVESTMENT	2816.	5040.	11178.	22205.	2681.	4764.	3476.	52159.	104.32
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	1189.	1189.	2.38
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	3177.	3177.	6.35
TOTAL DIRECT INVESTMENT	2816.	5040.	11178.	22205.	2681.	4764.	7843.	56526.	113.05
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	197.	353.	782.	1554.	188.	333.	243.	3651.	7.30
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	56.	101.	224.	444.	54.	95.	70.	1043.	2.09
CONSTRUCTION EXPENSES (16.0 %)	451.	806.	1788.	3553.	429.	762.	556.	8345.	16.69
CONTRACTOR FEES (5.0 %)	141.	252.	559.	1110.	134.	238.	174.	2608.	5.22
CONTINGENCY (10.0 %)	366.	655.	1453.	2887.	349.	619.	452.	6781.	13.56
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	1483.	1483.	2.97
SUBTOTAL FIXED INVESTMENT	4026.	7206.	15985.	31753.	3834.	6812.	10821.	80437.	160.87
STARTUP & MODIFICATION ALLOWANCE (8.0, 0.0 %)	322.	577.	1279.	2494.	307.	545.	398.	5967.	11.93
INTEREST DURING CONSTRUCTION (15.6 %)	628.	1124.	2494.	4953.	598.	1063.	1688.	12548.	25.10
ROYALTIES (0.0 %)	0.	0.	0.	0.	0.	0.	0.	0.	0.0
LAND ($ 6000. ACRE)	15.	1.	2.	1.	1.	0.	684.	704.	1.41
WORKING CAPITAL	187.	335.	744.	1478.	178.	317.	522.	3761.	7.52
TOTAL CAPITAL INVESTMENT	5179.	9244.	20503.	40725.	4918.	8737.	14112.	103417.	206.83

The overtime option (IOTIME) allows an overtime labor rate (OTRATE) to be applied to 7% of total capital investment labor as defined in the premises in Appendix B. When IOTIME is 1, the specified overtime rate is applied to 7% of all applicable labor costs; when IOTIME is zero, no overtime labor adjustments are made. The added costs for overtime labor are not shown separately in the model output, but a message is printed in the listing of the model inputs to indicate if overtime is specified. An example printout with overtime specified is shown in the base case printout in Appendix D.

<u>Separate Waste Disposal Site Construction Indirect Investment Factors Option</u>

Line No.	Input data
12	1 4 3.5 6 0 1 1.5 1 2 1 8 5 10 0
	INDPND PENGIN PARCH PFLDEX PFEES PCONT PSTART

The separate waste disposal indirect investment option (INDPND) allows the indirect capital investment for the waste disposal site construction to be calculated separately from the process indirect investment. The waste disposal site construction is usually less complicated than the FGD process construction and its indirect investment factors are usually lower. If INDPND is zero, the waste disposal site construction indirect investment is calculated using the same factors (ENGIN, ARCTEC, FLDEXP, FEES, CONT, and START) specified in line 11. If INDPND = 1, the factors specified by PENGIN (engineering design and supervision), PARCH (architectural and engineering contractor), PFLDEX (field expenses), PFEES (contractor fees), PCONT (contingencies), and PSTART (allowance for startup and modifications) are used to determine the waste disposal site indirect investment. All but PCONT and PSTART are calculated as a percentage of waste disposal site direct investment. If the current economic premises are used (IECON = 1 in line 11), the contingencies are a percentage of the sum of the waste disposal site direct investments plus each of the four preceding waste disposal site indirect investments. If the old economic premises are used (IECON = 0 in line 11), the contingency is calculated as a percentage of the waste disposal site direct investment only. The allowance for startup and modification is calculated as a percentage of the total fixed investment for waste disposal site construction. An example of output showing the use of separate indirect investment factors for landfill construction is shown in the example printout in Appendix D. An example of the use of a common indirect investment factor (INDPND = 0) for both the FGD process and the waste disposal site is shown in Table 24.

If the user wishes to specify an oversized waste disposal site to cover contingencies, or to specify an undersized site for applications in which the initial site is not designed for the full life of the plant, an appropriate PNDCAP factor, i.e., greater than or less than 1.0, can be specified.

The PNDCAP factor is also used automatically by the model to adjust the landfill size when fixation (ISLUDG = 5, IFIXS = 1 in line 10) is specified to account for the additional volume of the fly ash and lime. An example is shown in Table 25.

TABLE 24. EXAMPLE INVESTMENT SUMMARY TABLE WITH COMMON INDIRECT INVESTMENT FACTORS FOR PROCESS AND LANDFILL

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED CAPITAL INVESTMENT REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 SCRUB	OXID	REHEAT	SOLID SEP	TOTAL	DOLLARS PER KWH
EQUIPMENT									
MATERIAL	839.	2376.	3490.	9499.	980.	3292.	812.	21287.	42.57
LABOR	134.	187.	64.	1279.	473.	208.	215.	2558.	5.12
PIPING									
MATERIAL	37.	416.	0.	5723.	25.	559.	851.	7611.	15.22
LABOR	17.	192.	0.	735.	57.	263.	271.	1536.	3.07
DUCTWORK									
MATERIAL	0.	0.	2918.	0.	102.	0.	0.	3020.	6.04
LABOR	0.	0.	2424.	0.	182.	0.	0.	2606.	5.21
FOUNDATIONS									
MATERIAL	215.	114.	49.	103.	45.	0.	35.	561.	1.12
LABOR	524.	219.	88.	208.	90.	0.	69.	1197.	2.39
STRUCTURAL									
MATERIAL	142.	67.	0.	393.	0.	0.	0.	602.	1.20
LABOR	36.	124.	0.	722.	0.	0.	0.	882.	1.76
ELECTRICAL									
MATERIAL	177.	178.	338.	437.	202.	66.	250.	1641.	3.28
LABOR	540.	365.	1103.	780.	226.	67.	529.	3610.	7.22
INSTRUMENTATION									
MATERIAL	1.	167.	60.	942.	69.	32.	55.	1325.	2.65
LABOR	0.	24.	12.	127.	10.	7.	72.	252.	0.50
BUILDINGS									
MATERIAL	0.	161.	0.	0.	34.	0.	61.	256.	0.51
LABOR	0.	166.	0.	0.	34.	0.	61.	260.	0.52
SALES TAX (4.0%) AND FREIGHT (3.5%)	105.	261.	514.	1282.	109.	296.	155.	2723.	5.45
TOTAL PROCESS CAPITAL	2762.	5015.	11059.	22230.	2639.	4790.	3434.	51930.	103.86
SERVICES AND MISCELLANEOUS (6.0 %)	166.	301.	664.	1334.	158.	287.	206.	3116.	6.23
TOTAL DIRECT PROCESS INVESTMENT	2927.	5316.	11723.	23564.	2797.	5077.	3640.	55046.	110.09
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	1189.	1189.	2.38
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	3177.	3177.	6.35
LANDFILL SALES TAX (4.0%) AND FREIGHT (3.5%)	0.	0.	0.	0.	0.	0.	113.	113.	0.23
TOTAL DIRECT INVESTMENT	2927.	5316.	11723.	23564.	2797.	5077.	8120.	59525.	119.05
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	205.	372.	821.	1649.	196.	355.	479.	4077.	8.15
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	59.	106.	234.	471.	56.	102.	105.	1133.	2.27
CONSTRUCTION EXPENSES (16.0 %)	468.	851.	1876.	3770.	448.	812.	1095.	9320.	18.64
CONTRACTOR FEES (5.0 %)	146.	266.	586.	1178.	140.	254.	342.	2912.	5.82
CONTINGENCY (10.0 %)	381.	691.	1524.	3063.	364.	660.	1014.	7697.	15.39
SUBTOTAL FIXED INVESTMENT	4186.	7602.	16764.	33697.	4000.	7261.	11155.	84664.	169.33
STARTUP & MODIFICATION ALLOWANCE (8.0, 0.0 %)	335.	608.	1341.	2696.	320.	581.	790.	6671.	13.34
INTEREST DURING CONSTRUCTION (15.6 %)	653.	1186.	2615.	5257.	624.	1133.	1740.	13208.	26.42
ROYALTIES (0.0 %)	0.	0.	0.	0.	0.	0.	0.	0.	0.0
LAND ($ 6000. ACRE)	15.	1.	2.	1.	1.	0.	684.	704.	1.41
WORKING CAPITAL	192.	348.	768.	1543.	183.	333.	532.	3898.	7.80
TOTAL CAPITAL INVESTMENT	5381.	9745.	21490.	43193.	5128.	9307.	14901.	109145.	218.29

TABLE 25. EXAMPLE RESULTS ILLUSTRATING THE EFFECTS OF FIXATION ON LANDFILL DESIGN

LANDFILL DESIGN

(LANDFILL DESIGNED FOR 157.49 % OF PROJECTED LIFETIME CAPACITY)

(LANDFILL VOLUME INCLUDES SLUDGE FIXATION PROCESS VOLUME)

LANDFILL DIMENSIONS

HEIGHT OF LANDFILL	127.83	FT
HEIGHT OF LANDFILL CAP	107.83	FT
SLOPE OF LANDFILL CAP	6.	DEGREES
LENGTH OF LANDFILL DISPOSAL SIDE	2152.	FT
LENGTH OF LANDFILL TRENCH	8754.	FT
LENGTH OF PERIMETER FENCE	11030.	FT
SURFACE AREA OF LANDFILL	4694.	THOUSAND FT2
FILL AREA LAND EXPOSED TO RAIN	4911.	THOUSAND FT2
SURFACE AREA OF RECLAIM STORAGE	675.	THOUSAND FT2
DISPOSAL LAND AREA OF LANDFILL	4631.	THOUSAND FT2
LAND AREA OF LANDFILL SITE	6448.	THOUSAND FT2
LAND AREA OF LANDFILL SITE	148.	ACRES
VOLUME OF EXCAVATION	402.	THOUSAND YD3
VOLUME OF RECLAIM STORAGE	401.	THOUSAND YD3
VOLUME OF SLUDGE TO BE	8909.	THOUSAND YD3
DISPOSED OVER LIFE OF PLANT	5522.	ACRE FT
VOLUME OF FLYASH TO BE	2980.	THOUSAND YD3
DISPOSED OVER LIFE OF PLANT	1847.	ACRE FT
DENSITY OF DISCHARGE CAKE	85.00	LBS/FT3
DENSITY OF COMPACTED CAKE	100.00	LBS/FT3
DEPTH OF CATCHMENT POND	25.18	FT
LENGTH OF CATCHMENT POND	420.59	FT
VOLUME OF CATCHMENT POND	129.	THOUSAND YD3

(Continued)

TABLE 25. (Continued)

LANDFILL COSTS (THOUSANDS OF DOLLARS)

LANDFILL EQUIPMENT			1474.
TAX AND FREIGHT			108.
LANDFILL EQUIPMENT TOTAL			1582.

	LABOR	MATERIAL	TOTAL
CLEARING LAND	326.		326.
EXCAVATION	795.		795.
DISCHARGE TRENCH	28.		28.
GRAVEL	68.	80.	147.
LINING(12. IN. CLAY)	1241.		1241.
DRAINAGE LANDFILL	13.	132.	145.
SEEDING LANDFILL SITE	114.	68.	182.
ROAD CONSTRUCTION	87.	52.	139.
PERIMETER COSTS, FENCE	75.	84.	160.
RECLAMATION EXPENSE	378.		378.
RECLAMATION CLAY COVER	589.		589.
MONITOR WELLS	6.	5.	11.
SUBTOTAL DIRECT	3721.	420.	4142.
TAX AND FREIGHT		32.	32.
TOTAL DIRECT LANDFILL INVESTMENT	3721.	452.	4173.
ENGINEERING DESIGN AND SUPERVISION (2.0)			83.
ARCHITECT AND ENGINEERING CONTRACTOR(1.0)			42.
CONSTRUCTION EXPENSES (8.0)			334.
CONTRACTOR FEES (5.0)			209.
CONTINGENCY (20.0)			1285.
TOTAL FIXED INVESTMENT			7708.
LAND COST			888.

REVENUE QUANTITIES

LANDFILL LABOR	33280.	MAN-HRS
DIESEL FUEL	121021.	GALLONS
ELECTRICITY	181303.	KWH
WATER	5785.	K-GALLONS
ANALYSIS	59.	MAN-HRS

Operating Profile Option

Line No.	Input data
14	3 .6 30 1 5 .8 1.0 3 .65 1 1 1.10 1985 363.4
	IOPSCH ONCAP IYPROP

One of the most important variables affecting the economics of a power plant and an associated FGD system is the operating profile (number of years of operation and the hours of operation per year) over the life of the unit. The effects of the year-by-year profile on capital investment and annual revenue requirements are determined by the economic premises option (line 11, IECON), the operating and maintenance cost levelizing factor (line 11, XLEVEL) used with the current economic premises, and the waste disposal option (line 10, ISLUDG). The model provides five options for specifying this profile. The input variable for these options is IOPSCH. If IOPSCH = 1, the model uses the operating schedule shown in Figure 2 which is based on a profile developed by TVA for several past economic evaluations (15). If IOPSCH = 2, the operating schedule is based on historical Federal Energy Regulatory Commission (FERC) data (16) as shown in Figure 3. If IOPSCH = 3, the user must input the operating profile as shown below. If IOPSCH = 4, a levelized operating profile of 5,500 hours per year is used (see Appendix D). If IOPSCH = 5, the user supplies a fractional capacity factor, UNCAP, and the hours of operation each year are calculated by multiplying the fractional capacity factor by 8,760 hours per year. The cumulative hours of operation over the life of the plant are obtained by multiplying the resulting annual hours of operation by the number of years of operation, IYROP, which is also an input. A 30-year operating life is assumed for IOPSCH = 1, 2, or 4. The operating life in years must be specified by the variable IYROP when using IOPSCH options 3 and 5. When the operating profile is specified by the user (IOPSCH = 3), the projected operating life in years cannot exceed 50. Beginning on line 16, the total number of hour-per-year entries must be equal to the value of IYROP. The number of entries per line must be equal to 10. Less than 10 entries are allowed on the last line only, depending on the number of years required. An example using 25 years is shown below.

Line No.	Input data
14	3 1 5 .8 1.0 3 .65 1 1 1.10 1985 363.4
15	25
16	5000 5000 5000 5000 5000 6000 6000 6000 6000 6000
17	6250 6250 6250 6250 6250 6250 6250 6250 6250 6250
18	4500 4500 3500 2500 1000
19	END

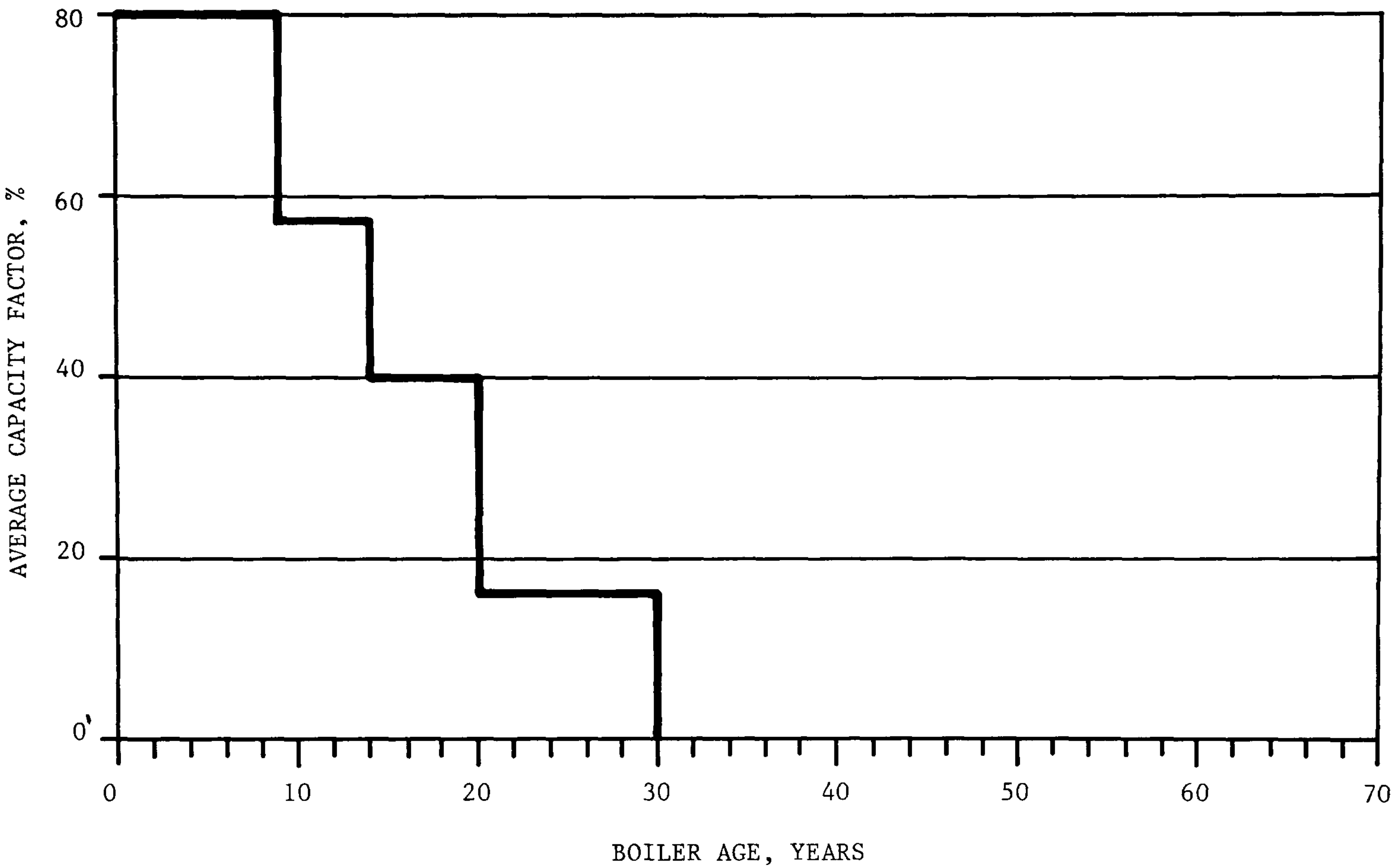


Figure 2. Operating profile assumed for IOPSCH = 1 based on old TVA premises.

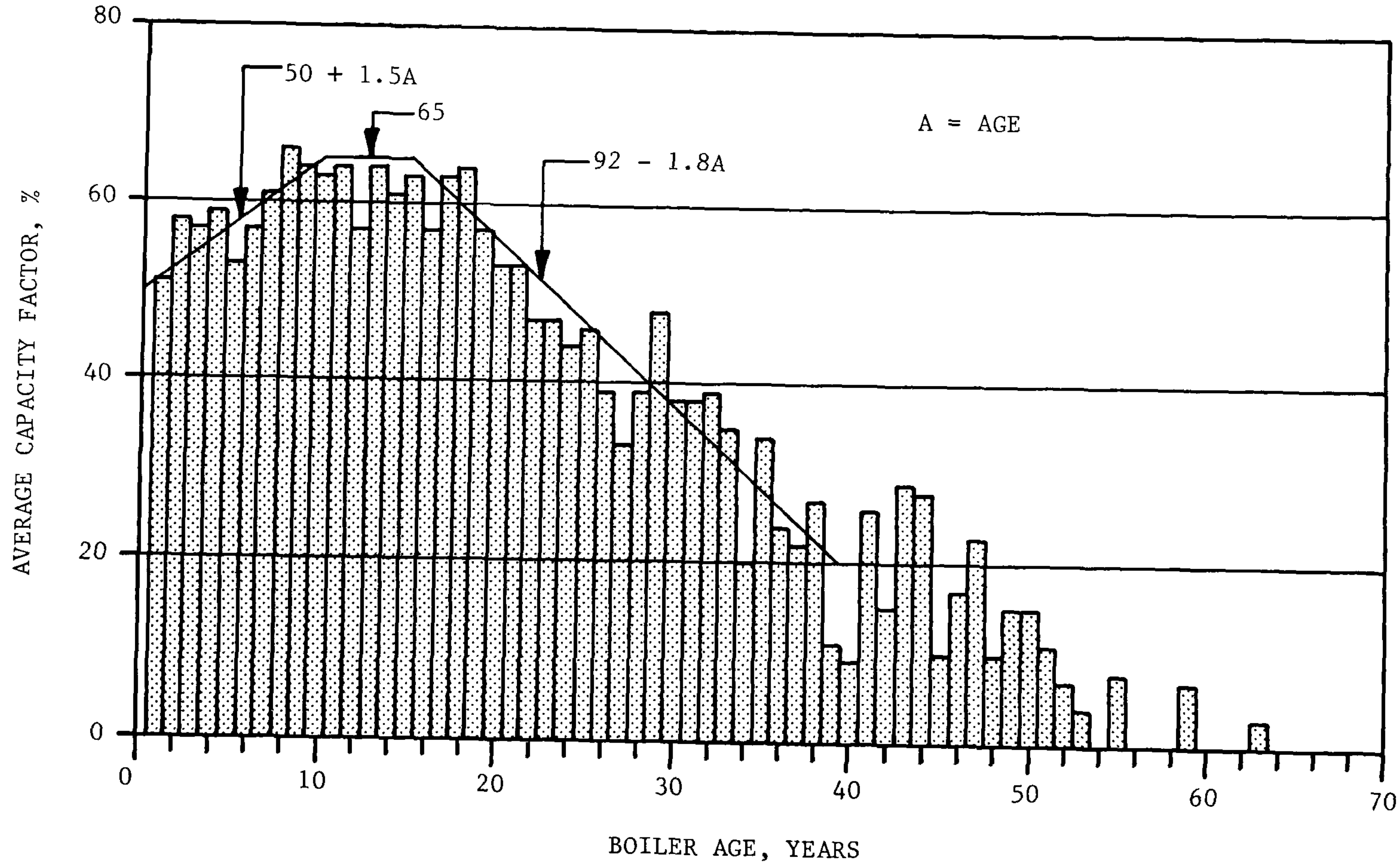


Figure 3. Operating profile assumed for IOPSCH = 2 based on historical Federal Energy Regulatory Commission data.

If levelized operating and maintenance costs under the current premises are used, a levelizing factor (line 11, XLEVEL) that corresponds to the operating profile should be used.

Example output resulting from the Figure 2 operating profile (IOPSCH = 1) is shown in Table 26. Table 27 illustrates the results of the Figure 3 FERC data operating profile (IOPSCH = 2). Example output resulting from a user-supplied operating profile (IOPSCH = 3) is shown in Table 28. The base case printout in Appendix D shows the results of specifying a levelized operating profile of 5,500 hours per year. Example output resulting from a user-specified operating capacity factor in conjunction with a 26-year operating profile is shown in Table 29.

TABLE 26. EXAMPLE LIFETIME REVENUE REQUIREMENTS USING THE OLD TVA PREMISES OPERATING PROFILE

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED LIFETIME REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL

TOTAL CAPITAL INVESTMENT: $ 108153000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR /KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BYPRODUCT RATE, EQUIVALENT TONS/YEAR DRY SLUDGE	SLUDGE FIXATION FEE $/TON DRY SLUDGE	ADJUSTED GROSS ANNUAL REVENUE REQUIREMENT EXCLUDING SLUDGE FIXATION COST, $/YEAR	TOTAL ANNUAL SLUDGE FIXATION COST, $/YEAR	NET ANNUAL INCREASE IN TOTAL REVENUE REQUIREMENT, $	CUMULATIVE NET INCREASE IN TOTAL REVENUE REQUIREMENT, $
1	7000	33250000	1420900	40300	275700	0.0	35769100	0	35769100	35769100
2	7000	33250000	1420900	40300	275700	0.0	36961200	0	36961200	72730300
3	7000	33250000	1420900	40300	275700	0.0	38224900	0	38224900	110955200
4	7000	33250000	1420900	40300	275700	0.0	39564900	0	39564900	150520100
5	7000	33250000	1420900	40300	275700	0.0	40984500	0	40984500	191504600
6	7000	33250000	1420900	40300	275700	0.0	42490000	0	42490000	233994600
7	7000	33250000	1420900	40300	275700	0.0	44085300	0	44085300	278079900
8	7000	33250000	1420900	40300	275700	0.0	45776600	0	45776600	323856500
9	7000	33250000	1420900	40300	275700	0.0	47569000	0	47569000	371425500
10	7000	33250000	1420900	40300	275700	0.0	49469200	0	49469200	420894700
11	5000	23750000	1015000	28800	196900	0.0	43264700	0	43264700	464159400
12	5000	23750000	1015000	28800	196900	0.0	44906800	0	44906800	509066200
13	5000	23750000	1015000	28800	196900	0.0	46647200	0	46647200	555713400
14	5000	23750000	1015000	28800	196900	0.0	48492000	0	48492000	604205400
15	5000	23750000	1015000	28800	196900	0.0	50447700	0	50447700	654653100
16	3500	16625000	710500	20200	137800	0.0	43781200	0	43781200	698434300
17	3500	16625000	710500	20200	137800	0.0	45454300	0	45454300	743888600
18	3500	16625000	710500	20200	137800	0.0	47227700	0	47227700	791116300
19	3500	16625000	710500	20200	137800	0.0	49107500	0	49107500	840223800
20	3500	16625000	710500	20200	137800	0.0	51099900	0	51099900	891323700
21	1500	7125000	304500	8600	59100	0.0	35882100	0	35882100	927205800
22	1500	7125000	304500	8600	59100	0.0	37081800	0	37081800	964286600
23	1500	7125000	304500	8600	59100	0.0	38352200	0	38352200	1002639700
24	1500	7125000	304500	8600	59100	0.0	39699400	0	39699400	1042338400
25	1500	7125000	304500	8600	59100	0.0	41127500	0	41127500	1083465900
26	1500	7125000	304500	8600	59100	0.0	42641100	0	42641100	1126107000
27	1500	7125000	304500	8600	59100	0.0	44245700	0	44245700	1170352700
28	1500	7125000	304500	8600	59100	0.0	45946600	0	45946600	1216299300
29	1500	7125000	304500	8600	59100	0.0	47749300	0	47749300	1264048600
30	1500	7125000	304500	8600	59100	0.0	49660400	0	49660400	1313709000
TOT	127500	605625000	25881500	734000	5021500		1313709000	0	1313709000	

LIFETIME AVERAGE INCREASE IN UNIT REVENUE REQUIREMENT			
DOLLARS PER TON OF COAL BURNED	50.76	0.0	50.76
MILLS PER KILOWATT-HOUR	20.61	0.0	20.61
CENTS PER MILLION BTU HEAT INPUT	216.92	0.0	216.92
DOLLARS PER TON OF SULFUR REMOVED	1789.79	0.0	1789.79
REVENUE REQUIREMENT DISCOUNTED AT 10.0% TO INITIAL YEAR, DOLLARS	399442600	0	399442600
LEVELIZED INCREASE IN UNIT REVENUE REQUIREMENT EQUIVALENT TO DISCOUNTED REQUIREMENT OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	35.87	0.0	35.87
MILLS PER KILOWATT-HOUR	14.56	0.0	14.56
CENTS PER MILLION BTU HEAT INPUT	153.27	0.0	153.27
DOLLARS PER TON OF SULFUR REMOVED	1264.46	0.0	1264.46

UNIT COSTS INFLATED AT 6.00% PER YEAR

TABLE 27. EXAMPLE LIFETIME REVENUE REQUIREMENTS USING THE HISTORICAL FERC/FPC OPERATING PROFILE

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED LIFETIME REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL

TOTAL CAPITAL INVESTMENT: $ 108190000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR /KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BYPRODUCT RATE, EQUIVALENT TONS/YEAR DRY SLUDGE	SLUDGE FIXATION FEE $/TON DRY SLUDGE	ADJUSTED GROSS ANNUAL REVENUE REQUIREMENT EXCLUDING SLUDGE FIXATION COST, $/YEAR	TOTAL ANNUAL SLUDGE FIXATION COST, $/YEAR	NET ANNUAL INCREASE IN TOTAL REVENUE REQUIREMENT, $	CUMULATIVE NET INCREASE IN TOTAL REVENUE REQUIREMENT, $
1	4512	21432000	915900	26000	177700	0.0	32030300	0	32030300	32030300
2	4643	22054300	942500	26700	182800	0.0	33368200	0	33368200	65398500
3	4775	22681300	969300	27500	188000	0.0	34809300	0	34809300	100207800
4	4906	23303500	995900	28300	193200	0.0	36355400	0	36355400	136563200
5	5037	23925800	1022500	29000	198400	0.0	38016400	0	36016400	174579600
6	5169	24552800	1049300	29800	203500	0.0	39804600	0	39804600	214384200
7	5300	25175000	1075900	30500	208700	0.0	41721700	0	41721700	256015900
8	5432	25802000	1102600	31300	213900	0.0	43784500	0	43784500	299890400
9	5563	26424300	1129200	32000	219100	0.0	45995300	0	45995300	345885700
10	5694	27046500	1155800	32800	224200	0.0	48368300	0	48368300	394254000
11	5695	27051300	1156000	32800	224300	0.0	50320900	0	50320900	444574900
12	5695	27051300	1156000	32800	224300	0.0	52385900	0	52385900	496960800
13	5695	27051300	1156000	32800	224300	0.0	54574700	0	54574700	551535500
14	5695	27051300	1156000	32800	224300	0.0	56895000	0	56895000	608430500
15	5695	27051300	1156000	32800	224300	0.0	59354500	0	59354500	667785000
16	5537	26300800	1124000	31900	218000	0.0	60989600	0	60989600	728774600
17	5379	25550300	1091900	31000	211800	0.0	62659400	0	62659400	791434000
18	5221	24799800	1059800	30100	205600	0.0	64361100	0	64361100	855795100
19	5064	24054000	1027900	29200	199400	0.0	66099800	0	66099800	921894900
20	4906	23303500	995900	28300	193200	0.0	67857400	0	67857400	989752300
21	4748	22553000	963800	27400	187000	0.0	69637100	0	69637100	1059389400
22	4591	21807300	931900	26400	180800	0.0	71443400	0	71443400	1130832800
23	4433	21056800	899900	25500	174600	0.0	73253400	0	73253400	1204086200
24	4275	20306300	867800	24600	168300	0.0	75069700	0	75069700	1279155900
25	4118	19560500	835900	23700	162200	0.0	76895800	0	76895800	1356051700
26	3960	18810000	803800	22800	155900	0.0	78702600	0	78702600	1434754300
27	3802	18059500	771800	21900	149700	0.0	80491100	0	80491100	1515245400
28	3645	17313800	739900	21000	143500	0.0	82264100	0	82264100	1597509500
29	3487	16563300	707800	20100	137300	0.0	83983500	0	83983500	1681493000
30	3329	15812800	675800	19200	131100	0.0	85648000	0	85648000	1767141000
TOT	146001	693505700	29636800	841000	5749400		1767141000	0	1767141000	

	ADJUSTED GROSS	TOTAL SLUDGE FIXATION	NET
LIFETIME AVERAGE INCREASE IN UNIT REVENUE REQUIREMENT			
DOLLARS PER TON OF COAL BURNED	59.63	0.0	59.63
MILLS PER KILOWATT-HOUR	24.21	0.0	24.21
CENTS PER MILLION BTU HEAT INPUT	254.81	0.0	254.81
DOLLARS PER TON OF SULFUR REMOVED	2101.24	0.0	2101.24
REVENUE REQUIREMENT DISCOUNTED AT 10.0% TO INITIAL YEAR, DOLLARS	440948400	0	440948400
LEVELIZED INCREASE IN UNIT REVENUE REQUIREMENT EQUIVALENT TO DISCOUNTED REQUIREMENT OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	45.62	0.0	45.62
MILLS PER KILOWATT-HOUR	18.52	0.0	18.52
CENTS PER MILLION BTU HEAT INPUT	194.94	0.0	194.94
DOLLARS PER TON OF SULFUR REMOVED	1607.54	0.0	1607.54

UNIT COSTS INFLATED AT 6.00% PER YEAR

TABLE 28. EXAMPLE LIFETIME REVENUE REQUIREMENTS USING A USER-SUPPLIED OPERATING PROFILE

PROJECTED LIFETIME REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

TOTAL CAPITAL INVESTMENT: $ 107981000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR /KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BYPRODUCT RATE, EQUIVALENT TONS/YEAR DRY SLUDGE	SLUDGE FIXATION FEE $/TON DRY SLUDGE	ADJUSTED GROSS ANNUAL REVENUE REQUIREMENT EXCLUDING SLUDGE FIXATION COST, $/YEAR	TOTAL ANNUAL SLUDGE FIXATION COST, $/YEAR	NET ANNUAL INCREASE IN TOTAL REVENUE REQUIREMENT, $	CUMULATIVE NET INCREASE IN TOTAL REVENUE REQUIREMENT, $
1	5000	23750000	1015000	28800	196900	0.0	32735000	0	32735000	32735000
2	5000	23750000	1015000	28800	196900	0.0	33746700	0	33746700	66481700
3	5000	23750000	1015000	28800	196900	0.0	34819000	0	34819000	101300700
4	5000	23750000	1015000	28800	196900	0.0	35956000	0	35956000	137256700
5	5000	23750000	1015000	28800	196900	0.0	37160900	0	37160900	174417600
6	6000	28500000	1217900	34600	236300	0.0	41798600	0	41798600	216216200
7	6000	28500000	1217900	34600	236300	0.0	43354300	0	43354300	259570500
8	6000	28500000	1217900	34600	236300	0.0	45003300	0	45003300	304573800
9	6000	28500000	1217900	34600	236300	0.0	46750800	0	46750800	351324600
10	6000	28500000	1217900	34600	236300	0.0	48603500	0	48603500	399928100
11	6250	29687500	1268700	36000	246100	0.0	51670300	0	51670300	451598400
12	6250	29687500	1268700	36000	246100	0.0	53818000	0	53818000	505416400
13	6250	29687500	1268700	36000	246100	0.0	56094800	0	56094800	561511200
14	6250	29687500	1268700	36000	246100	0.0	58507900	0	58507900	620019100
15	6250	29687500	1268700	36000	246100	0.0	61066000	0	61066000	681085100
16	6500	30875000	1319400	37400	256000	0.0	65243100	0	65243100	746328300
17	6500	30875000	1319400	37400	256000	0.0	68205700	0	68205700	814534000
18	6500	30875000	1319400	37400	256000	0.0	71345700	0	71345700	885879700
19	6500	30875000	1319400	37400	256000	0.0	74674000	0	74674000	960553700
20	6500	30875000	1319400	37400	256000	0.0	78201900	0	78201900	1038755600
21	4500	21375000	913500	25900	177200	0.0	65816200	0	65816200	1104571800
22	4000	19000000	812000	23000	157500	0.0	64337000	0	64337000	1168908800
23	3500	16625000	710500	20200	137800	0.0	62384400	0	62384400	1231293200
24	2500	11875000	507500	14400	98400	0.0	54386400	0	54386400	1285679600
25	1000	4750000	203000	5800	39400	0.0	37218800	0	37218800	1312289840
TOT	134250	637687500	27251500	773300	5286800		1322898400	0	1322898400	

LIFETIME AVERAGE INCREASE IN UNIT REVENUE REQUIREMENT			
DOLLARS PER TON OF COAL BURNED	48.54	0.0	48.54
MILLS PER KILOWATT-HOUR	19.71	0.0	19.71
CENTS PER MILLION BTU HEAT INPUT	207.45	0.0	207.45
DOLLARS PER TON OF SULFUR REMOVED	1710.72	0.0	1710.72
REVENUE REQUIREMENT DISCOUNTED AT 10.0% TO INITIAL YEAR, DOLLARS	415455700	0	415455700
LEVELIZED INCREASE IN UNIT REVENUE REQUIREMENT EQUIVALENT TO DISCOUNTED REQUIREMENT OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	40.98	0.0	40.98
MILLS PER KILOWATT-HOUR	16.64	0.0	16.64
CENTS PER MILLION BTU HEAT INPUT	175.12	0.0	175.12
DOLLARS PER TON OF SULFUR REMOVED	1444.06	0.0	1444.06

UNIT COSTS INFLATED AT 6.00% PER YEAR

TABLE 29. EXAMPLE LIFETIME REVENUE REQUIREMENTS USING A USER-SUPPLIED PLANT LIFETIME PROFILE AND OPERATING CAPACITY FACTOR

IMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

ROJECTED LIFETIME REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL CAPACITY FACTOR

TOTAL CAPITAL INVESTMENT: $ 108086000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR /KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BYPRODUCT RATE, EQUIVALENT TONS/YEAR DRY SLUDGE	SLUDGE FIXATION FEE $/TON DRY SLUDGE	ADJUSTED GROSS ANNUAL REVENUE REQUIREMENT EXCLUDING SLUDGE FIXATION COST, $/YEAR	TOTAL ANNUAL SLUDGE FIXATION COST, $/YEAR	NET ANNUAL INCREASE IN TOTAL REVENUE REQUIREMENT, $	CUMULATIVE NET INCREASE IN TOTAL REVENUE REQUIREMENT, $
1	5256	24966000	1066900	30300	207000	0.0	33140500	0	33140500	33140500
2	5256	24966000	1066900	30300	207000	0.0	34175400	0	34175400	67315900
3	5256	24966000	1066900	30300	207000	0.0	35272700	0	35272700	102588600
4	5256	24966000	1066900	30300	207000	0.0	36435700	0	36435700	139024300
5	5256	24966000	1066900	30300	207000	0.0	37668500	0	37668500	176692800
6	5256	24966000	1066900	30300	207000	0.0	38975500	0	38975500	215668300
7	5256	24966000	1066900	30300	207000	0.0	40360700	0	40360700	256029000
8	5256	24966000	1066900	30300	207000	0.0	41828900	0	41828900	297857900
9	5256	24966000	1066900	30300	207000	0.0	43385500	0	43385500	341243400
10	5256	24966000	1066900	30300	207000	0.0	45035100	0	45035100	386278500
11	5256	24966000	1066900	30300	207000	0.0	46784000	0	46784000	433062500
12	5256	24966000	1066900	30300	207000	0.0	48637700	0	48637700	481700200
13	5256	24966000	1066900	30300	207000	0.0	50602500	0	50602500	532302700
14	5256	24966000	1066900	30300	207000	0.0	52685300	0	52685300	584988000
15	5256	24966000	1066900	30300	207000	0.0	54893200	0	54893200	639881200
16	5256	24966000	1066900	30300	207000	0.0	57233400	0	57233400	697114600
17	5256	24966000	1066900	30300	207000	0.0	59714100	0	59714100	756828700
18	5256	24966000	1066900	30300	207000	0.0	62343500	0	62343500	819172200
19	5256	24966000	1066900	30300	207000	0.0	65130900	0	65130900	884303100
20	5256	24966000	1066900	30300	207000	0.0	68085400	0	68085400	952388500
21	5256	24966000	1066900	30300	207000	0.0	71217200	0	71217200	1023605700
22	5256	24966000	1066900	30300	207000	0.0	74536900	0	74536900	1098142600
23	5256	24966000	1066900	30300	207000	0.0	78056000	0	78056000	1176198600
24	5256	24966000	1066900	30300	207000	0.0	81786000	0	81786000	1257984600
25	5256	24966000	1066900	30300	207000	0.0	85739700	0	85739700	1343724300
26	5256	24966000	1066900	30300	207000	0.0	89931000	0	89931000	1433655300
TOT	136656	649116000	27739400	787800	5382000		1433655300	0	1433655300	

	ADJUSTED GROSS ANNUAL REVENUE REQUIREMENT	TOTAL ANNUAL SLUDGE FIXATION COST	NET ANNUAL INCREASE IN TOTAL REVENUE REQUIREMENT
LIFETIME AVERAGE INCREASE IN UNIT REVENUE REQUIREMENT			
DOLLARS PER TON OF COAL BURNED	51.68	0.0	51.68
MILLS PER KILOWATT-HOUR	20.98	0.0	20.98
CENTS PER MILLION BTU HEAT INPUT	220.86	0.0	220.86
DOLLARS PER TON OF SULFUR REMOVED	1819.82	0.0	1819.82
REVENUE REQUIREMENT DISCOUNTED AT 10.0% TO INITIAL YEAR, DOLLARS	412216000	0	412216000
LEVELIZED INCREASE IN UNIT REVENUE REQUIREMENT EQUIVALENT TO DISCOUNTED REQUIREMENT OVER LIFE OF POWER UNIT			
DOLLARS PER TON OF COAL BURNED	42.18	0.0	42.18
MILLS PER KILOWATT-HOUR	17.12	0.0	17.12
CENTS PER MILLION BTU HEAT INPUT	180.23	0.0	180.23
DOLLARS PER TON OF SULFUR REMOVED	1484.93	0.0	1484.93

UNIT COSTS INFLATED AT 6.00% PER YEAR

USING THE MODEL

As previously discussed, a copy of the model can be made available for independent user execution; or TVA, under an information-exchange agreement with EPA, can make specific runs of the model based on user-supplied input data. This section is provided for potential users who wish to obtain the model for independent use.

The model was developed for, and is executed on, the TVA in-house IBM 370-compatible computer system. The current model consists of two FORTRAN programs written in FORTRAN66 that are compiled using either the IBM G1 or H extended compiler. The first program, which calculates investment costs, is relatively large; it contains over 14,000 lines of source code. The second program, which calculates revenue requirements, contains about 2,000 lines.

Core storage requirements for the first program are about 375,000 bytes; the use of overlays can reduce this requirement to about 200,000 bytes. The second program executes within 150,000 bytes of core storage with no overlays. In addition to the core storage required for program execution, temporary online storage (disk) is also required for intermediate files and the transfer of data between the two programs. The only input data required for model execution are the user input data; all other data for default assumptions and option-related calculations are assigned the necessary values internally within the program. Temporary online storage requirements depend on the number of cases run but typically do not exceed 200,000 bytes.

The model is executed in both interactive and batch modes. The input data can be provided in three ways, depending on the mode of execution. For batch execution (typically remote batch), the input data variables are punched on cards and inserted in a model execution run deck. The second method of providing data applies to interactive model execution. Input is solicited at the terminal during actual model execution and the user must respond with the appropriate values. The third method is used for both interactive and batch execution. A data file is created interactively (typically using a text editor); all variable values (including the options selected) are examined and corrected if necessary, then the model is executed (either interactively or a batch run is submitted from the interactive terminal) and the input is processed as a standard data file.

The third method of providing input data has been found to be preferable in most cases. When separate but similar model runs are required, the data file containing the input is copied to a second file, variables and options are modified as necessary, and a second model run is submitted. This reduces both input preparation time and the number of input data errors because only the variables and options that differ from a previous run must be modified.

The job control language (JCL) required to execute the model in batch mode is stored in a catalogued procedure file. An example procedure file is shown in Table 30. The catalogued procedure uses a system utility program, IEBGENER, which can be replaced if necessary by a user program to copy from input card data to disk storage and from disk storage to an output print file. The overall procedure consists of four steps to (1) copy the input data to a temporary online storage file (disk), (2) copy the input data to an output print file, (3) execute the first program of the model, and (4) execute the second program. The programs are executed from load modules to avoid recompiling each time they are executed.

The remaining JCL required to execute the model in batch mode is shown in Table 31. If the input data have been prepared on cards, a card deck similar to example 1 in Table 31 would be submitted with the data cards following the //LOAD.DATA DD * ... card. In example 2, the catalogued procedure (Table 31) is executed and the required input is read from a previously created data file. The JCL examples shown in Tables 30 and 31 generally apply whether the job is submitted interactively or with a card deck.

Table 32 shows two example interactive procedures for model execution. Example 1 in Table 32 shows an example procedure for directly entering the data during model execution. Example 2 shows a procedure for interactive execution using a previously created data file.

The amount of computer time required for model execution is a function of the number of cases of input data and the particular computer system. On the TVA system (AMDAHL V8 with JES3), the average CPU time required per case is about 0.5 second but some cases have exceeded 2 seconds.

The model is usually distributed on magnetic tape for independent usage. A fairly wide range of tape format options is available but typically the tape is unlabeled; the density is 1600 bpi; the block size is 4,000 characters (50 records, 80 characters per record); and the tape contains two files, one for each program.

TABLE 30. EXAMPLE PROCEDURE FOR EXECUTING THE MODEL IN BATCH MODE

```
//SHAWNEE     PROC   PRTFMS=A                                                  00000010
//LOAD        EXEC   PGM=IEBGENER                                              00000020
//SYSPRINT    DD     SYSOUT=A                                                  00000030
//SYSIN       DD     DUMMY                                                     00000040
//SYSUT1      DD     DDNAME=DATA                                               00000050
//SYSUT2      DD     UNIT=SYSCR,SPACE=(TRK,(1,1),RLSE),DISP=(NEW,PASS),        00000060
//                   DCB=(RECFM=FB,LRECL=80,BLKSIZE=400)                       00000070
//LIST        EXEC   PGM=IEBGENER                                              00000080
//SYSPRINT    DD     SYSOUT=A                                                  00000090
//SYSIN       DD     DUMMY                                                     00000100
//SYSUT1      DD     DSN=*.LOAD.SYSUT2,DISP=(OLD,PASS)                         00000110
//SYSUT2      DD     SYSOUT=&PRTFMS,DCB=(RECFM=F,LRECL=80,BLKSIZE=80)          00000120
//INVEST      EXEC   PGM=INV,REGION=400                                        00000130
//STEPLIB     DD     DSN=CHM.SHAWNEE.LOAD,DISP=SHR                             00000140
//FT02F001    DD     UNIT=SYSCR,SPACE=(TRK,(1,1),RLSE),DISP=(NEW,PASS),        00000150
//                   DCB=(LRECL=404,BLKSIZE=408,RECFM=VBS)                     00000160
//FT08F001    DD     UNIT=SYSCR,SPACE=(TRK,(1,1),RLSE),DISP=(NEW,PASS),        00000170
//                   DCB=(LRECL=404,BLKSIZE=408,RECFM=VBS)                     00000175
//FT03F001    DD     SYSOUT=A                                                  00000180
//FT05F001    DD     DSN=*.LOAD.SYSUT2,DISP=(OLD,DELETE,DELETE)                00000190
//FT06F001    DD     SYSOUT=&PRTFMS                                            00000200
//FT09F001    DD     DSN=$LALQ01.FGDPB2.DATA,DISP=SHR                          00000210
//REVENUE     EXEC   PGM=REV,TIME=(,10),(0,LT,INVEST)                          00000220
//STEPLIB     DD     DSN=CHM.SHAWNEE.LOAD,DISP=SHR                             00000230
//FT02F001    DD     DSN=*.INVEST.FT02F001,DISP=(OLD,DELETE,DELETE)            00000240
//FT08F001    DD     DSN=$LALQ01.FGDPB2.DATA,DISP=MOD                          00000250
//FT06F001    DD     SYSOUT=&PRTFMS                                            00000260
```

TABLE 31. EXAMPLE JCL TO EXECUTE THE MODEL USING A PROCEDURE FILE

(Example 1)

```
//TXSHAWNE      JOB 123456,PRGMER.R501CEBM.2513,MSGLEVEL=1,CLASS=K,
//                  NOTIFY=CHM
/*MAIN ORG=RGROUP03
//PROCLIB   DD  DSN=CHM.PROCLIB,DISP=SHR
//SHAWNEE   EXEC SHAWNEE,PRTFMS=A
//LOAD.DATA   DD *         (INPUT DATA CARDS FOLLOW THIS CARD)
//
```

(Example 2)

```
//TXSHAWNE      JOB 123456,PRGMER.R501CEBM.2513,MSGLEVEL=1,CLASS=K,
//                  NOTIFY=CHM
/*MAIN ORG=RGROUP03
//PROCLIB   DD  DSN=CHM.PROCLIB,DISP=SHR
//SHAWNEE   EXEC SHAWNEE,PRTFMS=A
//LOAD.DATA   DD DISP=SHR,DSN=CHM.PART2.DATA
//
```

TABLE 32. SAMPLE COMMAND PROCEDURE FOR EXECUTING THE MODEL INTERACTIVELY

(Example 1)

```
FREEALL
TERM LINESIZE(132)
FREE FILE (FT02F001,FT08F001,FT03F001,FT05F001,FT06F001,FT09F001)
ALLOC FI(FT02F001) NEW BLOCK(13030) SPACE(10,5)
ALLOC FI(FT08F001) NEW BLOCK(13030) SPACE(10,5)
ALLOC FI(FT09F001) NEW BLOCK(13030) SPACE(10,5)
ALLOC FI(FT03F001)  DA(*)
ALLOC FI(FT05F001)  DA(*)
ALLOC FI(FT06F001)  DA(*)
CALL 'CHM.SHAWNEE.LOAD(INV)'
CALL 'CHM.SHAWNEE.LOAD(REV)'
FREEALL
```

(Example 2)

```
FREEALL
TERM LINESIZE(132)
FREE DA('CHM.PART2.DATA')
FREE FILE(FT02F001,FT08F001,FT03F001,FT05F001,FT06F001,FT09F001
ALLOC FI(FT02F001) NEW BLOCK(13030) SPACE(10,5)
ALLOC FI(FT08F001) NEW BLOCK(13030) SPACE(10,5)
ALLOC FI(FT09F001) NEW BLOCK(13030) SPACE(10,5)
ALLOC FI(FT03F001)  DA(*)
ALLOC FI(FT05F001)  DA('CHM.PART2.DATA')
ALLOC FI(FT06F001)  DA(*)
CALL 'CHM.SHAWNEE.LOAD(INV)'
CALL 'CHM.SHAWNEE.LOAD(REV)'
FREEALL
```

MODEL STRUCTURE

As described previously, the overall model consists of two FORTRAN programs. The first program which calculates investment costs consists of a main program and 101 subroutines. An alphabetical listing of the subroutines in this program with a general description of their function is shown in Table 33. The second program which calculates revenue requirements consists of a main program and 10 subroutines. An alphabetical listing of the subroutines in this program with a general description of their function is shown in Table 34. Since the subroutines are not executed in either alphabetical order or the order in which they occur in the two programs, hierarchy charts showing the sequence for calling the various subroutines during batch program execution and identifying the main program and subroutines from which they are called are shown in Tables 35 and 36.

Further documentation of the overall model is beyond the scope of this manual.

TABLE 33. ALPHABETICAL LISTING OF THE SUBROUTINES IN THE INVESTMENT PROGRAM IDENTIFYING THE FUNCTION OF EACH SUBROUTINE

Investment program subroutines	Function
ACTIVE	Allows investment program to be run interactively
ADAMGO	Calculates costs for adipic acid or MgO addition equipment
ADIPID	Calculates stoichiometry, L/G, SO_2 removal efficiency, and pH for adipic acid addition option
ADIPMD	Calls ADIPID when adipic acid model is run interactively
BECHTL	Initializes variables and calls subroutines used for calculating material balance
BEQ	Calculates aqueous equilibrium constants
BEQPRT	Prints modified Radian equilibrium program results (not activated by Shawnee model)
BYPASS	Used in projecting material balance and bypass design for partial scrubbing options
CASO3	Calculates aqueous concentration of $CaSO_3 \cdot 1/2H_2O$ at equilibrium
CASO4	Calculates aqueous concentation of $CaSO_4 \cdot 2H_2O$ at equilibrium
CASOX	Calculates aqueous concentration of $CaSO_x$ at equilibrium
CLARIF	Calculates size of the thickener-clarifier
CLEAN	Calculates composition and heating value of physically cleaned coal
CSA	Calculates cross-sectional area of scrubber
CSAFIL	Calculates required filtration area for dewatering FGD sludge
DUCWRK	Calculates design and costs for all ductwork, including dampers and expansion joints
DUST	Calculates fly ash contained in combustion products
EDIT	Checks validity of input data and determines which flags are set
EDIT1	Checks to determine if the correct number of variables are input when running in the batch mode
ELECTR	Calculates design and costs of electrical motors, wire, and conduit
EQCALL	Initializes equilibrium variables and coefficients
EQPSUM	Calculates sum of all FGD equipment costs
EQUIPR	Calls subroutines for printing equipment costs
EQUIPT	Calls subroutines for sizing all equipment
EQUPR1	Initializes equipment sizing-costing arrays
EQUPR2	Prints equipment lists for raw material and feed preparation areas
EQUPR3	Prints equipment lists for gas-handling, scrubbing, oxidation, and reheat areas

(Continued)

TABLE 33. (Continued)

Investment program subroutines	Function
EQUPR4	Prints equipment list for solids separation area
EQUPR5	Prints equipment list for landfill area
EQUPR6	Prints equipment list for fixation area
FANS	Calculates equipment costs for ID and FD fans
FILTER	Calculates equipment costs for drum filters
FIXIT	Calculates design and costs for the fixation area
FOROXD	Calculates equipment costs for forced-oxidation air compressors and spargers
FOUNDT	Calculates design and costs for foundations
H2OBAL	Calculates overall water balance considering H_2O added through alkali and rainfall, and H_2O losses from evaporation, seepage, and entrainment
H2OPMP	Calculates costs of makeup water and supernate return pumps
HOTGAS	Calculates flow rate, composition, and wet bulb temperature of flue gas exiting the boiler
INSTRM	Calculates design and costs for instrumentation
KCALC	Calculates activity coefficients
LAND	Calculates land area required for FGD equipment and waste disposal
LANDC	Calculates design of the landfill
LANDP	Prints material balance, design, and cost of the FGD landfill
LANFIL	Allows landfill option to be run interactively
LIMEPR	Calculates costs of the lime raw material receiving and preparation equipment
LSPREP	Calculates costs of the limestone raw material receiving and preparation equipment
MATBAL	Calculates the material balance based on equilibrium models and the Radian program
MBCON	Initializes coefficients for calculating pressure drop
MECOLL	Calculates costs for the mechanical collector
NSPS	Calculates allowable emissions based on 1979 NSPS
PARTIC	Calculates costs of particulate removal equipment based on Argonne models
PDROP	Calculates flue gas pressure drop attributed to the FGD system
PIPES	Calculates design and costs for piping
PNDCP	Prints pond cost versus capacity table (available only with interactive pond model)
PNDCST	Calculates cost of waste disposal pond
PNDDEP	Prints pond cost versus depth table (available only with interactive pond model)

(Continued)

TABLE 33. (Continued)

Investment program subroutines	Function
PNDEXC	Calculates cost for pond excavation
PNDOPT	Calculates cost for optimum size-depth pond
PNDPRT	Prints design and costs for pond
PNDSGN	Calculates design for pond
PNDSZE	Calculates dimensions of pond
PONDS	Allows pond model to be run interactively
PREPSM	Calculates ancillary investment costs for the raw material-handling and feed preparation areas
PRIN	Calls other subroutines for printing input data
PRIN01	Prints short version of program inputs
PRIN02	Prints boiler inputs, composition of raw coal, allowable emissions, and required removal
PRIN03	Prints composition and physical properties of the scrubbing alkali
PRIN04	Prints scrubber, forced-oxidation, and adipic acid inputs
PRIN05	Prints waste disposal, reheat, and water balance inputs
PRIN06	Prints economic premises inputs
PRINTI	Prints all FGD investment costs
PROUT	Calls subroutines for printing program outputs
PROUT1	Prints boiler design and hot gas to scrubber outputs
PROUT2	Prints wet gas from scrubber and flue gas to stack outputs
PROUT3	Prints steam reheater and water balance outputs
PROUT4	Prints scrubber system and system sludge discharge outputs
PROUT5	Prints flow rates of individual species and total flow rate for all liquid streams
READIN	Reads all inputs from unit 5 when model is run in the batch mode
REHEAT	Calculates design for oil-fired reheater option (option not available)
REHETR	Calculates costs for inline steam reheater
SCLAND	Initializes variables for landfill design model
SCRUBB	Calculates design and costs for the SO_2 absorber
SLPUMP	Calculates costs for rubber-lined slurry pumps
SO2ELM	Calculates SO_2 removal as % removed, equivalent emission in lbs SO_2/MBtu, or ppm SO_2 in outlet gas
SOOTBL	Calculates costs of sootblowing
SPRINT	Prints short-form FGD investment costs
SRMOD(ICR)	Calculates L/G, stoichiometry, or SO_2 removal when other scrubber parameters are input
STKGAS	Calculates flow rate and composition of flue gas exiting the stack

(Continued)

TABLE 33. (Continued)

Investment program subroutines	Function
STMRHT	Calculates design and costs for inline steam reheater
STREAM	Calculates composition of liquid FGD system streams
STRUCT	Calculates design and costs of structures
TANKS	Calculates costs for tanks and agitators
TCON	Initializes temperature dependent constants
THICK	Calculates costs for thickener
TOTALS	Sums costs for all components of the FGD system
TVAIN	Calls subroutines for calculating FGD investment costs
VPDROP	Calculates pressure drop or throat velocity for the venturi scrubber
WETGAS	Calculates flow rate and composition for gas exiting the scrubber
WORKCP	Calculates working capital component of FGD investment cost
WRITDS	Writes investment cost to a file for transfer to the revenue requirement model
ZERO	Initializes all major variables to zero

TABLE 34. ALPHABETICAL LISTING OF THE SUBROUTINES IN THE REVENUE REQUIREMENT PROGRAM IDENTIFYING THE FUNCTION OF EACH SUBROUTINE

Revenue requirement program subroutines	Function
PROGM2	Initializes arrays for lifetime cost projections
PRTALF	Prints first-year annual revenue requirements table
PRTASF	Prints short form of first-year annual revenue requirements table
PRTBLF	Prints titles for lifetime revenue requirements table
PRTBSF	Prints short-print titles for lifetime revenue requirements table
PRTCLF	Prints lifetime revenue requirements projections
PRTCSF	Prints short-print lifetime revenue requirements projections
PRTDLF	Prints summation of lifetime revenue requirements
PRTDSF	Prints short-print lifetime revenue requirements summation tables
RVHEAD	Creates revenue requirements table headings

TABLE 35. HIERARCHY CHART FOR EXECUTION OF THE INVESTMENT PROGRAM OF THE OVERALL COMPUTER MODEL IN THE BATCH MODE

```
MAIN DRIVER (INVESTMENT PROGRAM)
    CALL EDIT1
    CALL ZERO
    CALL READIN
        CALL EDIT
    CALL BECHTL
        CALL VPDROP
        IF(KCLEAN.GE.1) CALL CLEAN
        IF(ISO2.EQ.4) CALL NSPS
        CALL DUST
        CALL HOTGAS
        CALL SO2ELM
        CALL BYPASS
            CALL SO2ELM
        CALL PRIN
            CALL PRIN01
            CALL PRIN02
            CALL PRIN03
            IF(JSSVAR.EQ.1) CALL PRIN04
            IF(JINPUT.GT.0) CALL PRIN05
            IF(JINPUT.GT.0) CALL PRIN06
        CALL MBCON
        CALL MATBAL
            CALL EQCALL
                CALL BEQ
        CALL SRMOD(2)
        CALL SRMOD(1)
            CALL BEQ
                CALL TCON
                CALL KCALC
                CALL CASO3
                CALL CASO4
                CALL CASOX
                IF (IP.NE.0) CALL BEQPRT
        CALL SRMOD(1)
            CALL TCON
            CALL KCALC
            CALL CASO3
            CALL CASO4
            CALL CASOX
            IF (IP.NE.0) CALL BEQPRT
```

(Continued)

```
        CALL SRMOD(2)
        CALL SRMOD(1)
        CALL MATBAL
            CALL EQCALL
                CALL BEQ
        CALL ADIPID
        CALL MATBAL
            CALL EQCALL
                CALL BEQ
        IF (ICLAR.EQ.1) CALL CLARIF
        CALL WETGAS
        CALL CSA
        CALL PDROP
        IF (IRH.EQ.1) CALL REHEAT
        IF (IRH.NE.1) CALL STMRHT
        CALL STKGAS
        CALL PNDSGN
            CALL PNDOPT
                CALL PNDEXC
                    CALL PNDSZE
                CALL PNDCST
                    CALL PNDSZE
                CALL PNDEXC
                    CALL PNDSZE
                CALL PNDSZE
                CALL PNDCST
                    CALL PNDSZE
            CALL PNDEXC
                CALL PNDSZE
            CALL PNDCST
                CALL PNDSZE
        CALL STREAM
            CALL EQCALL
                CALL BEQ
        CALL H2OBAL
        CALL CSAFIL
    CALL PROUT
        CALL PROUT1
        CALL PROUT2
        CALL PROUT3
        CALL PROUT4
        CALL PROUT5
```

(Continued)

TABLE 35. (Continued)

```
IF (ISLUDG.LE.2) CALL PNDPRT
IF (ISLUDG.EQ.5) CALL SCLAND
    CALL LANDC
    CALL LANDP
CALL TVAIN
    CALL EQUIPT
        IF (IALK.EQ.1) CALL LSPREP
        IF (IALK.EQ.2) CALL LIMEPR
        IF (IADD.GT.0) CALL ADAMGO
        IF (ISLUDG.GT.1) CALL THICK
        IF (ISLUDG.GE.4) CALL FILTER
        CALL TANKS
        IF (IFOX.GT.0) CALL FOROXD
        CALL SLPUMP
        CALL PREPSM
        CALL MECOLL
        CALL PARTIC
        CALL FANS
        CALL SCRUBB
        IF (IRH.GT.0) CALL REHETR
        CALL SOOTBL
        CALL H2OPMP
        CALL EQPSUM
        IF (IEQPR.GE.1) CALL EQUIPR
            IF (IEQPR.GE.1) CALL EQUPR1
                CALL FIXIT
            IF (IEQPR.EQ.1.OR.IEQPR.EQ.2) CALL EQUPR2
            IF (IEQPR.EQ.1.OR.IEQPR.EQ.3) CALL EQUPR3
            IF (IEQPR.EQ.1.OR.IEQPR.EQ.4) CALL EQUPR4
            IF (IFIXS.GT.0) CALL EQUPR6
            IF (IEQPR.EQ.1.OR.IEQPR.EQ.5) CALL EQUPR5
    CALL STRUCT
    CALL FOUNDT
    CALL PIPES
    CALL DUCWRK
    CALL INSTRM
    CALL LAND
    CALL ELECTR
    CALL TOTALS
        CALL WORKCP
    CALL PRINTI
    CALL SPRINT
CALL WRITDS
```

TABLE 36. HIERARCHY CHART FOR EXECUTION OF THE REVENUE REQUIREMENT PROGRAM OF THE OVERALL COMPUTER MODEL

```
MAIN DRIVER (REVENUE REQUIREMENT PROGRAM)
    CALL RVHEAD
    CALL PRTALF
    CALL PRTASF
    CALL PROGM2
        CALL PRTBLF
        CALL PRTBSF
        CALL PRTCLF
        CALL PRTCSF
        CALL PRTDLF
        CALL PRTDSF
```

REFERENCES

1. Epstein, M., EPA Alkali Scrubbing Test Facility: Advanced Program, First Progress Report, EPA-600/2-75-050, U.S. Environmental Protection Agency, Washington, D.C.; Head, H. N., 1976, EPA Alkali Scrubbing Test Facility: Advanced Program, Second Progress Report, EPA-600/7-76-008, U.S. Environmental Protection Agency, Washington, D.C.; Head, H. N., 1977, EPA Alkali Scrubbing Test Facility: Advanced Program, Third Progress Report, EPA-600/7-77-105, U.S. Environmental Protection Agency, Washington, D.C.; Head, H. N., and S.-C. Wang, 1979, EPA Alkali Scrubbing Test Facility: Advanced Program, Fourth Progress Report, 2 volumes, EPA-600/7-79-244a and -244b, U.S. Environmental Protection Agency, Washington, D.C.; and Burbank. D. A., and S.-C. Wang, 1980, EPA Alkali Scrubbing Test Facility: Advanced Program - Final Report (October 1974-June 1978).

2. Zenz, F. A., 1963, Absorption, In: Kirk-Othmer Encyclopedia of Chemical Technology, 2d Ed., Vol. 1, pp. 44-77.

3. Danckwerts, P. V., 1970, Gas-Liquid Reactions, McGraw-Hill, New York.

4. Wen, C.-y., and L. S. Fan, 1975, Absorption of Sulfur Dioxide in Spray Column and Turbulent Contacting Absorbers, EPA-600/2-75-023 (NTIS PB 247334), U.S. Environmental Protection Agency, Washington, D.C.

5. Rochelle, G. T., and C. J. King, 1977, The Effect of Additives on Mass Transfer in $CaCO_3$ or CaO Slurry Scrubbing of SO_2 from Waste Gases, Industrial and Engineering Chemistry, Fundamentals, Vol. 16, No. 1, pp. 67-75.

6. Chang, C. S., and G. T. Rochelle, 1981, SO_2 Absorption Into Aqueous Solutions, American Institute of Chemical Engineers Journal, Vol. 27, No. 2, pp. 292-298.

7. Wen, C.-y, W. J. McMichael, and R. D. Nelsen, Jr., 1975, Scale Control in Limestone Wet Scrubbing Systems, EPA-650/2-75-031, U.S. Environmental Protection Agency, Washington, D.C.

8. Burbank, D. A., S.-C. Wang, R. R. McKinsey, and J. E. Williams, 1980, Test Results on Adipic Acid-Enhanced Limestone Scrubbing at the EPA Shawnee Test Facility - Third Report, In: Proceedings: Symposium on Flue Gas Desulfurization - Houston, October 1980, Vol. I, EPA-600/7-81-019a, U.S. Environmental Protection Agency, Washington, D.C., pp. 233-280.

9. Anders, W. L., and R. L. Torstrick, 1981, Computerized Shawnee Lime/ Limestone Scrubbing Model Users Manual, EPA-600/8-81-008, U.S. Environmental Protection Agency, Washington, D.C.

10. Lowell, P. S., D. M. Ottmers, Jr., K. Schwitzgebel, T. I. Strange, and D. W. DeBerry (Radian Corp.), 1970, A Theoretical Description of the Limestone Injection - Wet Scrubbing Process, Final report to the National Air Pollution Control Administration, NTIS PB 193029.

11. Torstrick, R. L., 1976, Shawnee Limestone-Lime Scrubbing Process Computerized Design Cost Estimates Program: Summary Description Report, Prepared for presentation at Industry Briefing Conference, Raleigh, North Carolina, October 19-21, 1976. Torstrick, R. L., L. J. Henson, and S. V. Tomlinson, 1978, Economic Evaluation Techniques, Results, and Computer Modeling for Flue Gas Desulfurization, In: Proceedings, Symposium on Flue Gas Desulfurization, Hollywood, Florida, November 1977 (Vol. 1), Ayer, F. A., ed., EPA-600/7-78-058B, U.S. Environmental Protection Agency, Washington, D.C., 1978, pp. 118-168. Stephenson, C. D., and R. L. Torstrick, 1978, Current Status of Development of the Shawnee Lime-Limestone Computer Program, Prepared for presentation at Industry Briefing Conference, Raleigh, North Carolina, August 29, 1978. Stephenson, C. D., and R. L. Torstrick, 1979, The Shawnee Lime-Limestone Computer Program, prepared for presentation at Industry Briefing Conference, Raleigh, North Carolina, December 5, 1979. Stephenson, C. D., and R. L. Torstrick, 1979, Shawnee Lime/Limestone Scrubbing Computerized Design/Cost-Estimate Model Users Manual.

12. Burnett, T. A., C. D. Stephenson, F. A. Sudhoff, and J. D. Veitch, 1983, Economic Evaluation of Limestone and Lime Flue Gas Desulfurization Processes, EPA-600/7-83-029, U.S. Environmental Protection Agency, Washington, D.C.

13. Argonne, 1979. The model that sizes and costs particulate removal devices was provided by Paul S. Farber of Argonne National Laboratory, Argonne, Illinois.

14. Code of Federal Regulations, Standards for Performance for New Stationary Sources, Title 40, part 60. Subpart Da contains standards for utility power plants upon which construction was, or will be, started after September 18, 1978.

15. Tomlinson, S. V., F. M. Kennedy, F. A. Sudhoff, and R. L. Torstrick, 1979, Definitive SO_x Control Process Evaluations: Limestone, Double-Alkali, and Citrate FGD Processes, EPA-600/7-79-177, U.S. Environmental Protection Agency, Washington, D.C.

16. Federal Energy Regulatory Commission, 1968, Hydroelectric Power Evaluation. FPC P-35 and Supplement No. 1, FPC P-38 (1969). Federal Energy Regulatory Commission, U.S. Government Printing Office, Washington, D.C.

17. Cavallaro, J. A., M. J. Johnson, and A. W. Deubrouck, 1976, Sulfur Reduction Potential of the Coals of the United States, Bureau of Mines Report of Investigation RI 8118, U.S. Bureau of Mines, Washington, D.C.

18. Hamersima, J. W., and M. L. Kraft, 1975, Applicability of the Meyers Process for Chemical Desulfurization of Coal: Survey of Thirty-Five Coals, EPA-650/2-74-025-A, U.S. Environmental Protection Agency, Washington, D.C.

19. Bureau of Mines, 1946, Bureau of Mines Information Circular 7346, Department of the Interior, Washington, D.C. Describes Rosin and Rammler chart.

20. National Coal Association, 1979, Steam-Electric Plant Factors, 1979, National Coal Association, Washington, D.C. National Electric Reliability Council, 1980, 1980 Summary of Projected Peak Demand, Generating Capability, and Fossil Fuel Requirements, National Electric Reliability Council, Princeton, New Jersey. Department of Energy, 1978, Steam-Electric Plant Construction Cost and Annual Production Expenses 1977, DOE/EIA-0033/3 (77), U.S. Department of Energy, Washington, D.C., DOE, 1979, Steam-Electric Plant Air and Water Quality Control Data, for the Year Ended December 31, 1976, DOE/FERC 0036, U.S. Department of Energy, Washington, D.C. These are issued annually.

21. Singer, J. G., ed., 1981, Combustion, Fossil Power Systems, Combustion Engineering, Inc., Windsor, Connecticut.

22. Babcock & Wilcox, Steam/Its Generation and Use, Babcock & Wilcox Co., New York, 1975.

23. Friedlander, G. D., 1978, 15th Steam Station Design Survey, Electrical World, Vol. 190, No. 10, November 1978, pp. 73-87; Friedlander, G. D., 1980, 16th Steam Station Design Survey, Electrical World, Vol. 194, No. 8, November 1980, pp. 67-82; and Friedlander, G. D., and M. C. Going, 1982, 17th Steam Station Design Survey, Electrical World, Vol. 196, No. 11, November 1982, pp. 71-79.

24. Code of Federal Regulations, Title 40, Part 60, Standard of Performance for New Stationary Sources, Subparts D and Da.

25. Federal Register, 1971, Standards of Performance for New Stationary Sources, Vol. 36, No. 247, December 23, pp. 24876-24895.

26. Federal Register, 1979, New Stationary Sources Performance Standards: Electric Utility Steam Generating Units, Vol. 44, No. 113, June 11, pp. 33580-33624.

27. Chemical Engineering, Economic Indicators.

28. Uhl, V. W., 1979, A Standard Procedure for Cost Analysis of Pollution Control Operations, Vols. I and II, EPA-600/8-79-018a and -018b, Research Triangle Park, North Carolina.

29. The Richardson Rapid System, Process Plant Estimation Standards, Vols. I, III, and IV, 1978-1979 edition. Richardson Engineering Services, Inc., Solano Beach, California.

30. Grant, E. L., and W. G. Ireson, 1970, Principles of Engineering Economy, Ronald Press, New York.

31. Unpublished data for 200 utility boilers compiled by PEDCo Environmental, Inc., Cincinnati, Ohio (T. C. Ponder to R. L. Torstrick, TVA, February 25, 1976). Retrofit factors vary widely from near unity to almost two times the cost of a new installation. Most are in the range of about 1.1 to 1.5.

32. EPRI, Technical Assessment Guide, EPRI, Special Report, Electric Power Research Institute, Palo Alto, California.

33. Jeynes, P. H., 1968, Profitability and Economic Choice, First Edition, The Iowa State University Press, Ames, Iowa.

34. McGraw, M. G., 1980, Metrication in the Electric Utility Industry, Electrical World, Vol. 194, No. 7, October 1980, pp. 69-100.

35. ASTM E 380 79, 1980, Annual Book of ASTM Standards, Part 41, American Society for Testing and Materials, Philadelphia, Pennsylvania.

Appendix A

PROCESS FLOWSHEETS AND LAYOUTS

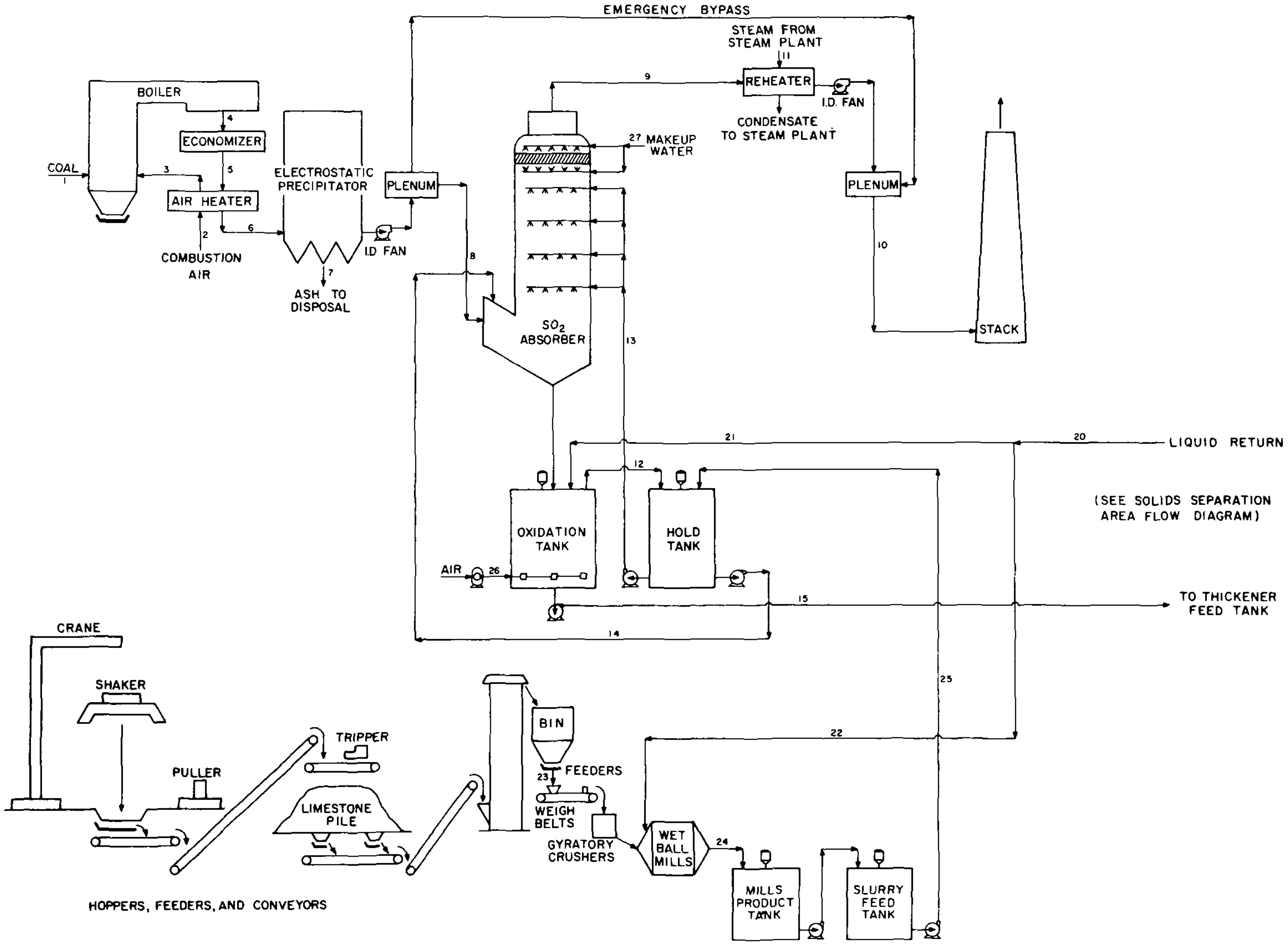


Figure A-1. Limestone-scrubbing process utilizing a spray tower and forced oxidation.

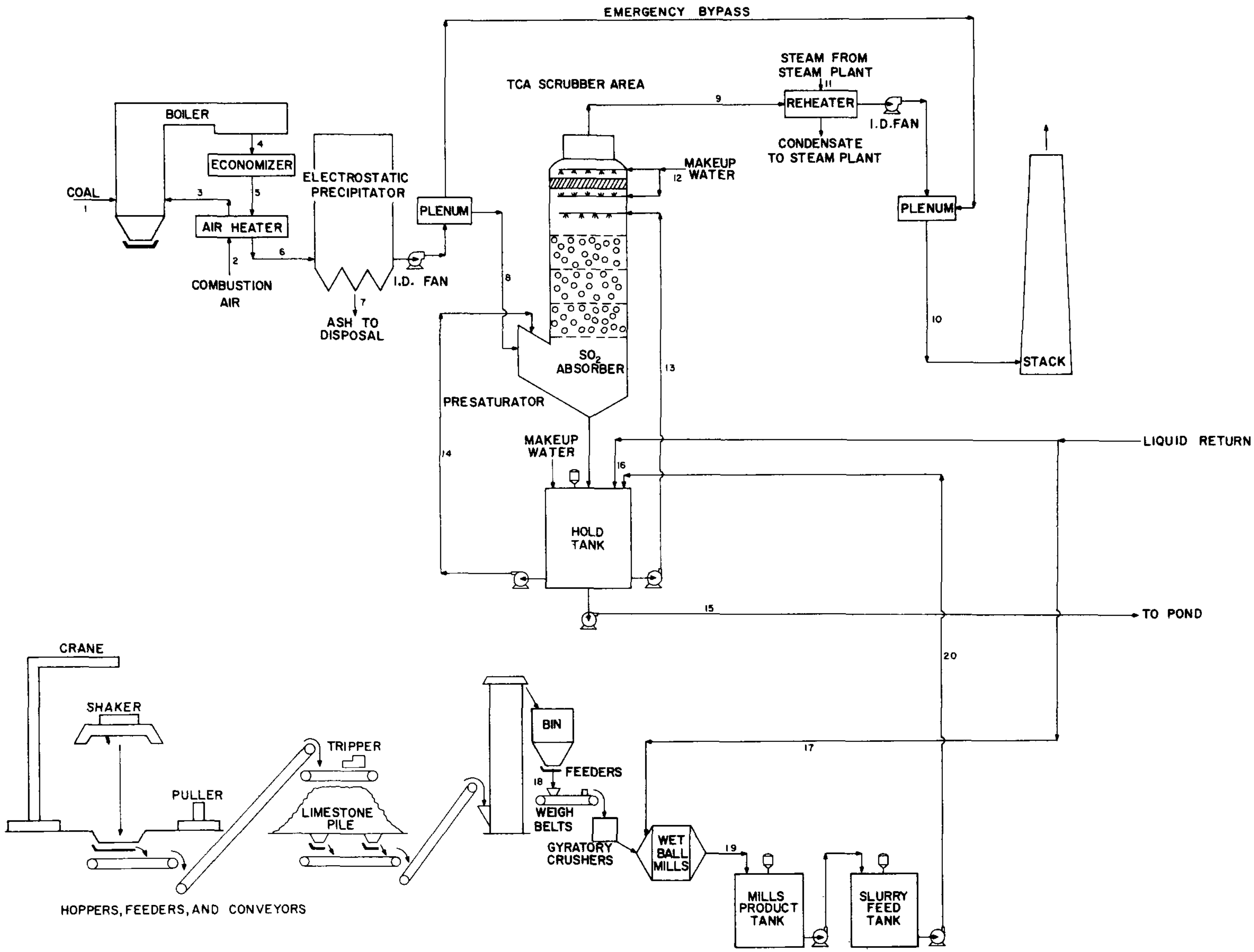


Figure A-2. Limestone-scrubbing process utilizing TCA absorber with natural oxidation.

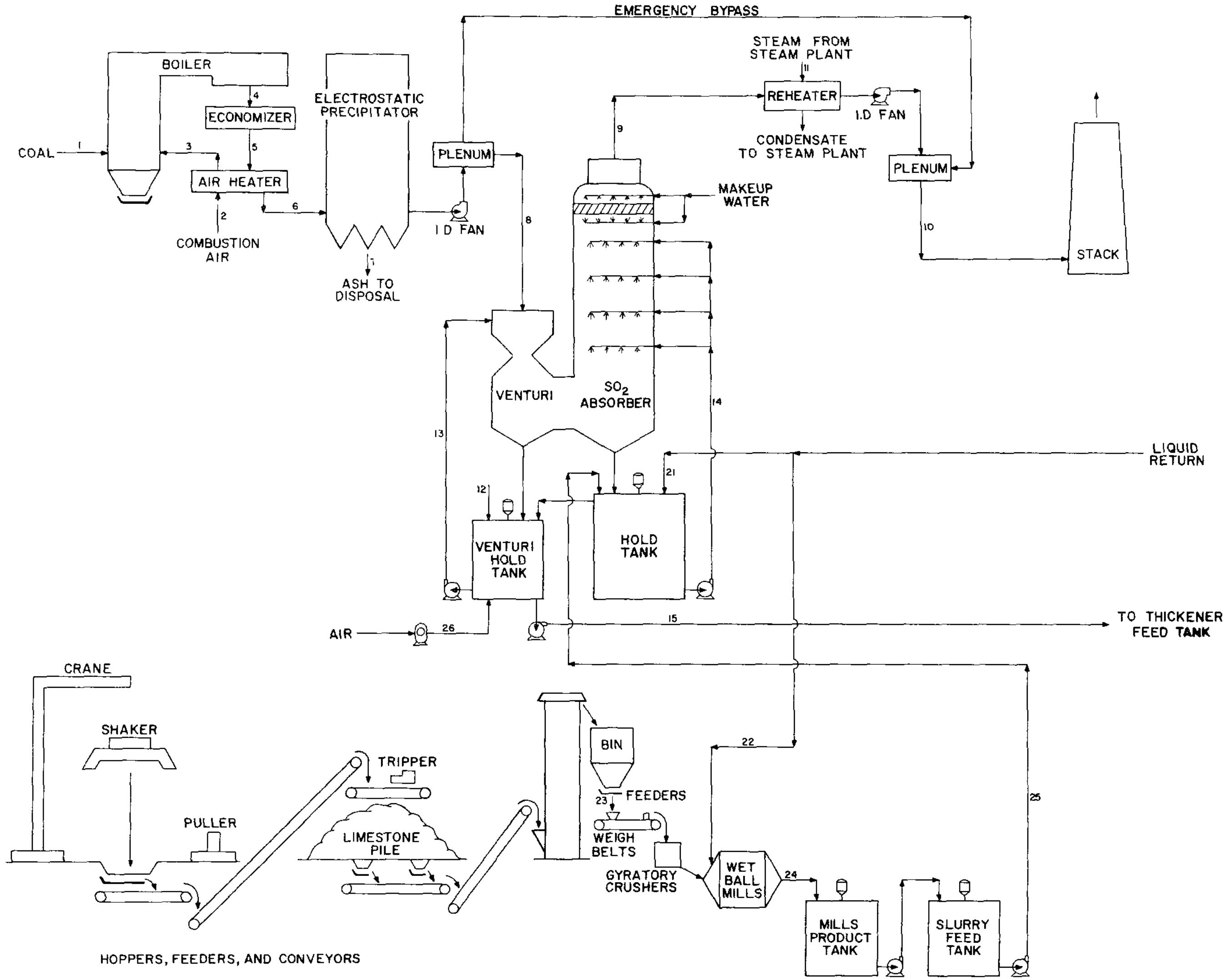


Figure A-3. Limestone-scrubbing process utilizing a venturi-spray tower.

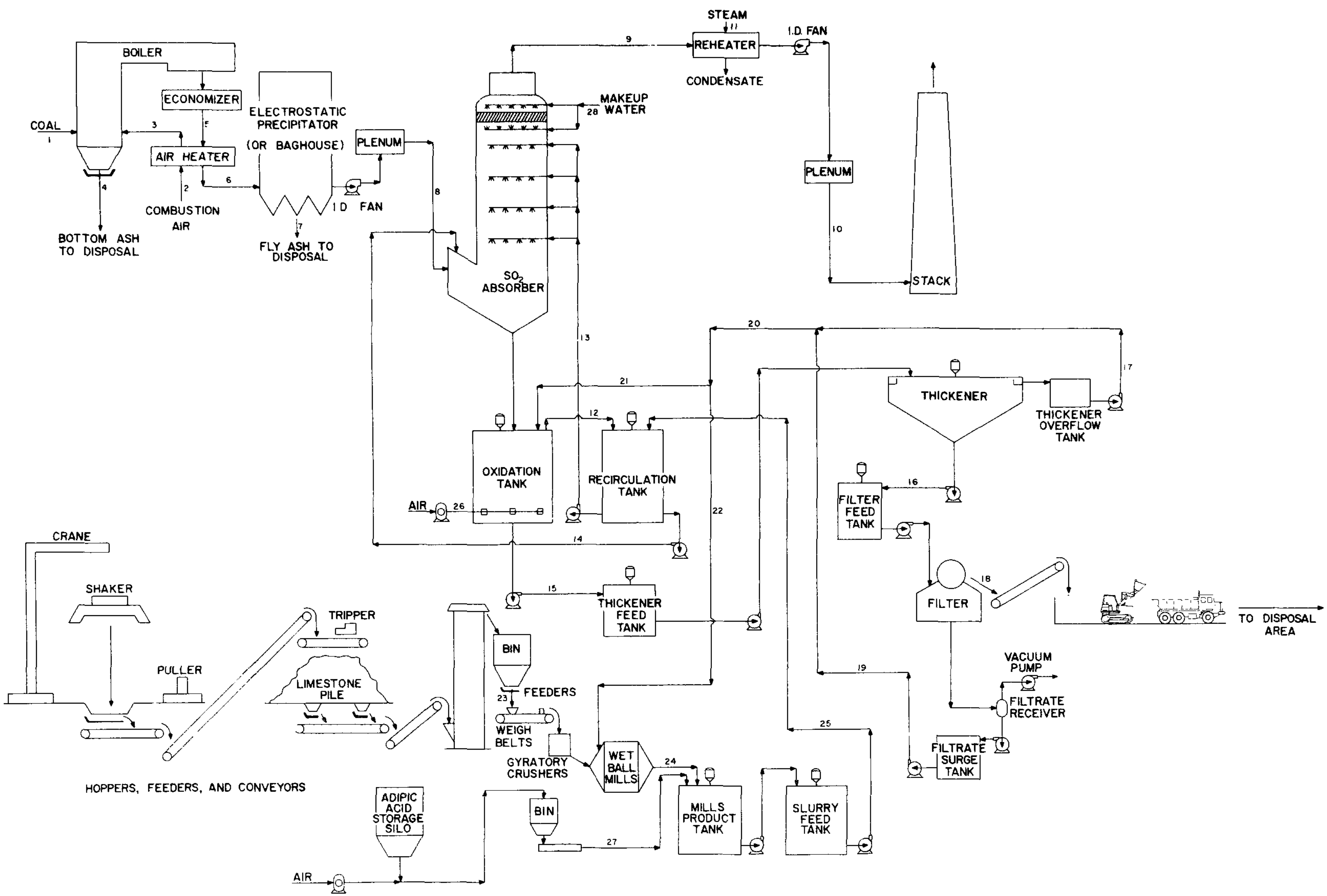


Figure A-4. Limestone-scrubbing process utilizing a spray tower with forced oxidation and adipic acid addition.

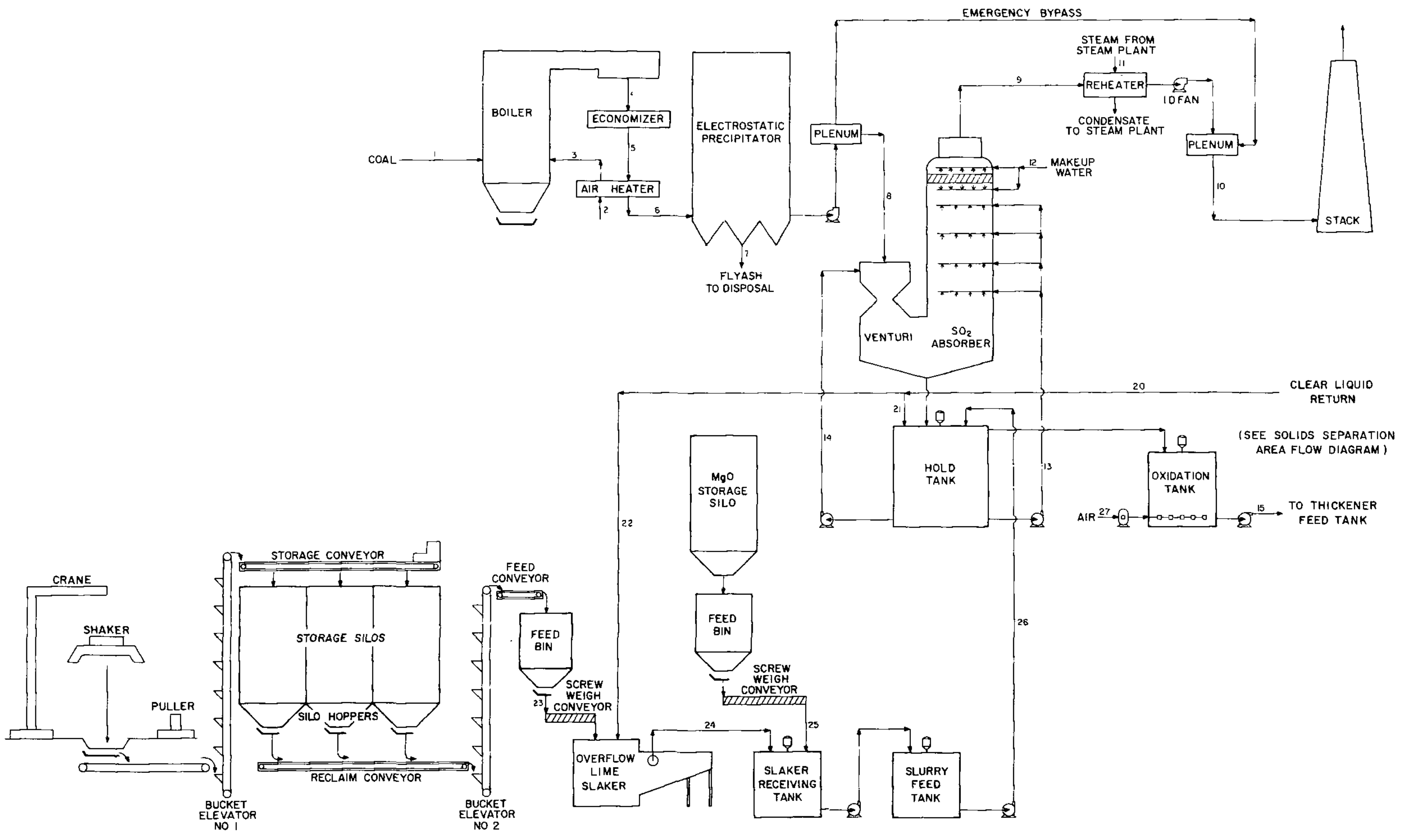


Figure A-5. Lime-scrubbing process utilizing a venturi-spray tower with MgO addition.

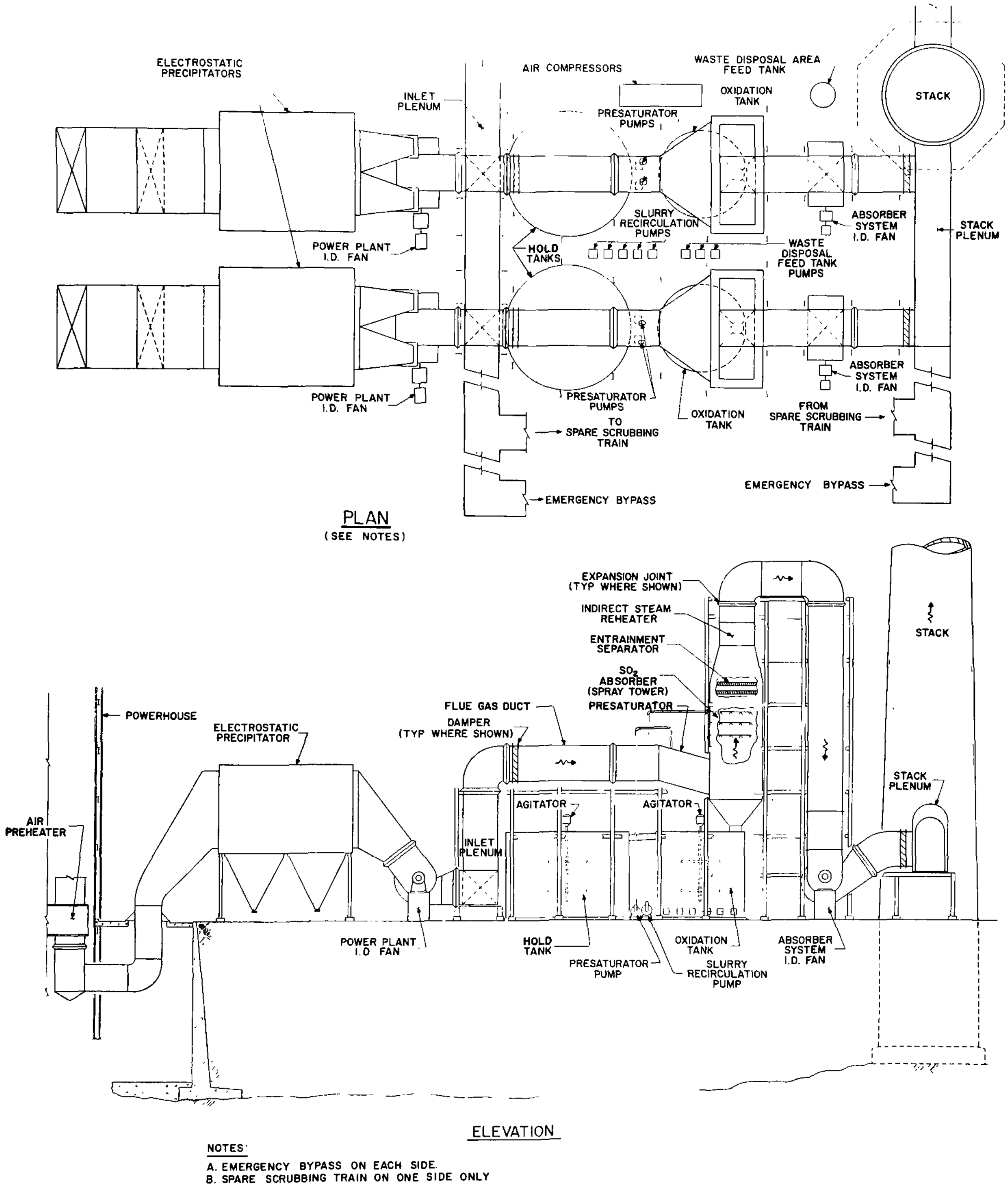


Figure A-6. Plan and elevation for a spray tower with forced oxidation.

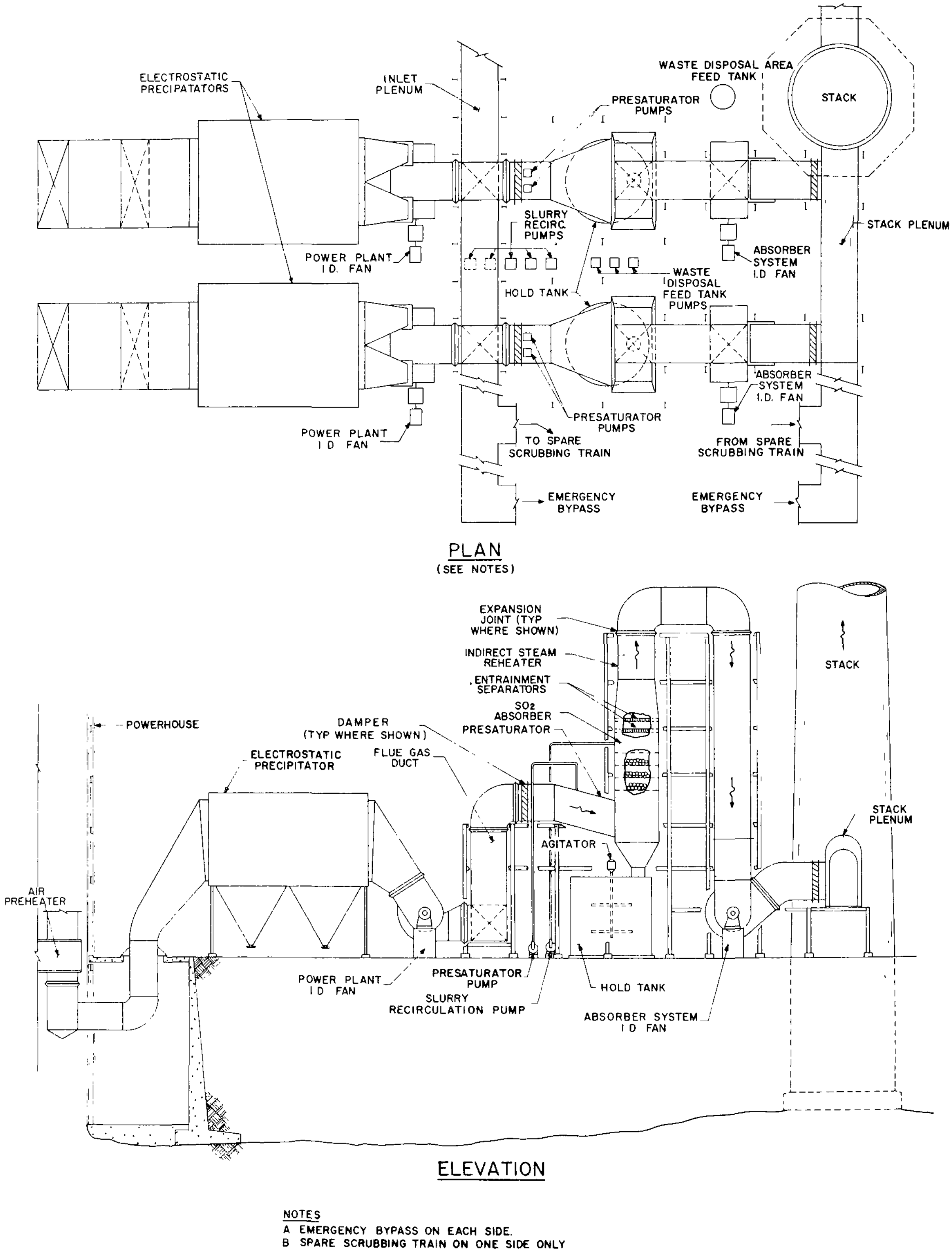


Figure A-7. Plan and elevation for a TCA without forced oxidation.

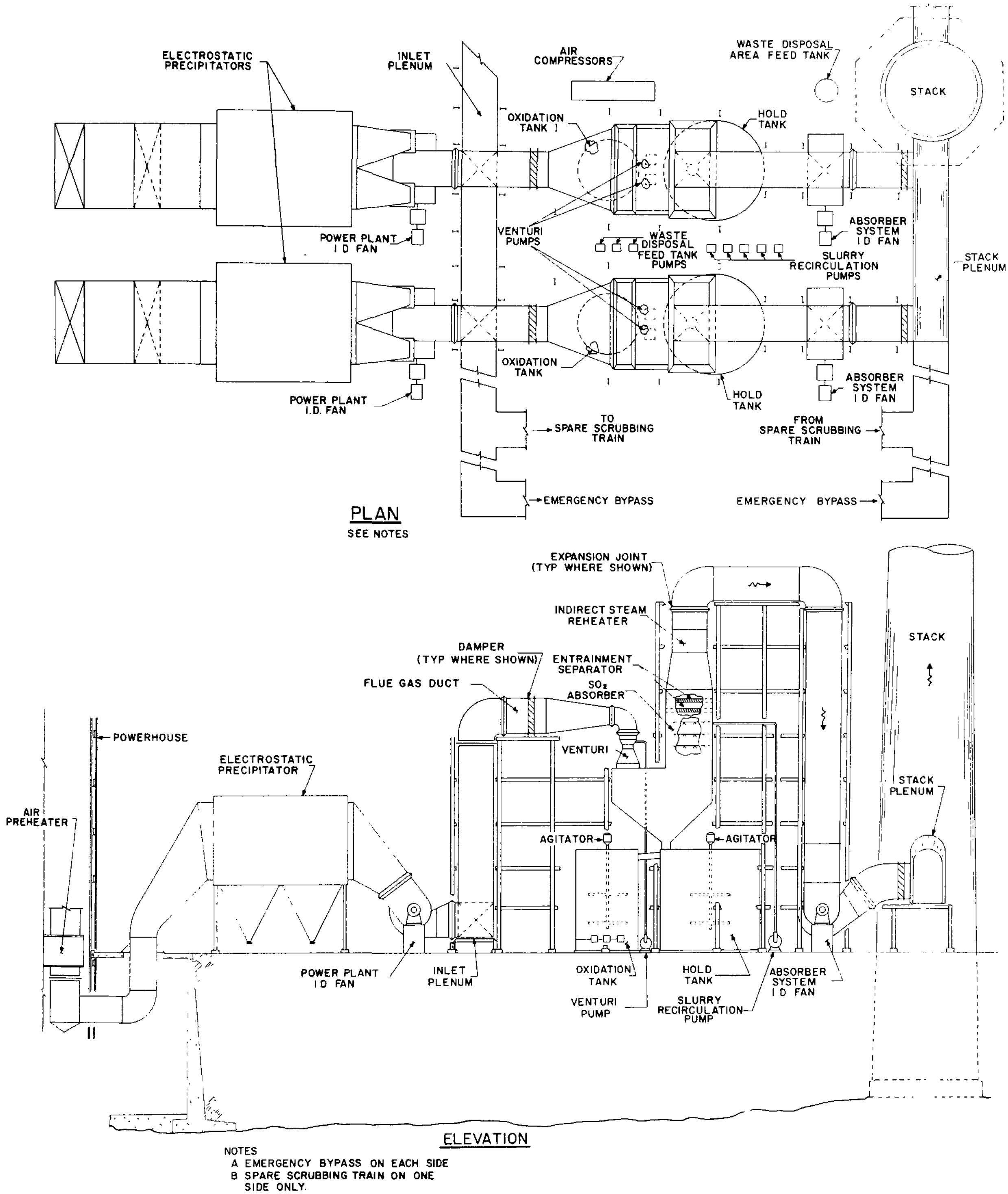


Figure A-8. Plan and elevation for a venturi-spray tower with forced oxidation.

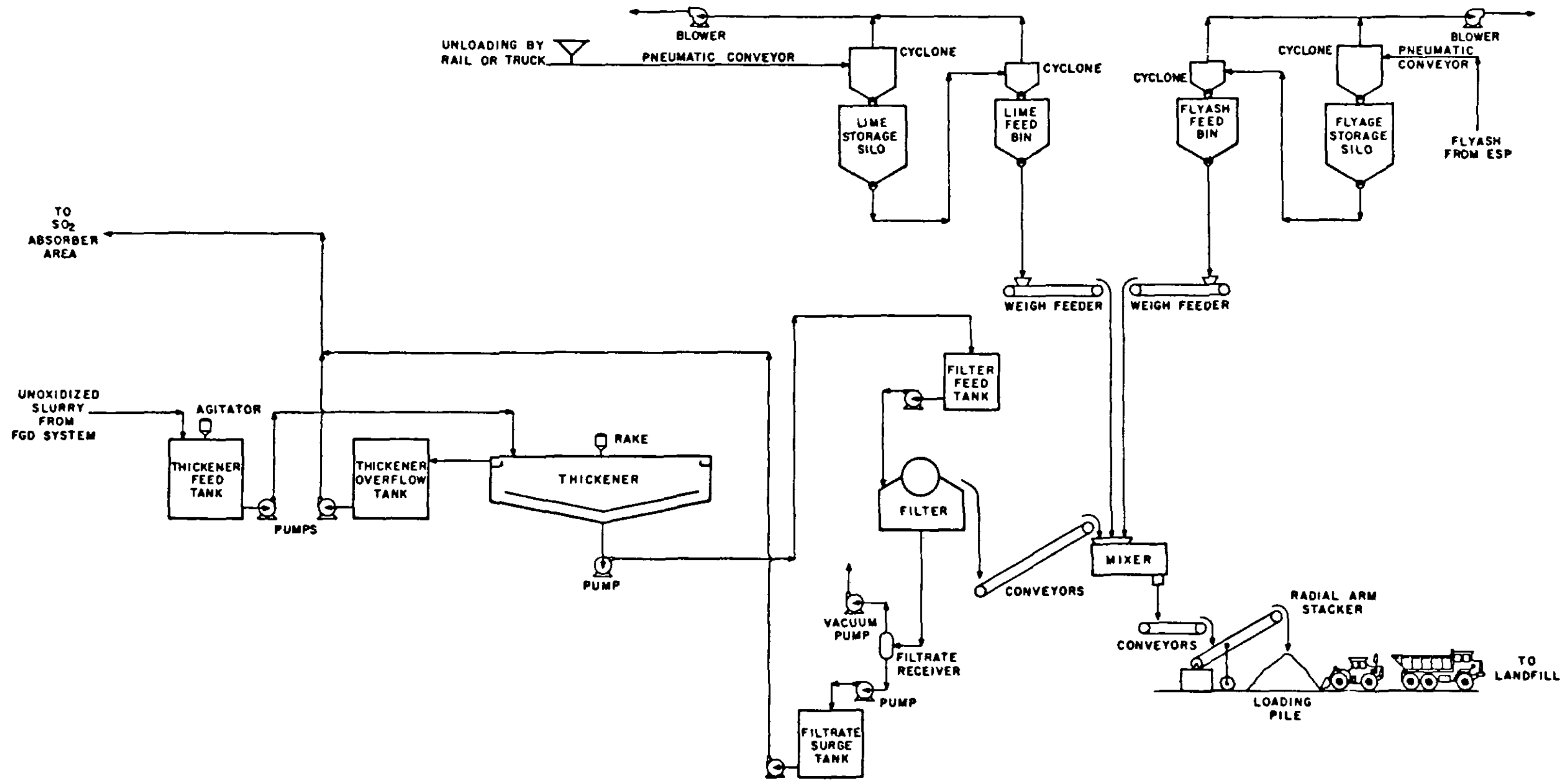
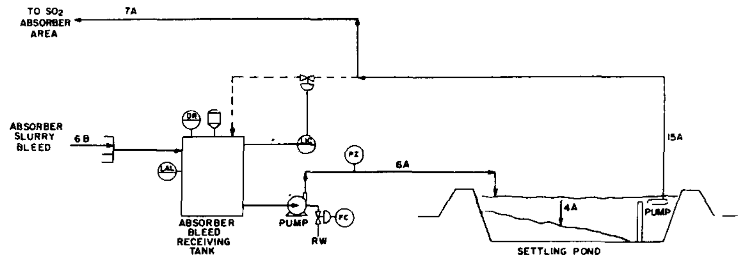
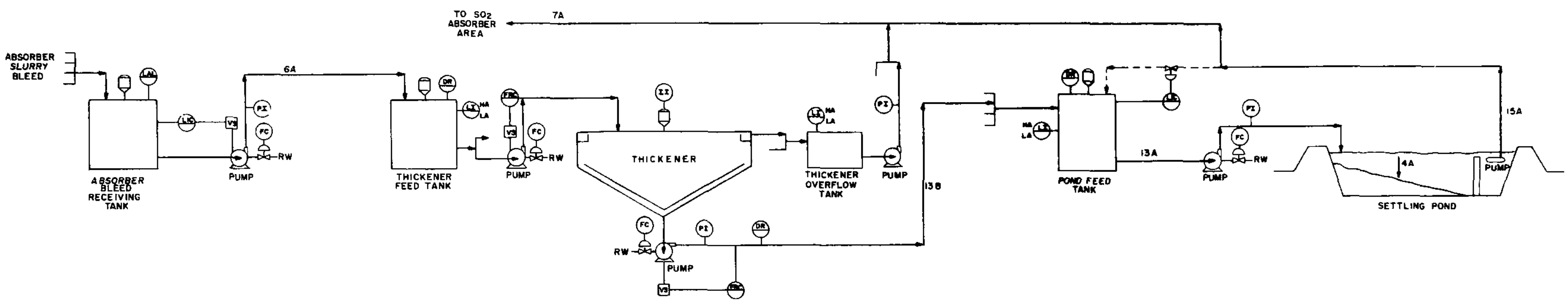


Figure A-9. Fixation waste disposal option.

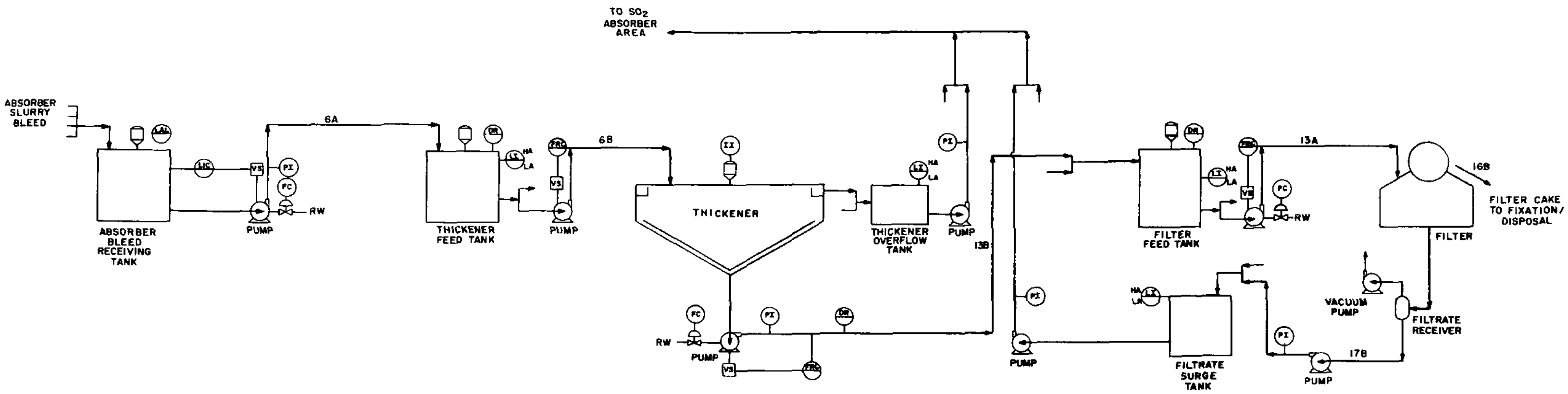


Onsite ponding (Option 1)

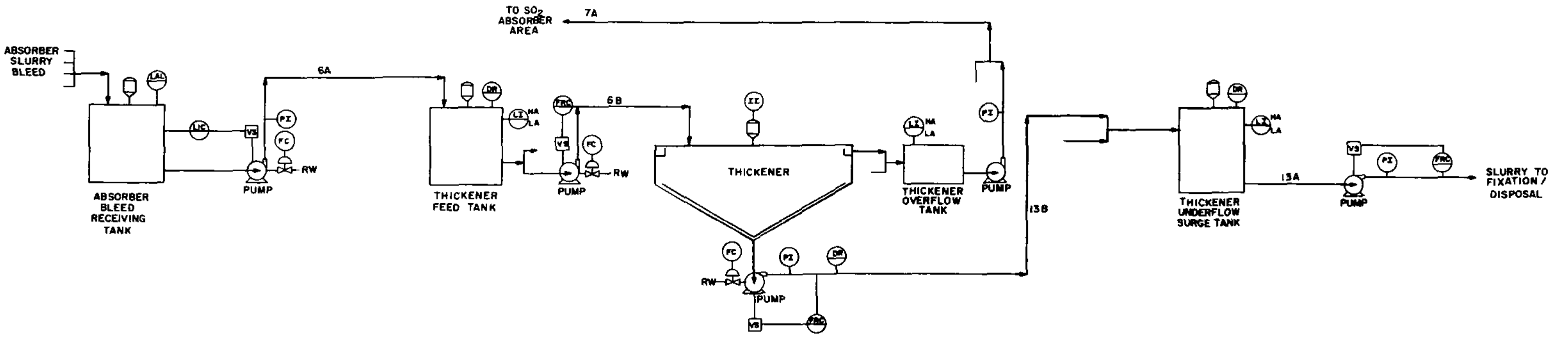


Thickener ponding (Option 2)

Figure A-10. Fixation waste disposal option.



Thickener - filter (Option 4)



Thickener - fixation fee (Option 3)

Figure A-11. Waste disposal options 3 and 4.

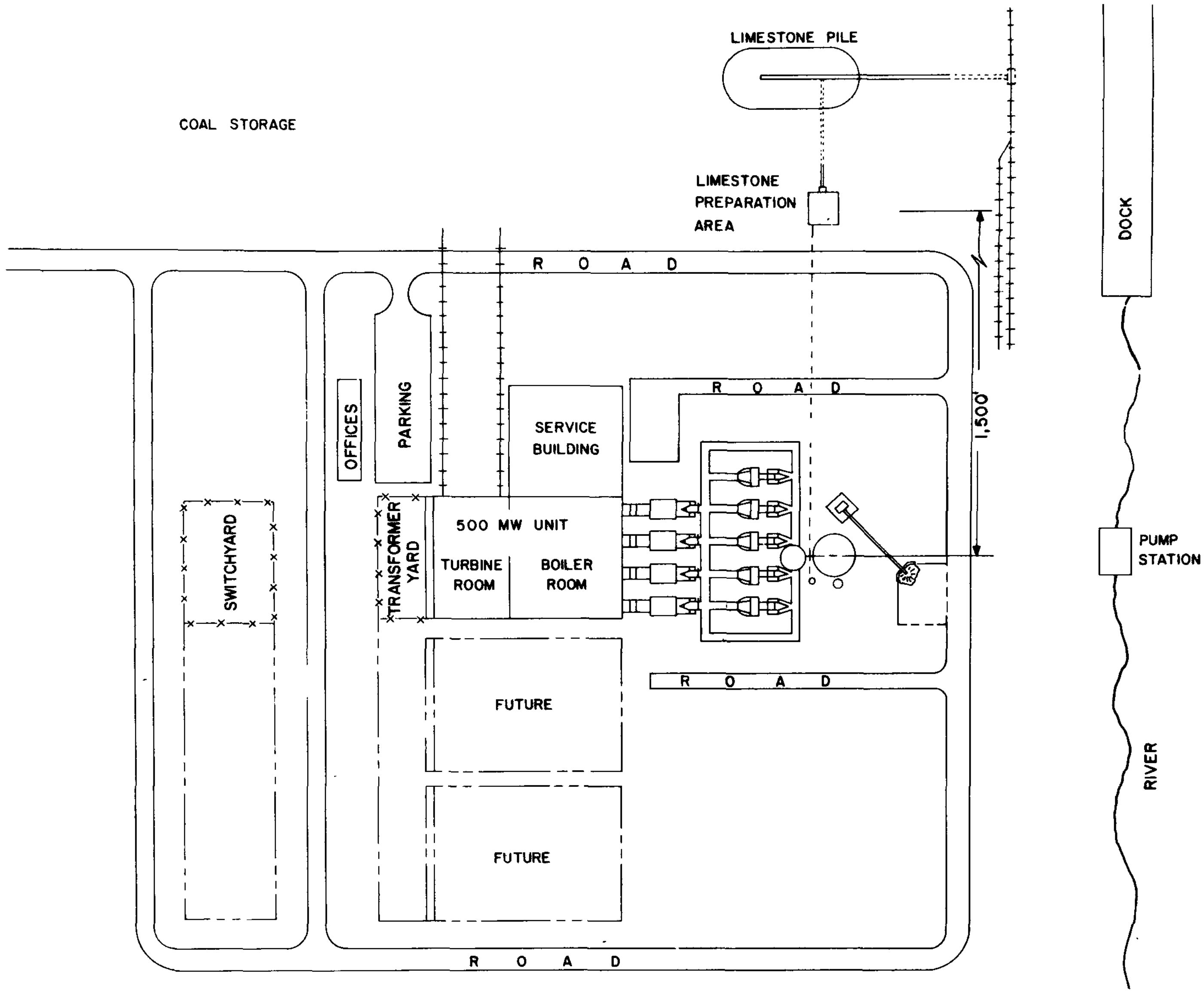


Figure A-12. Limestone slurry scrubbing process plant layout.

Appendix B

DESIGN AND ECONOMIC PREMISES FOR EMISSION CONTROL EVALUATIONS

DESIGN AND ECONOMIC PREMISES FOR EMISSION CONTROL EVALUATIONS

INTRODUCTION

These premises provide criteria for economic evaluations of emission control and related processes for electric utility power plants fired with pulverized coal. The design premises define representative coal and power unit conditions and emission control design practices. The economic premises are based on regulated utility economics; they prescribe procedures for determining capital investments and annual revenue requirements. The premises are directly applicable to economic evaluations of coal cleaning; flue gas desulfurization (FGD), nitrogen oxides (NO_x), and fly ash control; bottom ash handling; and ponding or landfill disposal of nonhazardous wastes.

The economic evaluations are based on a conceptual design based on the design premises and developed from engineering data such as flow diagrams, material balances, and equipment costs. Depending on the degree of accuracy specified, some costs are either scaled or developed from detailed design and operating data.

A new 500-MW power unit is used as a base case. Seven coals, representing typical steam coals used in the United States, are defined. Normally an eastern bituminous coal containing 3.5% sulfur and 16% ash (moisture-free basis) is used as the base case coal. The other coals represent eastern bituminous coals with different sulfur contents, western bituminous and subbituminous coals, and lignite.

These premises, updated in late 1983, are based on 1985 costs for capital investment and 1987 costs for annual revenue requirements. The cost basis and other premise criteria are updated periodically; usually the entire premise criteria are updated at one time rather than on a piecemeal basis to maintain the comparability of evaluations made over a period of time. The projection of new cost basis years using current economic factors is the major change from the previous premises, which were used since April 1980. The other changes are relatively minor revisions to the design premises: emission of 95% instead of 92% of the sulfur in eastern bituminous coals, updated spray dryer FGD designs, and a slightly modified landfill design.

DESIGN PREMISES

The design premises specify the coal properties; power unit conditions; emission control requirements; design features of NO_x, SO_2, and fly ash control processes; and waste-handling and disposal methodology.

COAL PREMISES

The premise coals consist of four eastern bituminous coals containing 5.0%, 3.5%, 2.0%, and 0.7% sulfur; a 0.7% sulfur western bituminous coal; a 0.7% sulfur western subbituminous coal; and a 0.9% sulfur North Dakota lignite. They are based on analyses of U.S. steam coals representative of the types in current use (17,18). The analysis data for each of these coals are summarized in Table B-1 and a fly ash analysis for each coal is shown in Table B-2.

TABLE B-2. FLY ASH COMPOSITIONS

Component	Bituminous fly ash, wt %	Subbituminous fly ash, wt %	Lignite fly ash, wt %
SiO_2	50.8	39.7	23.0
Al_2O_3	20.6	21.5	11.5
TiO_2	2.5	1.1	0.5
Fe_2O_3	16.9	7.4	8.6
CaO	2.0	20.0	21.6
MgO	1.0	4.7	6.0
Na_2O	0.4	1.7	5.9
K_2O	2.6	0.5	0.5
SO_3	2.4	2.3	19.2
P_2O_5	-	1.0	0.4
Other	0.8	0.1	2.8
Total	100.0	100.0	100.0

TABLE B-1. COMPOSITION OF PREMISE COALS

Coal	Sulfur: Total, %	Sulfur: Pyritic, %	Sulfur: Sulfatic, %	Sulfur: Organic, %	Ash, %	Moisture, %	Heat content, Btu/lb	Ultimate analysis: C, %	Ultimate analysis: H, %	Ultimate analysis: O, %	Ultimate analysis: N, %	Ultimate analysis: Cl, %
(As-fired basis)												
Eastern bituminous, 5.0% S	4.80	3.17	0.05	1.58	15.10	4.0	11,700	65.2	4.0	5.5	1.3	0.1
Eastern bituminous, 3.5% S	3.36	2.21	0.05	1.10	15.14	4.0	11,700	66.7	3.8	5.6	1.3	0.1
Eastern bituminous, 2.0% S	1.92	1.25	0.04	0.63	15.08	4.0	11,700	67.8	3.7	6.0	1.4	0.1
Eastern bituminous, 0.7% S	0.67	0.44	0.01	0.22	15.13	4.0	11,700	68.8	3.6	6.3	1.4	0.1
Western bituminous, 0.7% S	0.59	0.20	0.01	0.38	9.71	16.0	9,700	57.0	3.9	11.5	1.2	0.1
Western subbituminous, 0.7% S (Powder River Basin)	0.48	0.16	0.01	0.31	6.30	29.3	8,200	49.0	3.5	10.7	0.7	0.02
North Dakota lignite, 0.9% S	0.57	0.19	0.01	0.37	7.22	36.3	6,600	40.1	2.8	12.4	0.6	0.01
(Moisture-free basis)												
Eastern bituminous, 5.0% S	5.00	3.30	0.05	1.65	15.7			67.9	4.2	5.7	1.4	0.1
Eastern bituminous, 3.5% S	3.50	2.30	0.05	1.15	15.7			69.5	4.0	5.8	1.4	0.1
Eastern bituminous, 2.0% S	2.00	1.31	0.04	0.65	15.7			70.6	3.9	6.3	1.4	0.1
Eastern bituminous, 0.7% S	0.70	0.46	0.01	0.23	15.7			71.7	3.8	6.6	1.4	0.1
Western bituminous, 0.7% S	0.70	0.24	0.01	0.45	11.6			67.9	4.6	13.7	1.4	0.1
Western subbituminous, 0.7% S (Powder River Basin)	0.68	0.23	0.01	0.44	8.9			69.3	5.0	15.1	1.0	0.02
North Dakota lignite, 0.9% S	0.89	0.30	0.01	0.58	11.3			63.0	4.4	19.5	0.9	0.01

As-fired coal refers to the coal entering the coal-cleaning plant or power plant. This coal is supplied in a 3-inch top size after large rocks and trash have been removed from the run-of-mine coal. Broken coal is assumed to have the particle size distributions represented by the Bennett form of the Rosin and Rammler equation,

$$R = 100e^{-(x/\bar{x})^n}$$

which can be plotted on special graph paper devised by the U.S. Bureau of Mines (BOM) (19) as shown in Figure B-1. In the equation,

x = particle diameter or width of screen aperture in millimeters. It is the abscissa in Figure B-1.

$\bar{x}$ = a size constant, in millimeters, that is specific to each distribution line of particle size. In Figure B-1, it is the value of x when R = 36.79%; in turn R = 36.79% when $\bar{x}$ = x in the Rosin and Rammler equation.

n = a size distribution constant. In Figure B-1, it is the arithmetical slope of a distribution line. Parallel distribution lines have the same value of n.

e = the base of the natural logarithm.

R = the weight percentage of coal retained on a screen whose aperture is x. R expresses cumulative oversize and is the ordinate in Figure B-1.

For all distribution lines in Figure B-1, the value of n is 0.8840. Values of $\bar{x}$ for selected size distributions are given below.

Nominal top sizes	Actual aperture size (Tyler $\sqrt{2}$ series) in.	Actual aperture size (Tyler $\sqrt{2}$ series) mm	$\bar{x}$ mm
3 in.	2.970	75.43	13.40
2 in.	2.100	53.34	9.478
1-1/2 in.	1.485	37.71	6.702
3/4 in.	0.742	18.86	3.351
3/8 in.	0.371	9.429	1.676
3 mesh	0.093	2.357	0.4189
14 mesh	0.046	1.179	0.2094
28 mesh	0.023	0.589	0.1047

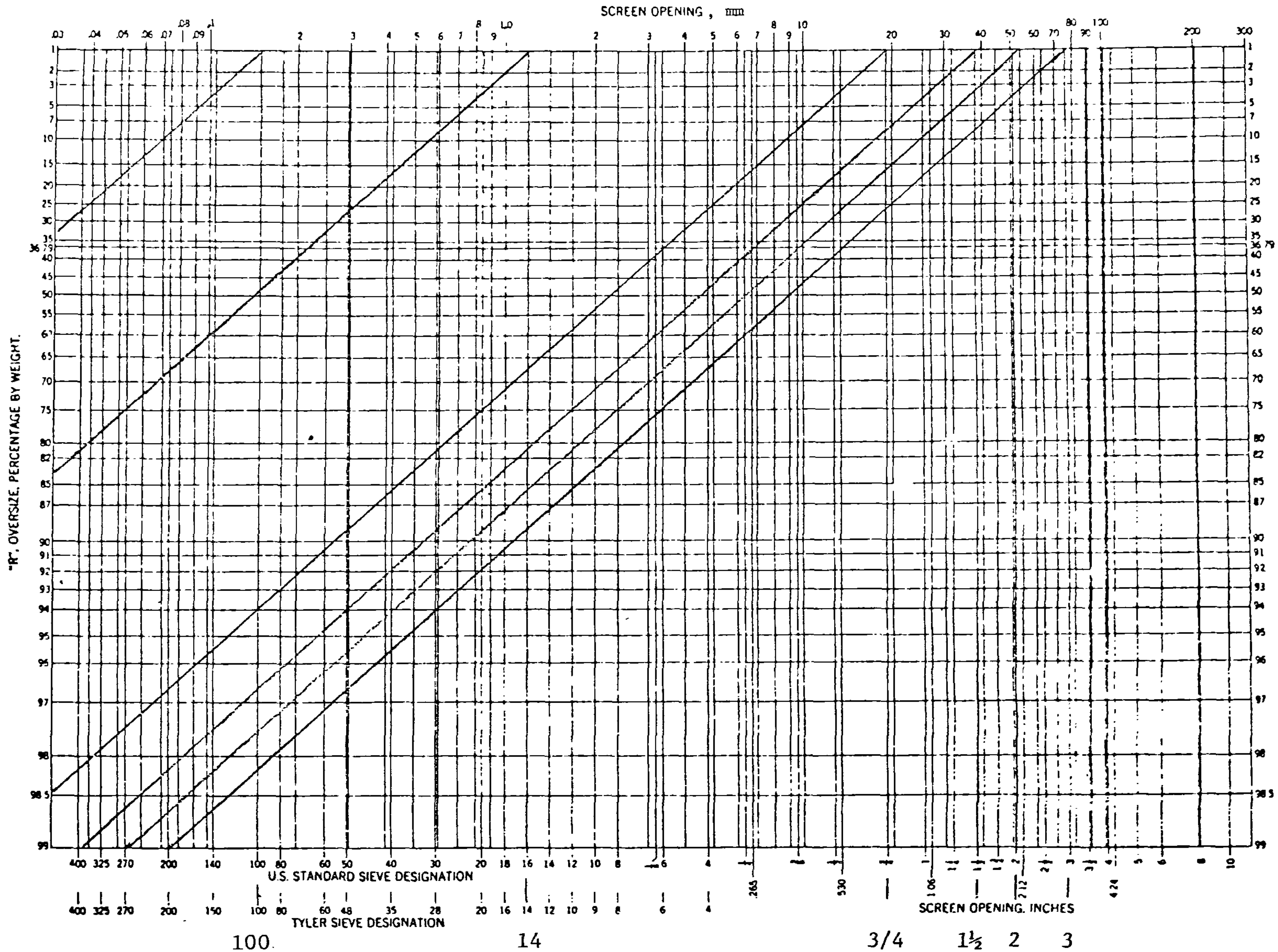


Figure B-1. Rosin-Rammler plots of premise coal sizes.

POWER PLANT

The power plant site is assumed to be in the north-central region (Illinois, Indiana, Ohio, Michigan, Kentucky, and Wisconsin). The location represents an area in which coal-fired power plants burning coals of diverse type and source are situated (20). The design is based on standard design practices (21,22) and current trends in utility boiler construction (23). The base case power unit is a new, single 500-MW, balanced-draft, dry-bottom boiler fired with pulverized coal. The steam pressure is 2,400 psi. The superheat and reheat temperatures are 1,000°F.

Power unit size case variations consist of similar 200-MW and 1,000-MW units. For new units, the systems being evaluated are assumed to be installed during construction of the power plant. New units are assumed to have a 30-year life and to operate at full load for 5,500 hours/yr. For case variations, identical existing units with 20 years of remaining life at 5,500 hours/yr of full-load operation are used. The heat rates are shown in Table B-3. They are based on coal type, unit size, and unit age. To provide for equitable comparisons, the power units are not derated for energy consumption by the systems evaluated. Instead, the energy requirements are charged as independently purchased commodities. Normally, cost estimates are based on a single power unit independent of other units at the site. In cases in which a plant-wide process or system is evaluated, a plant capacity of 1,000 MW is normally used.

TABLE B-3. POWER UNIT HEAT RATE

	New			Existing		
Power unit size, MW:	200	500	1,000	200	500	1,000
Remaining life, years	30	30	30	20	20	20
Full load, hr/yr	5,500	5,500	5,500	5,500	5,500	5,500
Heat rate, Btu/kWh						
Bituminous coal	9,700	9,500	9,200	9,900	9,700	9,500
Subbituminous coal	10,700	10,500	10,200	11,000	10,700	10,500
Lignite	11,200	11,000	10,700	11,400	11,200	11,000

FLUE GAS COMPOSITIONS

Flue gas compositions are based on combustion of pulverized coal assuming a total air rate equivalent to 139% of the stoichiometric requirement (defined as air for combustion of carbon, hydrogen, and sulfur). This includes 20% excess air to the boiler and 19% additional air leakage to the flue gas in the air heater. It is assumed that 80% of the ash present in all coals is emitted as fly ash. Sulfur emitted is dependent on the coal type; 95% of the sulfur in all eastern coals and 85% of the sulfur in all western coals and lignite are emitted as gaseous sulfur oxides (SO_x). The remaining sulfur is removed in the bottom ash and fly ash. No loss of sulfur in the pulverizers is assumed. Three percent of the sulfur emitted as SO_x is SO_3 and the remainder is SO_2.

A flow diagram around the boiler is shown in Figure B-2 and detailed boiler material balances and flue gas composition summaries for stream 8, for each premise coal, are shown in Tables B-4 through B-17. The streams shown in the material balances have excess significant digits for cases in which higher accuracy is needed. These numbers are not to be published without rounding to four significant digits, no more - no less.

ENVIRONMENTAL REGULATIONS

Emissions from new coal-fired utility plants are regulated by the new source performance standards (NSPS), which are promulgated by the U.S. Environmental Protection Agency (EPA) under authority of the Clean Air Act as amended in 1970 and 1977 (24). This section requires EPA to set Federal emission limitations that reflect the degree of control that can be achieved by using the best available control technology (BACT). In 1971, EPA issued NSPS to limit emissions of SO_2, NO_x, and particulate matter from utility power plants (25). The 1971 NSPS specify a maximum emission based on heat input of 0.10 lb/MBtu for particulate matter and 1.2 lb/MBtu for SO_2. They apply to power units, for which construction began between August 1971 and September 1978. In 1979, EPA revised the NSPS (26) as shown in Table B-18. The controlled outlet SO_2 emission and SO_2 removal efficiencies for the premise coals are shown in Figure B-3 and tabulated in Table B-19.

<u>Equation to determine equivalent SO_2 content of coal:</u>

$$E = (S/H)(2 \times 10^4)$$

where: S = % sulfur in coal, as fired
H = heat content of coal, as fired
E = equivalent SO_2 content of coal as fired, lb equivalent SO_2/MBtu

<u>Equations to determine overall % sulfur removal required</u>

<u>$E < 2.0$</u>

70% equivalent SO_2 removal required

<u>$2.0 < E < 6.0$</u>

% equivalent SO_2 removal required = $((E - 0.6)/E)(100)$

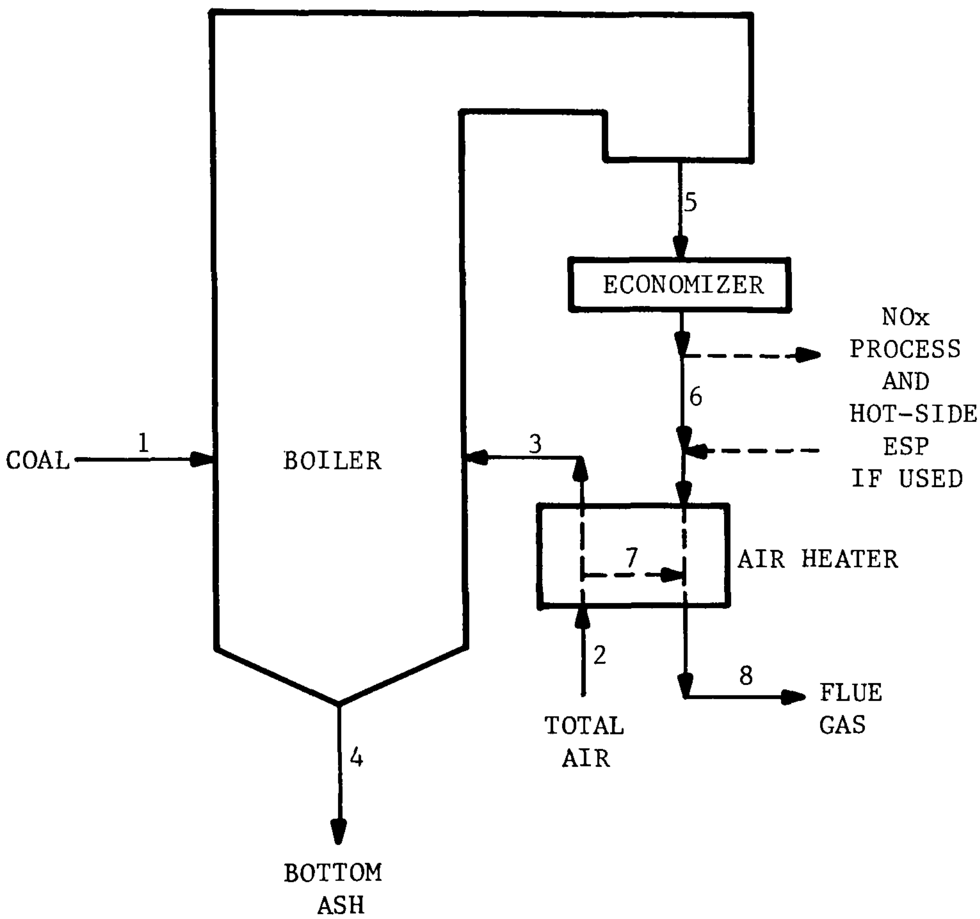


Figure B-2. Boiler flow diagram.

TABLE B-4. BOILER MATERIAL BALANCE FOR

5% SULFUR EASTERN BITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr	405,983	5,047,807	4,357,819	12,455
Flow rate, sft^3/min @ 60°F		1,115,166	962,733	
Temperature, °F		80		
N_2 (C) lb/hr	(264,701)	3,829,456	3,306,006	
O_2 (H) lb/hr	(16,239)	1,153,571	995,888	
CO_2 (O) lb/hr	(22,329)			
SO_2 (N) lb/hr	(5,278)			
SO_3 (Cl) lb/hr	(406)			
NO (S) lb/hr	(19,487)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	16,239	64,799	55,925	
Ash lb/hr	61,303			12,455

Stream No.	5	6	7	8
Description	Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr	4,751,973	4,751,973	689,988	5,441,961
Flow rate, sft^3/min @ 60°F	999,502	999,502	152,433	1,151,935
Temperature, °F				
N_2 lb/hr	3,310,415	3,310,415	523,451	3,833,866
O_2 lb/hr	164,941	164,941	157,682	322,623
CO_2 lb/hr	969,982	969,982		969,982
SO_2 lb/hr	35,915	35,915		35,915
SO_3 lb/hr	1,388	1,388		1,388
NO lb/hr	1,766	1,766		1,766
NO_2 lb/hr	142	142		142
HCl lb/hr	418	418		418
H_2O lb/hr	217,184	217,184	8,855	226,039
Ash	49,822	49,822		49,822

TABLE B-5. FLUE GAS COMPOSITION

FOR 5% SULFUR EASTERN BITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	75.12	136,900	3,834,000
O_2	5.53	10,080	322,600
CO_2	12.10	22,040	970,000
SO_2	0.31 (3,076 ppm)	561	35,920
SO_3	0.01 (96 ppm)	17	1,388
NO	0.03 (324 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (66 ppm)	12	418
H_2O	6.89	12,550	226,000
	100.00	182,200	5,392,000
Fly ash[a]			49,820
Total			5,442,000

Sft3/min (60°F) = 1,152,000
Aft3/min (300°F) = 1,684,000

Fly Ash Loading

	Gr/sft3
Wet	5.04
Dry	5.42

Sulfuric acid dewpoint temperature: 316°F

a. See Table B-2 for fly ash composition.

TABLE B-6. BOILER MATERIAL BALANCE FOR

3.5% SULFUR EASTERN BITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr	405,983	5,071,690	4,378,438	12,430
Flow rate, sft^3/min @ 60°F		1,120,442	967,288	
Temperature, °F		80		
N_2 (C) lb/hr	(270,791)	3,847,575	3,321,648	
O_2 (H) lb/hr	(15,427)	1,159,029	1,000,601	
CO_2 (O) lb/hr	(22,735)			
SO_2 (N) lb/hr	(5,278)			
SO_3 (Cl) lb/hr	(406)			
NO (S) lb/hr	(13,641)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	16,239	65,086	56,189	
Ash lb/hr	61,466			
				12,430

Stream No.	5	6	7	8
Description	Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr	4,772,430	4,772,430	693,252	5,465,682
Flow rate, sft^3/min @ 60°F	1,002,880	1,002,880	153,154	1,156,034
Temperature, °F				
N_2 lb/hr	3,326,058	3,326,058	525,927	3,851,985
O_2 lb/hr	165,726	165,726	158,428	324,154
CO_2 lb/hr	992,298	992,298		992,298
SO_2 lb/hr	25,140	25,140		25,140
SO_3 lb/hr	972	972		972
NO lb/hr	1,766	1,766		1,766
NO_2 lb/hr	142	142		142
HCl lb/hr	418	418		418
H_2O lb/hr	210,192	210,192	8,879	219,089
Ash lb/hr	49,718	49,718		49,718

TABLE B-7. FLUE GAS COMPOSITION

FOR 3.5% SULFUR EASTERN BITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	75.21	137,500	3,852,000
O_2	5.54	10,130	324,200
CO_2	12.33	22,550	992,300
SO_2	0.22 (2,149 ppm)	393	25,140
SO_3	0.01 (68 ppm)	12	972
NO	0.03 (323 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (66 ppm)	12	418
H_2O	6.65	12,160	219,100
	100.00	182,800	5,416,000
Fly ash[a]			49,720
Total			5,466,000

Sft^3/min (60°F) = 1,156,000
Aft^3/min (300°F) = 1,690,000

Fly Ash Loading

	Gr/sft^3
Wet	5.02
Dry	5.38

Sulfuric acid dewpoint temperature: 308°F

a. See Table B-2 for fly ash composition.

TABLE B-8. BOILER MATERIAL BALANCE FOR

2% SULFUR EASTERN BITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Air to furnace	Bottom ash
Total stream, lb/hr	405,983	5,081,446	4,386,860	12,322
Flow rate, sft^3/min @ 60°F	406,000	1,122,597	969,149	
Temperature, °F		80		
N_2 (C) lb/hr	(275,256)	3,854,977	3,328,038	
O_2 (H) lb/hr	(15,021)	1,161,258	1,002,525	
CO_2 (O) lb/hr	(24,359)			
SO_2 (N) lb/hr	(5,684)			
SO_3 (Cl) lb/hr	(406)			
NO (S) lb/hr	(7,795)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	16,239	65,211	56,297	
Ash lb/hr	61,223			12,322

Stream No.	5	6	7	8
Description	Flue gas to economizer	Flue gas to air heater	Air inleakage	Flue gas from air heater
Total stream, lb/hr	4,780,772	4,780,772	694,586	5,475,358
Flow rate, sft^3/min @ 60°F	1,004,532	1,004,532	153,449	1,157,981
Temperature, °F	800	705	535	300
N_2 lb/hr	3,332,854	3,332,854	526,939	3,859,793
O_2 lb/hr	166,047	166,047	158,733	324,780
CO_2 lb/hr	1,008,662	1,008,662		1,008,662
SO_2 lb/hr	14,366	14,366		14,366
SO_3 lb/hr	555	555		555
NO lb/hr	1,766	1,766		1,766
NO_2 lb/hr	142	142		142
HCl lb/hr	418	418		418
H_2O lb/hr	206,672	206,672	8,914	215,586
Ash lb/hr	49,290	49,290		49,290

TABLE B-9. FLUE GAS COMPOSITION

FOR 2% SULFUR EASTERN BITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	75.24	137,800	3,860,000
O_2	5.54	10,100	324,800
CO_2	12.52	22,920	1,009,000
SO_2	0.12 (1,225 ppm)	224	14,400
SO_3	0.00 (39 ppm)	7	555
NO	0.03 (322 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (66 ppm)	12	418
H_2O	6.54	11,970	215,600
	100.00	183,100	5,427,000
Fly ash[a]			49,240
Total			5,475,000

Sft^3/min (60°F) = 1,158,000
Aft^3/min (300°F) = 1,692,000

Fly Ash Loading

	Gr/sft^3
Wet	4.96
Dry	5.30

Sulfuric acid dewpoint temperature: 297°F

a. See Table B-2 for fly ash composition.

TABLE B-10. BOILER MATERIAL BALANCE FOR 0.7% SULFUR EASTERN BITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr	405,983	5,091,465	4,395,510	12,312
Flow rate, sft^3/min @ 60°F		1,124,811	971,060	
Temperature, °F		80		
N_2 (C) lb/hr	(279,316)	3,862,577	3,334,599	
O_2 (H) lb/hr	(14,616)	1,163,548	1,004,502	
CO_2 (O) lb/hr	(25,577)			
SO_2 (N) lb/hr	(5,684)			
SO_3 (Cl) lb/hr	(406)			
NO (S) lb/hr	(2,720)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	16,239	65,340	56,409	
Ash lb/hr	61,425			12,312

Stream No.	5	6	7	8
Description	Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr	4,789,268	4,789,268	695,955	5,485,223
Flow rate, sft^3/min @ 60°F	1,006,060	1,006,C60	153,751	1,159,811
Temperature, °F	800	705	535	300
N_2 lb/hr	3,339,415	3,339,415	527,978	3,867,393
O_2 lb/hr	166,376	166,376	159,046	325,422
CO_2 lb/hr	1,023,540	1,023,540		1,023,540
SO_2 lb/hr	5,013	5,013		5,013
SO_3 lb/hr	194	194		194
NO lb/hr	1,766	1,766		1,766
NO_2 lb/hr	142	142		142
HCl lb/hr	418	418		418
H_2O lb/hr	203,155	203,155	8,931	212,086
Ash	49,249	49,249		49,249

TABLE B-11. FLUE GAS COMPOSITION

FOR 0.7% SULFUR EASTERN BITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	75.27	138,100	3,867,000
O_2	5.55	10,170	325,400
CO_2	12.68	23,260	1,024,000
SO_2	0.04 (428 ppm)	78	5,013
SO_3	0.00 (11 ppm)	2	194
NO	0.03 (322 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (65 ppm)	12	418
H_2O	6.42	11,770	212,100
	100.00	183,400	5,436,000
Fly ash[a]			49,250
Total			5,485,000

Sft^3/min (60°F) = 1,160,000
Aft^3/min (300°F) = 1,695,000

Fly Ash Loading

	Gr/sft^3
Wet	4.95
Dry	5.29

Sulfuric acid dewpoint temperature: 273°F

a. See Table B-2 for fly ash composition.

TABLE B-12. BOILER MATERIAL BALANCE FOR

0.7% SULFUR WESTERN BITUMINOUS COAL

Stream No.			1	2	3	4
Description			Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr			489,691	5,117,371	4,417,874	9,596
Flow rate, sft^3/min @ 60°F				1,130,534	976,000	
Temperature, °F				80		
N_2	(C)	lb/hr	(279,124)	3,882,231	3,351,566	
O_2	(H)	lb/hr	(19,098)	1,169,468	1,009,613	
CO_2	(O)	lb/hr	(56,314)			
SO_2	(N)	lb/hr	(5,876)			
SO_3	(Cl)	lb/hr	(490)			
NO	(S)	lb/hr	(2,889)			
NO_2		lb/hr				
HCl		lb/hr				
H_2O		lb/hr	78,351	65,672	56,695	
Ash		lb/hr	47,549			9,596

Stream No.		5	6	7	8
Description		Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr		4,897,968	4,897,968	699,498	5,597,466
Flow rate, sft^3/min @ 60°F		1,045,965	1,045,965	154,534	1,200,499
Temperature, °F					
N_2	lb/hr	3,356,574	3,356,574	530,666	3,887,240
O_2	lb/hr	167,228	167,228	159,855	327,083
CO_2	lb/hr	1,022,834	1,022,834		1,022,834
SO_2	lb/hr	4,760	4,760		4,760
SO_3	lb/hr	184	184		184
NO	lb/hr	1,766	1,766		1,766
NO_2	lb/hr	142	142		142
HCl	lb/hr	504	504		504
H_2O	lb/hr	305,590	305,590	8,977	314,567
Ash		38,386	38,386		38,386

TABLE B-13. FLUE GAS COMPOSITION

FOR 0.7% SULFUR WESTERN BITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	73.10	138,800	3,887,000
O_2	5.38	10,220	327,100
CO_2	12.24	23,240	1,023,000
SO_2	0.04 (390 ppm)	74	4,760
SO_3	0.00 (10 ppm)	2	184
NO	0.03 (311 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (74 ppm)	14	504
H_2O	9.20	17,460	314,600
	100.00	189,800	5,559,000
Fly ash[a]			38,390
Total			5,597,000

Sft^3/min (60°F) = 1,200,000
Aft^3/min (300°F) = 1,755,000

Fly Ash Loading

	Gr/sft^3
Wet	3.73
Dry	4.11

Sulfuric acid dewpoint temperature: 278°F

a. See Table B-2 for fly ash composition.

TABLE B-14. BOILER MATERIAL BALANCE FOR

0.7% SULFUR WESTERN SUBBITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr	640,244	5,765,154	4,977,111	8,159
Flow rate, sft^3/min @ 60°F		1,273,643	1,099,548	
Temperature, °F		80		
N_2 (C) lb/hr	(313,720)	4,373,663	3,775,824	
O_2 (H) lb/hr	(22,409)	1,317,506	1,137,415	
CO_2 (O) lb/hr	(68,506)			
SO_2 (N) lb/hr	(4,482)			
SO_3 (Cl) lb/hr	(128)			
NO (S) lb/hr	(3,073)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	187,591	73,985	63,872	
Ash lb/hr	40,335			8,159

Stream No.	5	6	7	8
Description	Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr	5,609,196	5,609,196	788,043	6,397,239
Flow rate, sft^3/min @ 60°F	1,215,098	1,215,098	174,095	1,389,193
Temperature, °F				
N_2 lb/hr	3,779,506	3,779,506	597,839	4,377,345
O_2 lb/hr	188,611	188,611	180,091	368,702
CO_2 lb/hr	1,149,608	1,149,608		1,149,608
SO_2 lb/hr	5,063	5,063		5,063
SO_3 lb/hr	196	196		196
NO lb/hr	1,627	1,627		1,627
NO_2 lb/hr	131	131		131
HCl lb/hr	132	132		132
H_2O lb/hr	451,685	451,685	10,113	461,798
Ash lb/hr	32,637	32,637		32,637

TABLE B-15. FLUE GAS COMPOSITION

FOR 0.7% SULFUR WESTERN SUBBITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	71.13	156,300	4,377,000
O_2	5.25	11,520	368,700
CO_2	11.89	26,120	1,150,000
SO_2	0.04 (360 ppm)	79	5,063
SO_3	0.00 (9 ppm)	2	196
NO	0.02 (246 ppm)	54	1,627
NO_2	0.00 (14 ppm)	3	131
HCl	0.00 (18 ppm)	4	132
H_2O	11.67	25,630	461,800
	100.00	219,700	6,365,000
Fly ash[a]			32,640
Total			6,397,000

Sft^3/min (60°F) = 1,389,000
Aft^3/min (300°F) = 2,030,000

Fly Ash Loading

	Gr/sft^3
Wet	2.74
Dry	3.10

Sulfuric acid dewpoint temperature: 280°F

a. See Table B-2 for fly ash composition.

TABLE B-16. BOILER MATERIAL BALANCE FOR

0.9% SULFUR NORTH DAKOTA LIGNITE

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr	833,333	5,938,178	5,126,485	12,176
Flow rate, sft^3/min @ 60°F		1,311,867	1,132,547	
Temperature, °F		80		
N_2 (C) lb/hr	(334,167)	4,504,926	3,889,145	
O_2 (H) lb/hr	(23,333)	1,357,047	1,171,551	
CO_2 (O) lb/hr	(103,333)			
SO_2 (N) lb/hr	(5,000)			
SO_3 (Cl) lb/hr	(83)			
NO (S) lb/hr	(4,750)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	302,500	76,205	65,789	
Ash	60,167			12,176

Stream No.	5	6	7	8
Description	Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr	5,947,642	5,947,642	811,693	6,759,335
Flow rate, sft^3/min @ 60°F	1,296,872	1,296,872	179,320	1,476,192
Temperature, °F	800			
N_2 lb/hr	3,893,140	3,893,140	615,780	4,508,920
O_2 lb/hr	194,053	194,053	185,496	379,549
CO_2 lb/hr	1,224,537	1,224,537		1,224,537
SO_2 lb/hr	7,825	7,825		7,825
SO_3 lb/hr	302	302		302
NO lb/hr	2,045	2,045		2,045
NO_2 lb/hr	165	165		165
HCl lb/hr	86	86		86
H_2O lb/hr	576,786	576,786	10,417	587,203
Ash lb/hr	48,703	48,703		48,703

TABLE B-17. FLUE GAS COMPOSITION

FOR 0.9% SULFUR NORTH DAKOTA LIGNITE

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	68.95	161,000	4,509,000
O_2	5.08	11,860	379,500
CO_2	11.92	27,820	1,225,000
SO_2	0.05 (524 ppm)	122	7,825
SO_3	0.00 (17 ppm)	4	302
NO	0.03 (291 ppm)	68	2,045
NO_2	0.00 (17 ppm)	4	165
HCl	0.00 (9 ppm)	2	86
H_2O	13.97	32,600	587,200
	100.00	233,400	6,711,000
Fly ash[a]			48,700
Total			6,759,000

Sft3/min (60°F) = 1,476,000
Aft3/min (300°F) = 2,158,000

Fly Ash Loading

	Gr/sft3
Wet	3.85
Dry	4.47

Sulfuric acid dewpoint temperature: 295°F

a. See Table B-2 for fly ash composition.

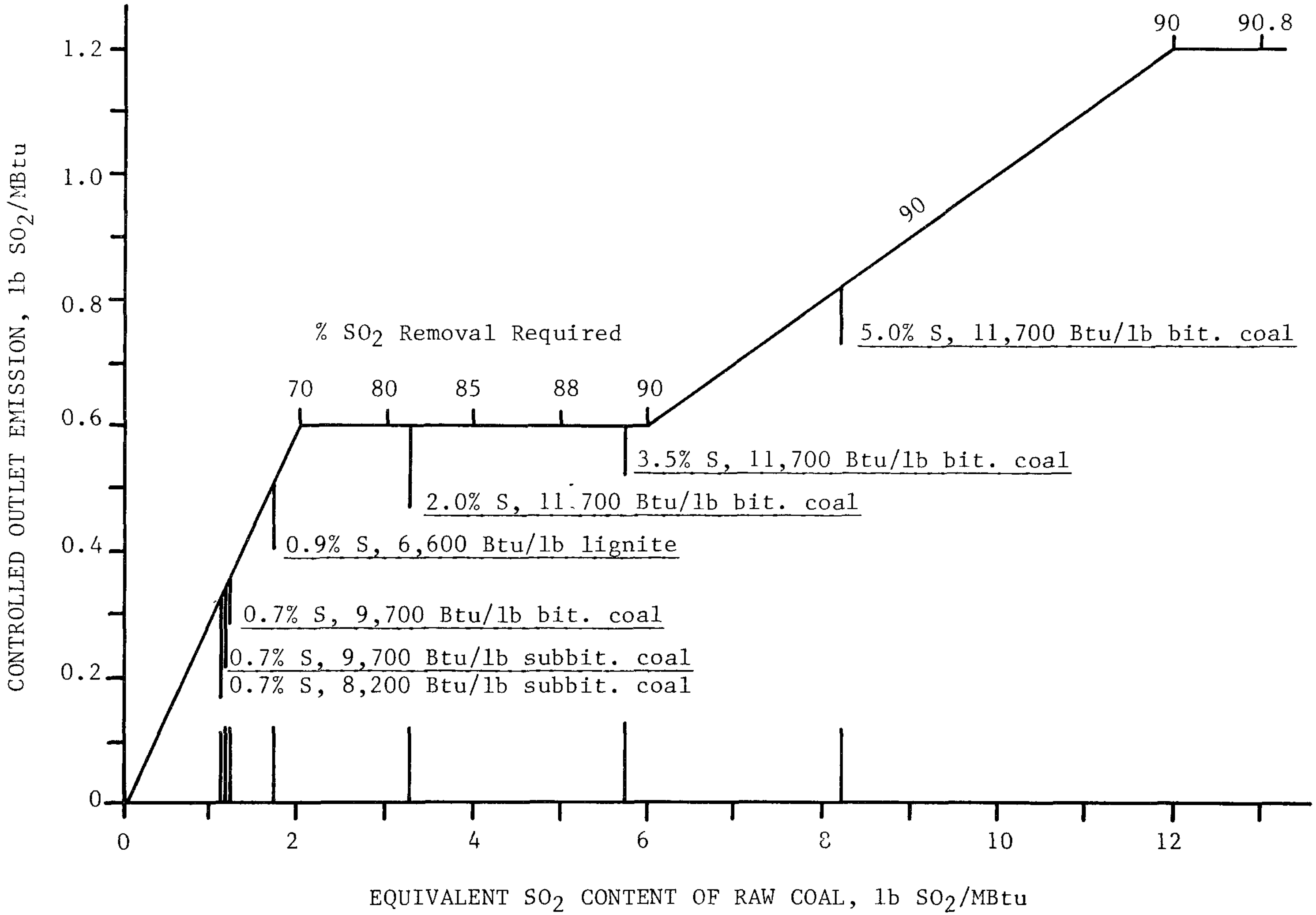


Figure B-3. Controlled SO_2 emission requirements for 1979 NSPS. Premise coals, shown underlined, are based on premise boiler conditions.

$6.0 < E < 12.0$

90% equivalent SO_2 removal required

$E > 12.0$

% equivalent SO_2 removal required = ((E - 1.2)/E)(100)

Equation to determine equivalent SO_2 removal required

% equivalent SO_2 removal required = ((A - B)/(1.0 - B))(100)

where: A = overall removal efficiency, decimal fraction
B = decimal fraction of S removed with ash: (1.0 - decimal fraction of sulfur emitted as SO_x)

TABLE B-18. 1979 NSPS EMISSION STANDARDS

SO_2
70% SO_2 removal (minimum) to a maximum SO_2 emission of 0.6 lb SO_2/MBtu
0.6 lb SO_2/MBtu maximum emission up to 90% SO_2 removal
90% SO_2 removal (minimum) to a maximum SO_2 emission of 1.2 lb SO_2/MBtu
1.2 lb SO_2/MBtu maximum emission
NO_x
Bituminous coal - 0.6 equivalent lb NO_2/MBtu
Subbituminous coal - 0.5 equivalent lb NO_2/MBtu
Lignite - 0.6 equivalent lb NO_2/MBtu
Particulate
0.03 lb/MBtu

Reference 26

EMISSION CONTROL PROCESS DESIGN

With the exception of some standard designs and frequently used reference processes--most notably the limestone FGD process--detailed design features that will be applicable to all evaluations cannot be specified. The diversities of processes and evaluation objectives and continuing technological advances make such an approach impractical. Most designs must be based on a thorough assessment of the objectives of the study, its relationship to past and possible future studies, and on aspects that enhance the scope and detail of the evaluation.

TABLE B-19. PREMISE COAL EMISSION STANDARDS FOR 1979 NSPS

Coal	Equivalent SO_2 content of coal, lb SO_2/MBtu	Overall equivalent SO_2 removal efficiency, %	Equivalent SO_2 removal required in FGD system, %[a]	Controlled outlet emission, lb SO_2/MBtu
Eastern bit., 5.0% S	8.21	90.0	89.5	0.82
Eastern bit., 3.5% S	5.74	89.6	89.1	0.60
Eastern bit., 2.0% S	3.28	81.7	80.7	0.60
Eastern bit., 0.7% S	1.15	70.0	68.4	0.34
Western bit., 0.7% S	1.22	70.0	64.7	0.36
Western subbit., 0.7% S	1.17	70.0	64.7	0.35
N.D. lignite, 0.9% S	1.73	70.0	64.7	0.52

a. Based on FGD system as the only SO_2 control device and the previously defined sulfur retention in the ash.

The standardized design features and procedures outlined in the following sections are followed to the maximum extent compatible with the objectives of the evaluation since this facilitates more detailed evaluations of significant design and operating features and more meaningful identification of cost elements. In all cases, the design and costing procedures are based on division of costs into definable functional areas so that the role of particular functions in determining costs can be identified.

Generic designs based on current practices and technology are usually preferable for evaluating technologies in which several vendors offer proprietary processes (limestone FGD, spray dryer FGD, and fabric filter baghouses are examples of the early 1980s). This approach allows a general assessment of the technology and of design trends and practices, less effected by the specific concepts and preferences of individual vendors.

Evaluations of proprietary designs depend on the nature and objectives of the evaluation. Standard design features are used as much as is consistent with the objectives of the evaluation. The vendor's specifications and suggestions are used for all features that represent and define the process while preferences that have no effect on the function of the process are--to different degrees, depending on the nature of the features and the objectives of the evaluation--avoided if they reduce the comparability of the process economics.

Particulate Matter

Fly ash and bottom ash collection, handling, and disposal or utilization are included in the evaluation of other emission control processes when the inclusion is pertinent to the evaluation or is expected to be in related future evaluations. (However, these costs are not included in the FGD costs from the Shawnee FGD computer model.) The standard bottom ash system consists of conventional vee-bottom water-filled hoppers with clinker grinders, a hydraulic conveying system with a combined ejector pump and centrifugal pump system, and a dewatering system one-fourth mile from the boiler.

Normal fly ash control consists of rigid-frame cold-side (after the air heater) electrostatic precipitators (ESPs) for coals with 2% or more sulfur and rigid-frame hot-side ESPs for coals with less than 2% sulfur. Fabric filter baghouses may be used in place of ESPs, particularly hot-side ESPs in low-sulfur coal cases, if this favors the evaluation. Baghouses are used with spray dryer FGD for particulate collection. Normally, economizer and air heater (and reactor for NO_x control, if used) and ash hoppers are included in fly ash costs.

Vacuum conveying systems are used for conveying distances less than 300 feet. Vacuum-pressure systems are used when longer conveying distances are necessary. In this case, the vacuum system is used to convey the solids from the collection hoppers to one or more collection points, from which they are conveyed to storage silos in the pressure system. Normally, the vacuum-pressure system is used when more than 24 collection hoppers are involved. The design of the waste conveying system is based on standard industry practices.

The bottom ash dewatering bins, fly ash silos, and spray dryer waste silos are sized for a 64-hour capacity to allow a 5-day, 2-shift disposal operation. The bins and silos are elevated for direct discharge to trucks. Silos for eastern coal fly ash are provided with moisturizer-mixers to add water to the ash as it is discharged.

Flue Gas Desulfurization

The FGD system consists of two or more trains of absorbers supplied by a common inlet plenum into which the flue gas from the power unit duct system discharges. The plenum allows optimization of the FGD system design by making it independent of the power plant duct configuration. The plenum and all equipment between it and the stack plenum are included in the FGD costs. This is based on the premise that in the absence of the FGD system, the flue gas discharged to the inlet plenum would be discharged directly to the stack plenum.

Unless process requirements dictate otherwise, the absorber trains have a maximum size of 125 MW or 513,000 sft^3/min (60°F), whichever is larger. All systems with capacities of 200 MW or more, or processing 340,000 aft^3/min of flue gas, have two or more absorber trains. Each train is assumed to have an annual availability of 85%. Spare trains are included to provide an excess capacity of at least 25%. (This allows the use of an emergency bypass, as discussed below.) All trains, including the spares, are identical although this results in a spare capacity over 25% in some cases: a 200-MW system would have three 100-MW trains, for example. The 500-MW systems with full scrubbing have four operating trains and one spare train and the 1,000-MW systems have eight operating and two spare trains.

All wet-scrubbing systems that do not include prescrubbers such as venturis are equipped with presaturators to cool the flue gas to the saturation temperature (approximately 127°F). Usually these are modified sections of inlet duct equipped with spray headers to spray the flue gas with absorbent liquid. The absorbers are also equipped with mist eliminators and reheaters as required to produce a stack temperature of 175°F. Booster fans are provided to compensate for the pressure drop in the system. Normally, these are induced draft (ID) fans in each train downstream from the reheater.

Emergency Bypass--

Because the 1979 NSPS allow emergency bypass around the FGD system under some conditions if spare scrubbing capacity is provided, spare scrubbing trains and bypass of 50% of the gas that would normally be scrubbed are included. An emergency bypass of 50% of the scrubbed gas is assumed to be an economic balance between the higher cost of providing additional bypass and the small likelihood of multiple scrubbing train failures, which would make higher bypass rates necessary. The bypass is installed as two identical ducts from each end of the inlet plenum to the stack plenum downstream from the scrubbing trains. Particulate collection equipment is not bypassed.

Partial Scrubbing--

In some cases, depending on the sulfur content of the coal and SO_2 removal requirements, scrubbing a portion of the flue gas at a high removal efficiency and combining it with the remaining flue gas may be more economical than scrubbing all of the flue gas at a lower removal efficiency. In such cases, the bypassed gas duct requirements and the emergency bypass capability are combined in the same duct. The ducts are sized to handle both the flue gas normally bypassed and emergency bypass of 50% of the flue gas scrubbed. Depending on sulfur content of the coal, for the 500-MW power unit, partial scrubbing could involve scrubbing as little as 375 MW of flue gas. Three operating scrubbing trains and one spare scrubbing train are provided for this case.

Ductwork--

Square ductwork with 2-inch insulation (in standard cases) is used for the inlet plenum and absorber trains. To prevent ash settling, a gas velocity of 50 ft/sec is used for the inlet plenum, all ductwork, and the emergency bypass. A gas velocity of 25 ft/sec is used for the reheater section. Duct material is usually 3/16-inch Cor-Ten steel when the gas temperature is higher than 150°F and 3/16-inch stainless steel when the gas temperature is lower than 150°F.

Removal Efficiencies--

It is assumed that 50% of the SO_3, 95% of the HCl, none of the NO_x, and 50% of the remaining fly ash in the flue gas are removed in the FGD system. For systems requiring a presaturator or humidifier, it is assumed that 5% of the SO_2 is removed in the presaturator and that the remaining SO_2 removal takes place in the FGD absorber.

Mist Eliminator--

The mist eliminator is a fiberglass-chevron-baffle type. The mist eliminator reduces entrained moisture to a maximum level of 0.1% (by weight) of the flue gas. This maximum level is used for calculation of the amount of flue gas reheat required.

Flue Gas Reheat--

A reheater consisting of a steam-heated tube bank is provided in each train to provide a stack temperature of 175°F. This is considered necessary to evaporate corrosive liquid not removed by the mist eliminator and to provide adequate plume buoyancy. The size of the reheater is determined by the temperature of the scrubbed flue gas (which is assumed to be 125°F for wet-scrubbing systems), the quantity of flue gas bypassed, and the heat of compression through the ID booster fans--which is assumed to be equivalent to an adiabatic compression equal to the pressure drop in the FGD system. Necessary information for calculation of the steam requirements and reheater surface area is shown in Table B-20 and a sample calculation is shown in Table B-21.

For full-scrubbing processes, the reheater tubes are Inconel 625 for corrosion resistance below 150°F and the remainder are Cor-Ten steel. In cases in which the scrubbed flue gas is not heated to 175°F (as in the case of partial bypass), the quantity of Inconel tubes remains the same and the quantity of Cor-Ten tubes is reduced.

Piping--

Carbon steel piping is used for water and other noncorrosive and non-abrasive liquids. Stainless steel is used for slurry and other corrosive or abrasive liquid lines 3 inches in diameter or less; neoprene-lined carbon steel is used for larger lines carrying these liquids. For slurry lines, plug valves are used for lines up to 3 inches in diameter; eccentric plug valves are used for 3- to 20-inch lines; and knife gate valves are used for lines larger than 20 inches in diameter. Pneumatic actuators are provided for valves 12 inches in diameter or larger.

Buildings--

Metal buildings are provided when it is necessary to provide weather protection. The buildings have 6-inch concrete floors, insulation, electrical heating, overhead doors, and other features required for their function. Normally, buildings are provided for feed preparation, waste dewatering,

TABLE B-21. SAMPLE REHEATER CALCULATIONS

Gas to Reheater

	lb/hr
CO_2	1,008,000
HCl	21
SO_2	2,850
O_2	319,800
N_2	3,852,000
H_2O (vapor)	444,873
Total gas	5,627,544
H_2O (liquid entrainment)	5,627
Total	5,633,171

Reheater Heat Duty

	lb/hr	x	Cpm(Btu/lb)[b]	=	Btu/hr
CO_2	1,008,000	x	10.8		10,886,400
HCl	21	x	9.5		200
SO_2	2,850	x	7.9		22,515
O_2	319,800	x	11.2		3,581,760
N_2	3,852,000	x	12.5		48,150,000
H_2O (vapor)	444,873	x	22.6		10,054,130
Total					72,695,005
H_2O (liquid entrainment)	5,627	x	1,043.2[b]		5,870,090
Total					78,565,095 Btu/hr

Steam Requirement

78,565,095 Btu/hr ÷ 751.9 Btu/lb = 104,489 lb/hr

Reheater Area

78,565,095 Btu/hr ÷ 4 operating reheaters ÷ 20.8 Btu/ft^2-hr-^oF ÷ 319^oF[a,b] = 2,960 ft^2

a. Log mean temperature difference (ΔT_L) = $(T_1 - T_2)/(\ln(T_1/T_2))$

T_1 = Tsteam - Tgas in = 470 - 125 = 345
T_2 = Tsteam - Tgas out = 470 - 175 = 295
$\Delta T_L = (345 - 295)/(\ln(345/295))$

b. For a temperature change from 125^oF to 175^oF only.

storage, offices, laboratories, and for spray dryer FGD reactors (for temperature control).

TABLE B-20. REHEATER DATA

Compound	C_{pm} (Btu/lb)[a]
CO_2	10.8
HCl	9.5
SO_2	7.9
SO_3	8.2
O_2	11.2
N_2	12.5
NO	12.0
NO_2	10.2
H_2O (vapor)	22.6

Steam:
saturated at 470°F (500 psig), heat of vaporization 751.9 Btu/lb

Reheater overall heat transfer coefficient:
20.8 Btu/ft^2-hr-°F

Entrained water enthalpy:
liquid at T = 125°F: 92.9 Btu/lb
vapor at T = 175°F: 1136.1 Btu/lb
ΔH^a = 1043.2 Btu/lb

a. For temperatures between 125°F and 175°F only.

Spare Equipment--

Spare equipment is provided in accordance with general practice. For most processes, the following spares are provided:

- A spare train of crushing and grinding equipment
- Slakers
- Waste filters
- Pumps
- A spare scrubbing train or trains

NO_x Control

Reduction of NO_x emissions to meet the 1979 NSPS is assumed to be met by modifications to the boiler combustion system. Evaluations of NO_x control processes are normally based on an 80% reduction of these emissions.

With the exception of selective catalytic reduction (SCR) processes, NO_x control processes are usually based on proprietary designs. These vary considerably, from various forms of combustion modification and furnace injection to--conceivably--wet scrubbing. The designs in these cases are dealt with on an individual basis, usually following the vendor's specification. For processes that control both NO_x and SO_2, the comparative processes are the standard limestone FGD process and a generic SCR process.

A generic SCR process design is based on the designs of U.S. vendors of the process. For the base case conditions, parallel vertical reactors up to 250 MW in size (two reactors for the 500-MW base case) are used. Flue gas is ducted from the outlet of the boiler economizer to the reactors and from the reactors to the boiler air heater. The air heater is modified to accommodate the buildup of ammonia salts and the incremental costs are included in the NO_x control costs. An economizer bypass to maintain the flue gas temperature during low-load operation and an emergency bypass for the reactors are also included. No spare reactor trains are provided. The assumed catalyst life is equivalent to the catalyst life generated by process vendors and the catalyst volume is based on maintenance of the design NO_x reduction over the catalyst life. Boiler operation is assumed to be unaffected by the process (catalyst changes and other maintenance occur during boiler outages).

WASTE PROCESSING AND DISPOSAL

For processes producing a waste, either landfill or pond disposal is provided. Normally, an onsite disposal facility one mile from the process facility is used. The size of the disposal facility is based on the lifetime volume of waste. Both the landfill and pond designs and costs are determined using the landfill and pond models in the Shawnee computer model.

Normally, landfill disposal is used for ash and insoluble FGD waste. Ponds are used for wastes such as coal-cleaning fines that are not normally dewatered. Ponds, which serve as solid impoundments, are also used for soluble wastes such as sodium-based FGD waste.

Waste storage facilities are normally based on truck transport and landfill disposal on a 2-shift, 5-day-week schedule. A 64-hour silo and stockpile storage capacity is provided to allow the landfill operating schedule. For pond disposal--which may be used in special studies or for waste that is normally ponded--an 8-hour storage tank is provided. The waste is pumped directly to the pond and the supernate is returned for reuse.

Waste Properties

The densities upon which equipment sizes and storage volumes are based are shown in Table B-22. Settled and compacted moisture contents and bulk densities are also shown for use in disposal site designs, which are discussed below. These are used in conceptual design evaluations in which uniform representative values are more useful than specific values or in which specific data are unavailable. The values in Table B-22 are based on published data and are representative of the rather large range over which the moisture contents and bulk densities of most wastes vary, depending on the conditions under which they were produced. In evaluations based on specific wastes, measured values or more specific estimates should be used.

TABLE B-22. WASTE BULK DENSITIES

	Model defaults bulk density, lb/ft^3	
	In-process waste	Compacted
Waste Sludge		
Sulfite (filtered)	70	85
Gypsum (filtered)	75	95
Fixed sulfite (filtered)	90	106
Fixed sulfate (filtered)	85	100
Dry FGD waste	70	85

FGD Waste Processing and Handling

High-sulfite slurry (70% $CaSO_3 \cdot 1/2H_2O$ and 30% $CaSO_4 \cdot 2H_2O$) is normally dewatered and mixed with dry fly ash and lime (100% fly ash and 3.5% lime, both based on the dry weight of FGD solids) for landfill disposal. The slurry from the absorbers is first dewatered to 30% solids in a thickener, then filtered to 55% solids in rotary vacuum filters. The filter cake is mixed with the fly ash and lime in a pug mill and conveyed to a radial-arm stacker that stacks it in a 64-hour capacity stockpile for removal to a landfill.

Gypsum waste (95% $CaSO_4 \cdot H_2O$ or more) is thickened to 30% solids and filtered to 85% solids in rotary vacuum filters. The filter cake is stacked in a 64-hour capacity stockpile by a radial-arm stacker from which it is removed to a landfill.

Waste Transportation

Trucks are used for transportation of solid wastes. Bottom ash and fly ash are discharged directly from the elevated dewatering bins and silos into the trucks. A moisturizer-mixer mounted on the storage silo is used to add water to fly ash from eastern bituminous coal (the quantity of water is based on the optimum compaction moisture) to control dusting. Other fly ash and spray dryer FGD waste, which is likely to have cementitious properties, is moisturized with similar truck-mounted moisturizers at the disposal site.

Wastes in slurry form are sluiced to the disposal site and the supernate is returned for reuse. If the slurry is abrasive (ash and coal-cleaning waste), an abrasion-resistant ash-sluicing pipe is used. Equipment for control of the return water pH and scaling potential is included in all wet sluicing systems.

Disposal Site

Both the pond and landfill design and costs are determined using the Shawnee flue gas desulfurization computer model, which allows numerous design variations. The standard conditions are described below. The disposal site is normally situated one mile from the process facility. Sufficient land is provided for disposal during the remaining life of the facility. The disposal site is assumed to be an area of low relief with sufficient soil for dike construction or landfill requirements.

Pond--

Disposal ponds are square, earthen-diked enclosures with a medium diverter dike. Dikes are constructed from material removed from the impoundment area as shown in Figure B-4. The entire impoundment area is lined with 12 inches of clay (assumed available onsite). Pond size and depth are normally adjusted to minimize the sum of land and construction costs. Pond costs include a 6-foot security fence around the perimeter dike, security lighting, a topsoil storage area, and one upstream and three downstream groundwater monitoring wells.

Landfill--

The landfill, one mile from the fixation area, has a square configuration with a 20-foot rise and a 6-degree cap, as shown in Figure B-5. After topsoil removal, the landfill area is lined with 12 inches of clay (assumed available onsite) with a drain system to a sump and 24 inches of bottom ash is placed on the liner. Surface runoff drains into a catchment ditch around the perimeter. The ditch drains into a catchment basin for pH adjustment. Land requirements include the landfill, the catchment basin, an office, equipment storage area, topsoil storage area, and a 50-foot perimeter of undisturbed land. Costs for access roads; a 6-foot security fence around the total landfill area; security lighting; and topsoil stripping, replacement, and revegetation are included. One upstream and three downstream groundwater monitoring wells are also included.

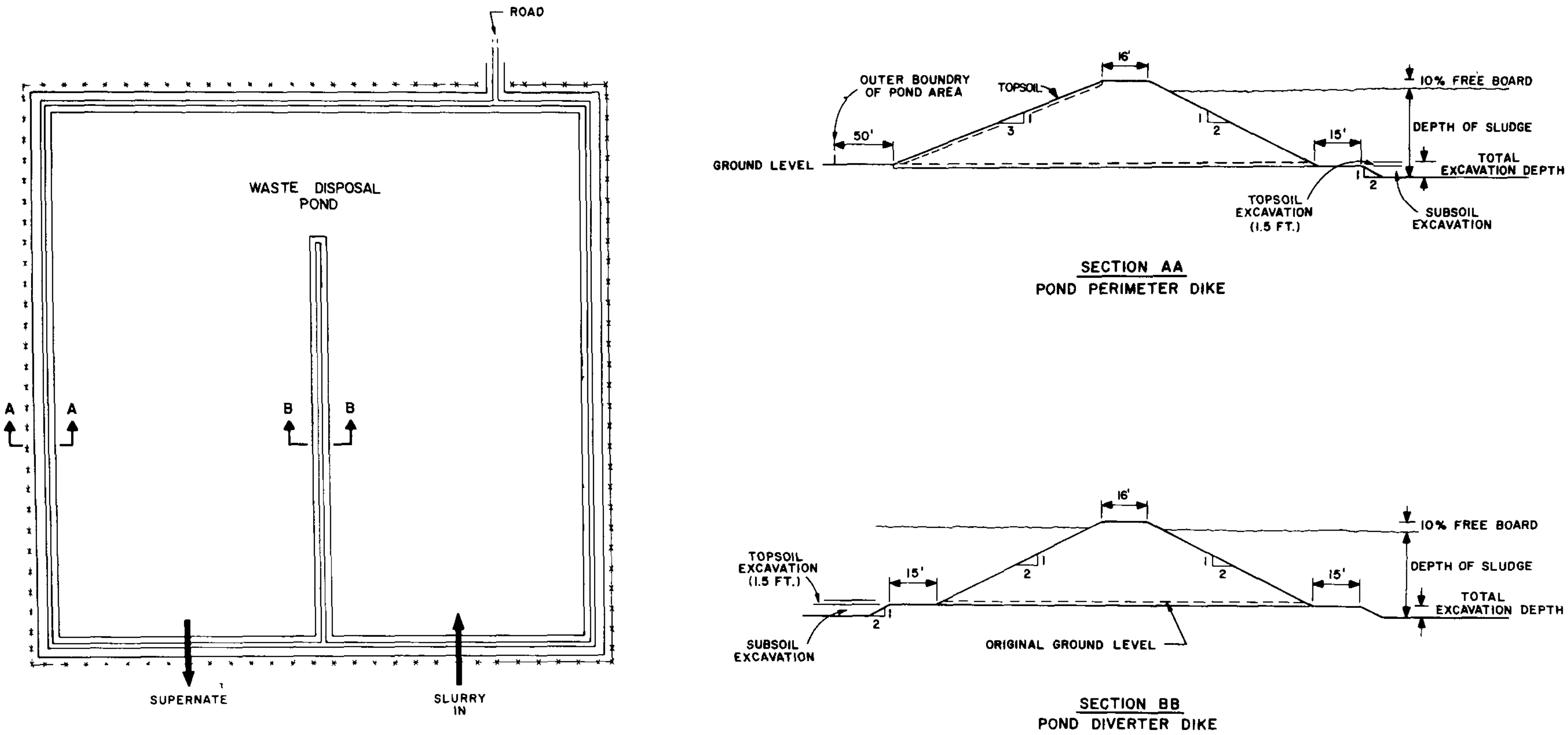


Figure B-4. Pond design.

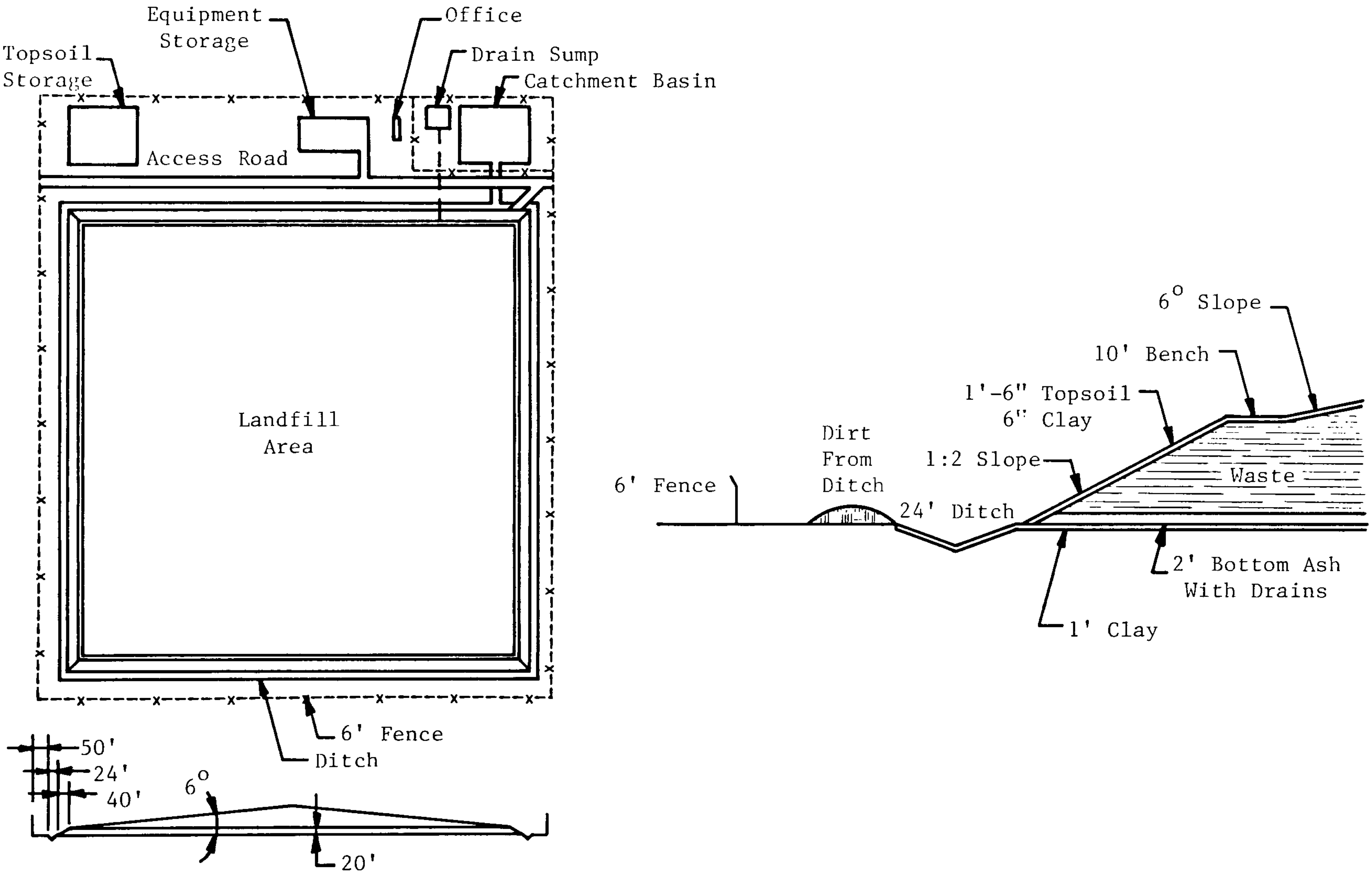


Figure B-5. Landfill design.

ECONOMIC PREMISES

Schedule and Cost Factors

The construction schedule used as a cost basis is shown in Figure B-6. A 3-year construction period, from early 1984 to late 1986, is used. Mid-1985 costs are used for capital investment. Mid-1987 costs are used for annual revenue requirements. These costs represent the midpoint of construction expenditures and the midpoint of the first year of operation. Costs are projected from Chemical Engineering cost indexes (27), as shown in Table B-23. Frequently used costs are shown in Table B-24.

Capital Cost Estimates

Four grades of capital cost estimates are prepared depending upon the intended use and the amount of information available. The grades, in increasing order of accuracy, are (1) order of magnitude, (2) study, (3) preliminary, and (4) definitive. The two grades normally used are the study and preliminary grades. The purpose, information required, and predicted accuracy are listed in Table B-25.

A typical capital investment sheet is shown in Table B-26. The capital investment sheet is divided into three major sections: direct investment, indirect investment, and other capital investment.

Direct Investment--

Direct investment consists of total process capital; services, utilities, and miscellaneous; and waste disposal investment. Total process capital is determined from the equipment list. Using standard estimating techniques (28,29,30) and the Chemical Engineering cost indexes and projections shown in Table B-23, the equipment cost and installation costs of each area are estimated. The installation costs include charges for all piping, foundations, excavations, structural steel, electrical equipment, instruments, ductwork (all ductwork is included in the gas-handling area), paint, buildings, taxes, freight, and a premium for 7% overtime construction labor as shown in Figure B-7. The total process area costs are summed on the area summary sheet shown in Figure B-8 to give the total process capital.

Service facilities such as maintenance shops, stores, communications, security, offices, and road and railroad facilities are estimated or allocated on the basis of process requirements. Included in the utilities investment are necessary electrical substations, conduit, steam, process water, fire and service water, instrument air, chilled water, inert gas, and compressed air distribution facilities. Services, utilities, and miscellaneous are in the range of 4% to 8% of the total process capital. For most cases, 6% is to be used, higher for processes and lower for waste disposal facilities. The base case limestone-scrubbing process is charged 6% for services, utilities, and miscellaneous.

All equipment and direct construction costs associated with waste disposal are included in waste disposal costs. For ponds, this includes pond

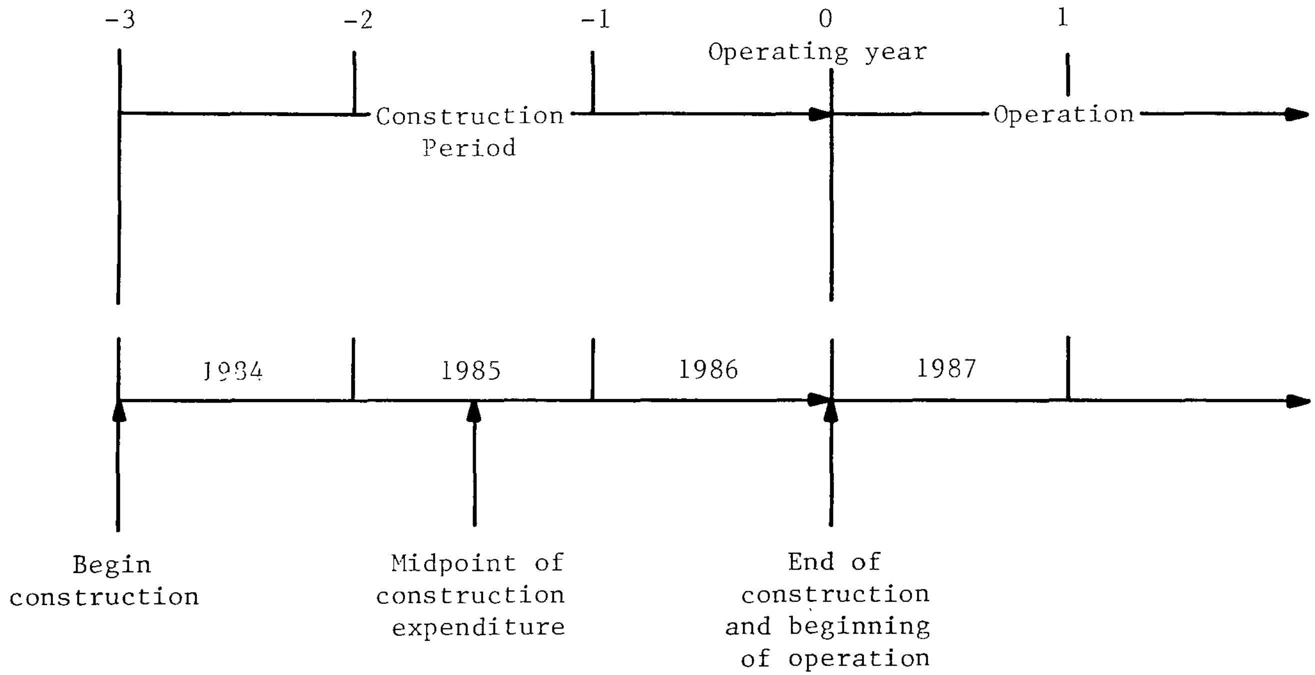


Figure B-6. Construction schedule.

TABLE B-23. COST INDEXES AND PROJECTIONS

Year:	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984[a]	1985[a]	1986[a]	1987[a]	1988[a]
Plant	137.2	144.1	165.4	182.4	192.1	204.1	218.8	238.7	261.1	297.0	314.0	316.9	326.4	346.0	366.8	388.8	412.1
Material[b]	135.4	141.9	171.2	194.7	205.8	220.9	240.6	264.4	292.6	323.0	336.2	336.0	346.1	366.8	388.9	412.2	436.9
Labor[c]	152.2	157.9	163.3	168.6	174.2	178.2	185.9	194.9	204.3	242.4	263.9	267.6	275.6	292.2	309.7	328.3	348.0

a. TVA projections.
b. Same as "equipment, machinery, supports," Chemical Engineering index.
c. Same as "construction labor," Chemical Engineering index.

TABLE B-24. COST FACTORS

1987 Utility Costs	
Electricity	\$0.055/kWh
Steam	\$4.00/klb; \$5.30/MBtu
Eastern bit. coal (<1% S)	\$63.00/ton; \$2.30/MBtu
Eastern bit. coal (2% S)	\$53.00/ton; \$2.03/MBtu
Eastern bit. coal (3% S)	\$43.00/ton; \$1.81/MBtu
Eastern bit. coal (4% S)	\$38.00/ton; \$1.71/MBtu
Western bit. coal (0.7% S)	\$65.00/ton; \$3.40/MBtu
Western subbit. coal (0.7% S)	\$35.00/ton; \$2.10/MBtu
N.D. lignite (0.9% S)	\$18.00/ton; \$1.35/MBtu
Fuel oil No. 6	\$10.50/MBtu
Diesel fuel	\$1.60/gal
Natural gas	\$6.00/MBtu
Filtered river water	\$0.16/kgal (up to 0.6 Ggal)
	\$0.14/kgal (0.6-2 Ggal)
	\$0.12/kgal (2-5 Ggal)
	\$0.10/kgal (over 5 Ggal)
1987 Labor Costs	
FGD	\$19.00/man-hr
Waste disposal	\$24.00/man-hr
Analysis	\$26.00/man-hr
1987 Raw Material Costs	
Limestone	\$15.00/ton (95% $CaCO_3$, dry basis)
Lime	\$90.00/ton (pebble, 95% CaO, dry basis)
Ammonia	\$230.00/ton
Soda ash	\$190.00/ton (99.8% Na_2CO_3)
Adipic acid	\$1,500.00/ton
MgO	\$510.00/ton
1985 Land Cost	
	\$6,000.00/acre

These cost factors are based on a north-central plant location.

TABLE B-25. CAPITAL COST ESTIMATE CLASSIFICATION

Grade	Purpose	Minimum information required	Predicted accuracy, +%	Predicted accuracy, -%
Order of magnitude (ratio estimate)	Preliminary feasibility study to determine whether continued investigation is merited. Rough comparison of alternatives.	General design basis,[a] flowsheet and material balance, heat and energy balance. For the order-of-magnitude estimates, this information is of a tentative nature, developed from a preliminary process concept.	>50	>50
Study (factored estimate)	Comparison of alternatives. Preliminary screening. Preliminary budget preparation. Authorization for funding for an engineering study or for development of additional information.	All of the above on a firm, rather tentative basis plus overall layout of manufacturing and nonmanufacturing facilities, sized equipment and instrument lists, and performance data sheets.	40	20
Preliminary (initial budget or scope estimate)	Preliminary budget approval. More accurate comparison of alternatives. Follow up of an order-of-magnitude or study estimate.	All of the study estimate requirements plus process control diagrams, process piping sketches with sizes, plan and elevation drawings, offsite descriptions, including sizes and capacities.	30	15
Definitive (project control estimate)	Final capital authorization. Project cost control. Follow up on order-of-magnitude, study, or preliminary estimates for more accurate information. Generally reserved for a real construction project with a known site.	All of the preliminary estimate requirements plus piping plan and elevation drawings integrated with the equipment plan and elevation drawings, electrical layout single line drawings, detailed piping and instrumentation flowsheets, layout of nonmanufacturing facilities, design sketches for unusual equipment items, and specific site data, including utilities and transportation availability, soil bearing, wind and snow loads.	20	10

a. General design basis includes product, product specifications, plant capacity, storage requirements, operating stream time, provisions for expansion, and raw materials and their storage requirements.

TABLE B-26. CAPITAL INVESTMENT SHEET

TABLE LIMESTONE PROCESS CAPITAL INVESTMENT

(500-MW new coal-fired power unit; 3.5% S in coal; 89% SO_2 removal; onsite solids disposal)

Direct Investment	Investment, k$
Materials handling	
Feed preparation	
Gas handling	
SO_2 absorption	
Stack gas reheat	
Oxidation	
Solids separation	
Total process capital	
Services, utilities, and miscellaneous	
Total direct investment excluding landfill	
Solids disposal equipment	
Landfill construction	
Total direct investment	
Indirect Investment	
Engineering design and supervision	
Architect and engineering contractor	
Construction expense	
Contractor fees	
Contingency	
Disposal area indirects	
Total fixed investment	
Other Capital Investment	
Allowance for startup and modifications	
Interest during construction	
Royalties	
Land	
Working capital	
Total capital investment	
Dollars of total capital per kW of generating capacity	

Basis: North-central plant location represents project beginning early 1984, ending late 1986; average cost basis for scaling, mid-1985. One spare scrubber train, 50% emergency bypass, spare pumps. Landfill located one mile from power plant. FGD process costs begin with feed plenum. Stack plenum and stack excluded.

Area	% of process equipment	Material	Labor[a]	Total
Process equipment	X			
Piping & insulation				
Concrete foundations				
Excavations, site preparation, roads, etc.				
Structural				
Electrical				
Instrumentation				
Ducts, chutes, expansion joints, etc.				
Paint & miscellaneous				
Buildings				
Trucks & earthmoving equipment				
Subtotal				
Freight (3.5% of process material)			X	
Tax (4% of material subtotal)			X	
Total process area cost				

a. Includes premium for 7% overtime, i.e., labor is 0.93 (straight time labor) + (0.07)(1.5)(straight time labor) or 1.035 (straight time labor).

Figure B-7. Process area cost summary sheet.

Area	Description	Total process area cost, $	Total process capital, $
1	Materials handling		
2	Feed preparation		
3	Gas handling		
4	SO_2 absorption		
5	Stack gas reheat		
6	Oxidation		
7	Solids separation & disposal		

Figure B-8. Area summary sheet.

construction costs from the computer pond model. For landfills, mobile equipment and construction costs are included. All mobile equipment involved in loading and transporting the waste from the in-process storage area, as well as working the landfill, is included in solids disposal equipment. The landfill construction cost, as calculated from the landfill computer model, is listed separately from the solids disposal equipment. The sum of total process capital; services, utilities, and miscellaneous; and the waste disposal cost is the total direct investment.

Indirect Investment--

Indirect capital investment covers fees for engineering design and supervision, architect and engineering contractor, construction expense, contractor fees, and contingency. Listed in Table B-27 are the ranges to be used to calculate the process and waste disposal indirect investments. The base percentages are normally used. The low and high ranges are used if the process being studied is either much more complex than the typical system (the higher percentage factors are used) or much less complex (the lower percentage factors are used). The limestone- and lime-scrubbing processes use the low percentages for a 1,000-MW unit, base percentages for a 500-MW unit, and the high percentages for a 200-MW unit. Contingency is included to compensate for unforeseen expenses. The contingency varies depending on the process and the waste disposal method, as shown in Table B-28. The limestone- and lime-scrubbing processes are assessed a contingency of 10% for the process and 20% for the landfill.

Other Capital Investment--

The allowance for startup and modifications is applied as a percentage of the total fixed investment. Since the startup and modification costs for the waste disposal area are assumed to be negligible, this allowance is calculated as a percentage of the total process fixed investment only. The values used are shown in Table B-29. The limestone- and lime-scrubbing processes are assessed at a rate of 8% for this charge.

The cost of borrowed funds (interest) during construction is 15.6% of the total fixed investment (both process and waste disposal). This factor is based on an assumed 3-year construction schedule and is calculated with a 10% weighted cost of capital with 25% of the construction expenditures in the first year, 50% in the second year, and 25% in the third year of the project construction schedule. Expenditures in a given year are assumed uniform over that year. Startup costs are assumed to occur late enough in the project schedule that there are no charges for the use of money to pay startup costs. Table B-30 illustrates the calculation of the interest during construction for 3- through 6-year construction schedules.

Most processes will include a one-time royalty charge using either an actual royalty obtained from the vendor or 1% of the total process capital involved. Processes exempt from royalties due to their generic design are limestone and lime processes, including those with forced oxidation or adipic acid or both, and the magnesia process.

TABLE B-27. RANGE OF INDIRECT INVESTMENTS

Indirect Investment, Process

	% of total direct investment excluding waste disposal investment		
	Low	Base	High
Engineering design and supervision	6	7	8
Architect and engineering contractor	1	2	3
Construction expense	14	16	18
Contractor fees	4	5	6
Total	25	30	35

Waste Disposal Indirects FGD Pond, FGD Landfill, or Ash Pond

	% of total direct waste disposal investment[a]		
	Low	Base	High
Engineering design and supervision	2	2	2
Architect and engineering contractor	1	1	1
Construction expense	7	8	9
Contractor fees	4	5	6
Total	14	16	18

Ash Landfill

	% of total direct waste disposal investment[a]
	Base
Engineering design and supervision	6
Architect and engineering contractor	3
Construction expense	10
Contractor fees	6
Total	25

a. Pond (or landfill) construction only.

TABLE B-28. CONTINGENCY

Process Contingency	% of total direct investment excluding waste disposal plus process indirect investment
Limestone and lime slurry	10
Limestone and lime - forced oxidation	10
Limestone and lime - forced oxidation with adipic acid	10
All others	20

Waste Disposal Contingency	% of total waste disposal direct investment plus waste disposal indirect investment
FGD pond	10
Ash pond	10
FGD landfill	20
Ash landfill	10

TABLE B-29. ALLOWANCE FOR STARTUP AND MODIFICATIONS

Process	% of total fixed investment for process only
Limestone and lime (generic)	8
All other processes	10

Waste Disposal	% of total fixed investment for waste disposal only
Ponds and landfills	0

TABLE B-30. INTEREST DURING CONSTRUCTION ILLUSTRATION

Three-Year Construction Schedule

Years from startup	Compound amount factor[a]		Fraction of total plant investment		
3-2	1.2686	x	0.250	=	0.317
2-1	1.1533	x	0.500	=	0.577
1-0	1.0484	x	0.250	=	0.262

Total fixed investment plus interest during construction: 1.156

Interest during construction = 1.156 - 1.000 = 0.156 or 15.6%

Four-Year Construction Schedule

Years from startup	Compound amount factor[a]		Fraction of total plant investment		
4-3	1.3955	x	0.150	=	0.209
3-2	1.2686	x	0.300	=	0.381
2-1	1.1533	x	0.350	=	0.404
1-0	1.0484	x	0.200	=	0.210

Total fixed investment plus interest during construction: 1.204

Interest during construction = 1.204 - 1.000 = 0.204 or 20.4%

Five-Year Construction Schedule

Years from startup	Compound amount factor[a]		Fraction of total plant investment		
5-4	1.5349	x	0.10	=	0.154
4-3	1.3955	x	0.20	=	0.279
3-2	1.2686	x	0.30	=	0.381
2-1	1.1533	x	0.25	=	0.288
1-0	1.0484	x	0.15	=	0.157

Total fixed investment plus interest during construction: 1.259

Interest during construction = 1.259 - 1.000 = 0.259 or 25.9%

(Continued)

TABLE B-30. (Continued)

Six-Year Construction Schedule

Years from startup	Compound amount factor[a]		Fraction of total plant investment		
6-5	1.6886	x	0.10	=	0.169
5-4	1.5349	x	0.15	=	0.230
4-3	1.3955	x	0.25	=	0.349
3-2	1.2686	x	0.25	=	0.317
2-1	1.1533	x	0.15	=	0.173
1-0	1.0484	x	0.10	=	0.105

Total fixed investment plus interest during construction: 1.343

Interest during construction = 1.343 - 1.000 = 0.343 or 34.3%

a. Present worth and compound amount factor using the 10% cost of capital with continuous compounding (28).

Years from startup	Uniform expenditure present worth (28)	Compound amount factor (28)
7-6	0.5384	1.8574
6-5	0.5922	1.6886
5-4	0.6515	1.5349
4-3	0.7166	1.3955
3-2	0.7883	1.2686
2-1	0.8671	1.1533
1-0	0.9538	1.0484

Land--

All land associated with the process and waste disposal area is charged to the process. The cost of land is $6,000 per acre.

Working Capital--

Working capital is the total amount of money invested in raw materials, supplies, finished products, accounts receivable, and money on deposit for payment of operating expenses. For these premises, working capital is defined as the equivalent cost of 1 month's raw material cost, 1.5 months' conversion cost, 1.5 months' plant and administrative overhead costs (all of the above are found on the annual revenue requirements sheet), and 3% of the total direct capital investment (from the capital investment sheet). One month is defined as 1/12 of annual costs. The equation is shown below:

Working capital = 1/12 (total raw materials cost) +
(1.5) (1/12) (total conversion cost) +
(1.5) (1/12) (plant and administrative overhead) +
0.03 (total direct investment)

Battery Limits--

Since battery limits costs typically include most of the associated indirect investments, battery limits costs have their own indirect investment factors as shown below:

	% of battery limits cost
Engineering design and supervision	6
Architect and engineering contractor	1
Construction expense	14
Contractor fees	0
Contingency	10

Retrofit Factor--

For existing plant cases, a retrofit factor is assigned to cover the additional investment required. Each of the area investments (i.e., material handling, etc.) is multiplied by the retrofit factor. Retrofit factors vary widely depending on the process and the site involved (31). For emission control processes which are coupled to the boiler, the following retrofit factors are used:

Process	Retrofit factor	Reason
Limestone scrubbing	1.3	These scrubbing systems are add-on in that they require no boiler modifications. This factor for the retrofit cases is due to the need to fit the equipment into available space.
Spray dryer	1.5	These scrubbing systems require relatively minor modifications to the boiler and ductwork. This factor also includes the expense of fitting the equipment into the available space.
NO_x FGT (SCR)	1.7	These control systems require extensive modifications to the boiler economizers and air heaters and the associated ductwork. This factor also includes the expense of locating the equipment in the available space.

It is assumed that most FGD systems will be of the add-on type and, therefore, use the 1.3 retrofit factor.

Annual Revenue Requirements

Annual revenue requirements consist of various direct and indirect operating and maintenance costs and capital charges. Annual revenue requirements normally vary from year to year as operating and maintenance costs change and capital charges decline. Thus, no single year is necessarily representative of the lifetime costs, nor can single-year undistorted comparisons be made among processes with different ratios of operating costs to capital charges. In addition, it is necessary to take into account the effect of time on the value of money (for inflation, the future earning power of money spent, and other factors).

Frequently these factors are accounted for by levelizing (32). Levelization converts all the varying annual revenue requirements to a constant annual value, such that the sum of the present worths of the levelized annual revenue requirements equals the sum of the present worths of the actual annual revenue requirements. The levelized value is calculated by multiplying the revenue requirements for each year by the appropriate present worth factor and summing the present worth values. Then the single present worth value is converted to equal annual values by multiplying the result by the capital recovery factor.

In these premises, the operating and maintenance costs are levelized by multiplying the first-year operating and maintenance cost by a levelizing factor. The levelized capital charges are determined by levelizing the percentage of capital investment applied yearly as capital charges. The levelizing factor includes a discount factor reflecting the time value of money and an inflation factor reflecting the effects of inflation during the operating life of the system. The discount rate used is 10% and the inflation rate used is 6%. The levelizing factor produced varies with the remaining life of the system. Calculation of the levelizing factor for operating and maintenance costs and of levelized capital charges is discussed below.

A typical annual revenue requirement tabulation is shown in Table B-31. Direct costs consist of raw material and conversion costs. These, combined with overheads, are the operating and maintenance costs. For processes that produce a salable byproduct, byproduct sales are applied as a credit to the operating and maintenance costs. Levelized capital charges are calculated as a percentage of the capital investment and added to the operating and maintenance costs to provide the first-year annual revenue requirements. The levelized annual revenue requirements are determined by multiplying the operating and maintenance costs by the levelizing factor and adding the product to the same levelized capital charges used in the first-year annual revenue requirements.

Operating and Maintenance Costs--

Frequently used raw material costs and standard conversion costs are shown previously in Table B-24. Other costs are obtained from vendors or published information. These costs are converted to 1987 costs using the cost indexes in Table B-23 or industry projections.

Raw materials--Consumables required for their chemical or physical properties, other than fuel for the production of heat, are classified as raw materials. Raw material costs are determined as necessary from vendor quotations or published sources and escalated to 1987 costs. All costs are delivered costs.

Operating labor and supervision--Unit labor costs for 1987 were shown in Table B-24. The allocation of operating labor and supervision depends on the process complexity, number of process areas, labor intensity of the process, and operating experience.

Utilities--Services used, such as steam, electricity, process water, fuel oil, and heat credits, are charged under the utilities heading. Unit 1987 costs are shown in Table B-24. Costs for steam and electricity are based on the assumption that the required energy is purchased from another source. This simplifying assumption eliminates the need to derate the utility plant. Process water requirements are defined as any water used by the process being evaluated and are usually determined by the material balance. Steam requirements are for flue gas reheat and process requirements. Electrical power requirements are determined from the installed horsepower of operating electrical equipment (excluding the horsepower of spare equipment). Each motor in operation is assumed to be operating at rated capacity, although this results in higher power consumptions than would actually occur. Electrical requirements are obtained from the equipment list, where the motor horsepower is identified, plus an additional amount for functions such as lighting. A sample calculation is shown in Table B-32.

TABLE B-31. ANNUAL REVENUE REQUIREMENTS SHEET

TABLE LIMESTONE PROCESS ANNUAL REVENUE REQUIREMENTS

(500-MW new coal-fired power unit, 3.5% S in coal; 89% SO_2 removal; onsite solids disposal)

	Annual quantity	Unit cost, $	Total annual cost, k$
<u>Direct Costs - First Year</u>			
Raw materials			
Limestone	tons	/ton	______
Total raw material cost			
Conversion costs			
Operating labor and supervision			
FGD	man-hr	/man-hr	
Solids disposal	man-hr	/man-hr	
Utilities			
Process water	kgal	/kgal	
Electricity	kWh	/kWh	
Steam	klb	/klb	
Maintenance			
Labor and material			
Analysis	man-hr	/man-hr	______
Total conversion costs			
Total direct costs			
<u>Indirect Costs - First Year</u>			
Overheads			
Plant and administrative			
Marketing (10% of byproduct sales)			
Byproduct credit	tons	$/ton	______
Total first-year operating and maintenance costs			
Levelized capital charges (% of total capital investment)			______
Total first-year annual revenue requirements			
Levelized first-year operating and maintenance costs (first-year O and M)			
Levelized capital charges (% of total capital investment)			______
Levelized annual revenue requirements			

	M$	Mills/kWh
First-year annual revenue requirements		
Levelized annual revenue requirements		

Basis: One-year, 5,500-hour operation of the system described in the capital investment sheet; 1987 cost basis.

TABLE B-32. SAMPLE ELECTRICAL REQUIREMENT CALCULATION

Electricity requirements are determined by summing the horsepower of all operating electrical equipment and multiplying by a factor of 0.7457 kW/hp. It is assumed that the instantaneous load factor and the power load factor are equal and thus cancel. Additional electricity is added for functions such as lighting. For the limestone and lime processes, 100 kW is added. For other processes, more or less electricity, depending on the process type, size, and complexity, may be necessary.

Sample Calculation

Area	Total operating hp
Materials handling	70.5
Feed preparation	797.5
Gas handling	3,580.0
SO_2 absorption	6,189.0
Stack gas reheat	0.0
Oxidation	4,903.0
Solids disposal	71.0
Total	15,611.0 hp

15,611 hp x 0.7457 kW/hP = 11,641 kW
+ 100 kW

11,741 kW

11,741 kW x 5,500 hr = 64,575,500 kWh

Maintenance--Process maintenance costs are 3% to 10% of the total direct process capital investment depending on process complexity, process equipment, materials handled, process areas, and unit size. The percentages shown in Table B-33 are used under most circumstances. For specific FGD processes, the maintenance percentages shown in Table B-34 are used. For example, a 500-MW limestone-scrubbing process normally has a maintenance factor of 8%.

Waste disposal maintenance costs are estimated from the appropriate model and are typically 3% of the waste disposal site construction costs. Maintenance costs for waste disposal are not shown separately. If no other information is available, the maintenance material-to-labor ratio can be assumed to be 60:40.

TABLE B-33. MAINTENANCE FACTORS

Process conditions	% of total direct investment excluding waste disposal: Low	Base	High
Corrosive or abrasive slurry	6	8	10
Solids, high pressure, or high temperature	4	5	6
Liquids and gases	3	4	5

TABLE B-34. MAINTENANCE FACTORS FOR SPECIFIC FGD PROCESSES

	Maintenance, % of total direct investment			
	FGD system			
	200 MW	500 MW	1,000 MW	Waste disposal
Limestone and lime (generic)	9	8	7	3
Double alkali	7	6	5	3
Wellman-Lord	7	6	5	-
Magnesia	8	7	6	-
Lime spray dryer (including baghouse)	7	6	5	3

Analysis--Analysis costs are based on process complexity and are listed as a single entry.

Plant and Administrative Overheads--Plant and administrative overheads include plant services such as safety, cafeteria, and medical facilities; plant protection and personnel; general engineering (excluding maintenance), interplant communications and transportation; and the expenses connected with management activities. Plant and administrative overheads for the FGD process are 60% of the total conversion costs less utilities.

Marketing Overhead--This is calculated as 10% of byproduct sales income.

Byproduct Credit--Total revenue from the sale of byproducts is applied as a credit to processes in which a byproduct is salable.

Capital Charges--

Capital charges are those costs incurred by construction of the facility that must be recovered during its life. They consist of returns on equity and debt (discount rate), depreciation, income taxes, and other costs such as insurance and local taxes. In keeping with common practice for investor-owned utilities, the weighted cost of capital is used as the discount rate. Depreciation is stated as a sinking fund factor to simplify calculations. An allowance for interim replacement is included to compensate for possible early retirement of the facility. Credits are also included for tax preference allowances. The capital charges are shown in Table B-35. In keeping with standard practice, book, tax, and economic lives are used in the following calculations. In these premises, however, all three are assumed to be equal.

TABLE B-35. LEVELIZED ANNUAL CAPITAL CHARGES

	Levelized annual capital charge as % of total capital investment			
Remaining life, years	15	20	25	30
Weighted cost of capital	10.00	10.00	10.00	10.00
Depreciation (sinking fund factor)	3.15	1.75	1.02	0.61
Annual interim replacement	0.72	0.67	0.62	0.56
Levelized accelerated tax depreciation	(1.44)	(1.43)	(1.40)	(1.36)
Levelized investment tax credit	(2.39)	(2.14)	(2.00)	(1.93)
Levelized income tax	3.96	4.08	4.20	4.31
Insurance and property taxes	2.50	2.50	2.50	2.50
Levelized annual capital charge	16.5[a]	15.4[a]	14.9[a]	14.7[a]

a. Rounded to three significant figures.

The capital structure is assumed to be 35% common stock, 15% preferred stock, and 50% long-term debt. The cost of capital is assumed to be 11.4% for common stock, 10.0% for preferred stock, and 9.0% for long-term debt. The weighted cost of capital (WCC) is 10.0%. The discount rate (r) is equal to the weighted cost of capital.

Other economic factors used in financial calculations are a 10% investment tax credit rate, 50% State plus Federal income taxes, 2.5% property tax and insurance, and an annual inflation rate of 6%. Salvage value is assumed to be less than 10% and equal to removal cost.

Weighted cost of capital is calculated as follows:

WCC = (fraction long-term debt) (long-term debt cost, %) +
(fraction preferred stock) (preferred stock cost, %) +
(fraction common stock) (common stock cost, %)

The sinking fund factor method of depreciation is used since it is equivalent to straight-line depreciation levelized for the economic life of the facility using the weighted cost of capital. The use of the sinking fund factor does not suggest that regulated utilities commonly use sinking fund depreciation. All factors and rates are expressed as decimals. The equation is:

$$SFF = (WCC)/((1 + WCC)^{N_e} - 1)$$

where: SFF = sinking fund factor
WCC = weighted cost of capital
N_e = economic life in years

An annual interim replacement (retirement dispersion) allowance of 0.56% for new plants and 0.67% for existing plants is also included as an adjustment to the depreciation account to ensure that the initial investment will be recovered within the actual rather than the forecasted life of the facility. Since power plant retirements occur at different ages, an average service life is estimated. The type S-1 Iowa State (33) retirement dispersion pattern is used. The S-1 pattern is symmetrical with respect to the average life axis and the retirements are represented to occur at a low rate over many years. The interim replacement allowance covers replacement of individual items of equipment with typical lifespans less than the life of the power plant. Repair of other equipment is covered by the maintenance charge.

Tax preference allowances are incentives designed to encourage investment as a stimulus to the overall economy. The basic accounting method used is the flow-through method which passes the tax advantage to revenue requirements as soon as they occur.

Using the sum of the years digits method, which allocates costs early in the life of the facility, the accelerated tax depreciation (ATD) is calculated as follows:

$$ATD = (2)(CRF_e)(N_t - (1/CRF_t))/(N_t)(N_t + 1)(WCC)$$

where: CRF_e = capital recovery factor (WCC + SFF) for the economic life
CRF_t = capital recovery factor (WCC + SFF) for the tax life
N_t = tax life in years

Levelized accelerated tax depreciation is calculated as follows:

$$LATD = (ATD - SLD)(ITR)/(1 - ITR)$$

where: SLD = straight-line depreciation = $1/N_b$
N_b = book life in years
ITR = income tax rate

The levelized investment tax credit is calculated as follows:

$$LITC = (CRF_e)(\text{investment tax credit rate})/(1 + WCC)(1 - ITR)$$

The levelized income tax is calculated as follows:

$$LIT = (CRF_b + AIR - SLD)(1 - ((\text{debt ratio} \times \text{debt cost})/WCC))(ITR)/(1 - ITR)$$

where: LIT = levelized income tax
CRF_b = capital recovery factor (WCC + SFF) for the book life
AIR = annual interim replacement

The capital charges are applied as a percentage of the total capital investment, including land and working capital. Although land and most of working capital cannot be depreciated and are not subject to investment tax credit, their inclusion has an insignificant effect on capital charges.

Levelized Operating and Maintenance Costs--

Assuming a constant inflation rate, the levelized operating and maintenance costs are determined by multiplying the first-year operating and maintenance costs by an appropriate levelizing factor, L_f. The levelizing factor is calculated as follows:

$$L_f = CRF_e (K + K^2 + K3 + \text{---} + K^N)$$
$$= CRF_e (K(1 - K^N))/(1 - K)$$

where: CRF_e = capital recovery factor (WCC + SFF) for the economic life (see the discussion of capital charges)
K = $(1 + i)/(1 + r)$; present worth of an inflationary value
i = inflation rate
r = discount rate
N_b = book life in years

An inflation rate of 6% ($i = 0.06$) and a discount rate of 10% ($r = 0.10$) are used for new units. Values of L_f for power units with a remaining life of

15, 20, 25, and 30 (new unit) years are shown in Table B-36. The first-year operating and maintenance costs are multiplied by the appropriate L_f to obtain the levelized operating and maintenance costs.

TABLE 36. LEVELIZING FACTORS

Book[a] life, N_b	$K = \frac{1 + i}{1 + r}$	$\frac{K(1 - K^{N_b})}{1 - K}$	CRF_b[b] (r, N_b)[b]	Levelizing factor, L_f
15	0.96364	11.2965	0.13147	1.485
20	0.96364	13.8669	0.11746	1.629
25	0.96364	16.0028	0.11017	1.763
30[c]	0.96364	17.7775	0.10608	1.886

a. Same as economic life (N_e) and tax life (N_t).
b. Discount rate (r) of 10%.
c. New units.

SI SYSTEM NOTATION

The SI system of metric units is not used as the primary numerical system in these premises because of the widespread use of traditional units in correlative and supportive literature and general practice. Use of the SI system is not standardized in the utility industry, although steps in this direction are being made (34). The SI system specifies a number of rules of usage, form, and style in addition to the numerical standards. These too are part of the SI system and should be followed when using it. Detailed procedures for use of SI conventions in the primary data or conversion to SI convention are readily available in the literature. A detailed general guide to SI convention is available in ASTM E 380 79 (35). To provide uniformity in the comparison of data developed from these premises, such a guide should be consulted in using the SI system.

Appendix C

DETAILED DESCRIPTIONS OF MODEL INPUT VARIABLES

TABLE C-1. MODEL INPUTS - FORTRAN VARIABLE NAMES

Line	
1	XINPUT XBC XALK XSSV XSRHT
2	OUTPUT XHGAS XWGAS XRAIR XRGAS XSRHO XSKGAS XSSO XDIS XSTR XGPM XIT
3	IRPT IWAST IEQPR IWTBAL NOPART
4	Case identification (up to 72 alphanumeric characters)
5	XESP MW BHR HVC EXSAIR THG XRH KEPASS KPASO2 PSSO2X KCLEAN PREC SPASH WPRITE TSK TSTEAM HVS
5B	SMRW SMCL ASHCLN HVCLN
6A	INPOPT WPC WPH WPO WPN WPSUL WPCL WPASH WPH2O SULO ASHO IASH ASHUPS ASHSCR
6B	INPOPT VCO2 VHCL VSO2 VO2 VN2 VH2O SCFM WASH SULO ASHO IASH ASHUPS ASHSCR
7	XLG VLG VTR V VRH ISO2 XSO2 TR ISR SRIN XIALK IADD WPMGO XMGOAD AD ADDC WPI WPM ASHCAO ASHMGO
8	WPS PSD RS PSC IFOX OX SRAIR PSF FILRAT PHLIME IVPD VPD DELTAP PRES IFAN
9	ISCRUB XNS XNG HS RAIN SEEPRT EVAPRT WINDEX HPTONW NSPREP NOTRAN NOREDN PCNTRN
10	ISLUDG IFIXS SDFEE PSAMAX ACRE$ PDEPTH PMXEXC DISTPD ILINER XLINA XLINB
11	ENGIN ARCTEC FLDEXP FEES CONT START CONINT XINT PCTMNT PDMNTP XINFLA IECON PCTOVR XLEVEL/PCTADM CAPCHG/UNDCAP PCTMKT/PCTINS
12	ITAXFR TXRAT FRRAT SERVRT ROYALT IOTIME OTRATE INDPND PENGIN PARCH PFLDEX PFEES PCONT PSTART
13	UC(1) - UC(11) XINDEX YINDEX INVYR IREVYR
14	IOPSCH ONCAP IYROP PNDCAP BAGDLP BAGRAT BGCOST BGLIFE EFFPS ESPDLP RESIST SCARAT ICEPYE CEPNDX
15	IA(1) - IA(10)
16	IA(11) - IA(20)
17	IA(21) - IA(30)
18	END or NEXT

Note: Line 5B is needed only if KCLEAN $\geq$1. Lines 15-18 are needed only if IOPSCH = 3. The number of entries required on lines 15-17 depends on the number of years specified with the IYROP variable on line 14. Although 30 years is normally used as a maximum plant life, up to 50 years are allowed and up to two additional lines may be used for IA(31) - IA(50).

TABLE C-2. MODEL INPUT VARIABLE DEFINITIONS

Line No.	Variable	Definition	Unit or value
1	XINPUT	Option to control the printing of input data variables. If a value of zero is selected, no input data variables are printed; the options to individually control the printing of input variables are ignored.	0 = no input data printed 1 = print input variables according to individual input print options
1	XBC	Controls the printing of boiler characteristics input variables.	0 = no print 1 = print
1	XALK	Controls the printing of alkali input variables.	0 = no print 1 = print
1	XSSV	Controls the printing of scrubber system input variables.	0 = no print 1 = print
1	XSRHT	Controls the printing of steam reheater input variables.	0 = no print 1 = print
2	OUTPUT	Option to control the printing of model output. If a value of zero is selected, no output listings are printed and the options to individually control the printing of output listings are ignored.	0 = no output data printed 1 = print output listings according to individual output print options
2	XHGAS	Controls the printing of calculated properties of hot gas to scrubber.	0 = no print 1 = print
2	XWGAS	Controls the printing of calculated properties of wet gas from scrubber.	0 = no print 1 = print
2	XRAIR	Controls the printing of calculated properties of reheater air.	0 = no print 1 = print
2	XRGAS	Controls the printing of calculated properties of reheater gas (oil-fired reheater only).	0 = no print 1 = print

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or valu
2	XSRHO	Controls the printing of calculated properties of inline steam reheater.	0 = no print 1 = print
2	XSKGAS	Controls the printing of calculated properties of stack gas.	0 = no print 1 = print
2	XSSO	Controls the printing of calculated scrubber system parameters.	0 = no print 1 = print
2	XDIS	Controls the printing of calculated properties of system discharge stream.	0 = no print 1 = print
2	XSTR	Controls the printing of calculated properties of scrubber system internal streams (excluding sludge discharge and makeup water). This option does not affect the printout of total stream flow rate.	0 = no print 1 = print
2	XGPM	Controls the printing of total flow rates (gpm and lb/hr) of internal streams (excluding sludge discharge and makeup water).	0 = no print 1 = print
2	XIT	For the iterative calculation of stoichiometry, this option controls the printing of the iteration number and of the current and the preceding stoichiometry values.	0 = no print 1 = print
3	IRPT	Option to select either a short-form printout (totals only) or a long-form printout.	0 = short print 1 = long print
3	IWAST	Controls the printing of calculated waste disposal flow rates, physical properties and resulting costs.	0 = no print 1 = print

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
3	IEQPR	Controls the printing of equipment list.	0 = no print 1 = print entire list 2 = print only material-handling and feed preparation area lists 3 = Print only gas-handling, SO_2 scrubbing, oxidation, and reheat area lists 4 = Print only solids separation area list 5 = Print only landfill area list
3	IWTBAL	Controls the printing of calculated properties of water balance scrubber.	0 = no print 1 = print
3	NOPART	Controls the printing of input design conditions and calculated properties projected by the Argonne particulate removal model.	0 = no print 1 = print
4	CASEID	Case identification - this field is free form and may be up to 72 characters in length.	
5	XESP	Particulate collection option	
		No mechanical collector available	0
		Mechanical collector available	1
		Print internal model examples (costs are not included in FGD costs).	2

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
5	MW	Electric power output	megawatts
5	BHR	Boiler heat rate	Btu/kWh
5.	HVC	Heating value of coal	Btu/lb
5	EXSAIR	Excess air	%
5	THG	Temperature of hot gas to scrubber	^{o}F
5	XRH	Reheat option	
		No reheat	0
		Inline steam reheater (XRH value = 2) is the only type of reheat available at this time.	2
5	KEPASS	Emergency bypass option	
		No emergency bypass	0
		Emergency bypass	1
5	KPASO2	Partial scrubbing/bypass option	
		No partial scrubbing/bypass	0
		Partial scrubbing/bypass	1
5	PSSO2X	Percent SO_2 removal in the scrubber when partial scrubbing/bypass is specified	% removal
5	KCLEAN	Coal-cleaning option	
		No coal cleaning - line 5B must not be input	0
		Coal cleaning - line 5B is required input	1
5	PREC	Percent weight recovery (lb clean coal per 100 lb raw coal) when coal cleaning is specified	%
5	SPASH	Weight percent of sulfur in cleaned coal when coal cleaning is specified	wt %
5	WPRITE	Weight percent of pyritic sulfur in raw coal when coal cleaning is specified	wt %

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
5	TSK	Temperature of stack gas	°F
5	TSTEAM	Temperature of reheater steam	°F
5	HVS	Heat of vaporization of reheater steam	Btu/lb
5B	SMRW	Surface moisture of raw coal	wt %
5B	SMCL	Surface moisture of cleaned coal	wt %
5B	ASHCLN	Ash content of cleaned coal	wt %
5B	HVCLN	Heating value of cleaned coal	Btu/lb
		The composition input specified on either line 6A or 6B depends on the composition option, INPOPT. If a coal composition will be input (INPOPT = 1) then line 6A is used. If a flue gas composition will be input (INPOPT = 2) then line 6B is used.	
6A	INPOPT	Composition input option Coal composition will be input using line 6A	 1
6A	WPC }		
6A	WPH }		
6A	WPO }		
6A	WPN }	--Amount of component (C, H, O, N, S, Cl, ash, H_2O) in coal. WPSUL is the total of both organic sulfur and pyritic sulfur.	wt %
6A	WPSUL }		
6A	WPCL }		
6A	WPASH }		
6A	WPH2O }		

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
6A	SULO	Sulfur to overhead as SO_2 gas (remainder goes to bottom ash).	wt %
6A	ASHO	Ash to overhead as particulates (remainder goes to bottom ash).	wt %
6A	IASH	Unit of measure option for particulate removal	
		Default to model assumptions	0
		Percent removal	1
		Pounds particulates per MBtu	2
		Upstream removal (percent) with scrubber default	3
		(The actual values for particulate removal are provided by the ASHUPS and ASHSCR variables that immediately follow.)	
6A	ASHUPS	Value for particulate removal upstream from scrubber. (Unit of measure is indicated by the IASH option above.)	
6A	ASHSCR	Value for particulate removal within scrubber. (Unit of measure is indicated by the IASH option above.)	
6B	INPOPT	Composition input option	
		Flue gas composition will be input using line 6B	2
6B	VCO2 }		
6B	VHCL }		
6B	VSO2 }	-- Amount of component (CO_2, HCl, SO_2, O_2, N_2, and H_2O) in flue gas	vol %
6B	VO2 }		
6B	VN2 }		
6B	VH2O }		

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
6B	SCFM	Standard cubic feet per minute (60°F), gas from boiler	sft3/min
6B	WASH	Pounds of ash per hour in hot gas from boiler	lb/hr
6B	SULO	Should be set to 100 when flue gas composition is input	
6B	ASHO	Should be set to 100 when flue gas composition is input	
6B	IASH	See line 6A	
6B	ASHUPS	See line 6A	
6B	ASHSCR	See line 6A	
7	XLG	L/G ratio in scrubber (Refer to the ISR option on the following page.)	gal/kaft3
7	VLG	L/G ratio in venturi	gal/kaft3
7	VTR	Venturi/oxidation hold tank residence time. This variable is used to specify residence time in the second effluent tank when two tanks are specified. Two tanks may be specified by the forced-oxidation option (IFOX, line 8), the scrubber option (ISCRUB, line 9), or both. VTR should be set to zero when only one effluent tank is used (see the TR variable below).	min
7	V	Scrubber gas velocity (superficial)	ft/sec
7	VRH	Superficial gas velocity through reheater (face velocity)	ft/sec

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
7	IS02	Unit of measure option for SO_2 removal	
		SO_2 to be removed is a percent value	1
		SO_2 emission concentration is a pounds SO_2/MBtu value	2
		SO_2 emission concentration is a ppm value	3
		1979 NSPS	4
		(The actual value for SO_2 removal is provided by the XS02 variable that immediately follows.)	
7	XS02	Value for SO_2 to be removed. Unit of measure is indicated by the IS02 option above; refer to the ISR option below for additional requirements. The value for XS02 is automatically calculated when IS02 = 4 and any input value will be ignored.	
7	TR	Recirculation/oxidation hold tank residence time. This variable is used to specify residence time in the effluent tank when only one tank is specified. If two tanks are specified, TR specifies residence time in the first tank (see the VTR variable above).	min
7	ISR	Stoichiometry, L/G in scrubber, and SO_2 removal option. This option controls model processing of the stoichiometry value, SRIN, below; the L/G ratio in the scrubber, XLG, on the preceding page; and the SO_2 to be removed, XS02, above (if XS02 is required then IS02 is also required).	
		SRIN, XLG, and XS02 (also IS02) will be processed as input variables. (No checks are made for validity or consistency among the specified values.)	0

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
		XLG and XSO2 (also ISO2) will be processed as input variables and SRIN will be calculated by the model.	1
		SRIN and XSO2 (also ISO2) will be processed as input variables and XLG will be calculated by the model.	2
		SRIN and XLG will be processed as input variables; the value for SO_2 to be removed (XSO2) will be calculated by the model; and all three units of measure (ISO2) will be provided in the calculated results. Any user input values for ISO2 and XSO2 will be ignored.	3
7	SRIN	Value for stoichiometry (refer to the ISR option above)	mols $CaCO_3$ added as limestone per mol SO_2 + 2HCl absorbed
7	XIALK	Alkali addition option	
		Limestone	1
		Lime	2
7	IADD	Chemical additive option	
		No chemical additive	0
		MgO added	1
		Adipic acid added	2
7	WPMGO	Soluble MgO in limestone or lime	wt % dry basis
7	XMGOAD	Soluble MgO added to system (applied only when MgO added, see IADD above)	lb soluble MgO/100 lb limestone
7	AD	Adipic acid in scrubbing liquid (applied only when adipic acid added, see IADD above)	ppm (wt)

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
7	ADDC	Adipic acid degradation constant (applied only when adipic acid added, see IADD above)	
7	WPI	Insolubles in limestone-lime additive	wt % dry basis
7	WPM	Moisture in limestone-lime additive	lb/100 lb dry additive
7	ASHCAO	Soluble CaO in particulates	wt %
7	ASHMGO	Soluble MgO in particulates	wt %
8	WPS	Solids in recycle slurry to scrubber	wt %
8	PSD	Solids in sludge discharge	wt %
8	RS	Thickener solids settling rate	ft/hr
8	PSC	Percent solids in thickener underflow	wt %
8	IFOX	Forced-oxidation option	
		No forced oxidation	0
		Forced oxidation in a single effluent tank	1
		Forced oxidation in the first of two effluent tanks	2
		Forced oxidation in the disposal feed tank	3
8	OX	Oxidation of sulfite in scrubber liquid	mol %
8	SRAIR	Air stoichiometry value	g-atoms O/g-mol SO_2 absorbed
8	PSF	Percent solids in filter cake	wt %
8	FILRAT	Filtration rate	tons/ft^2/day
8	PHLIME	Recirculation liquor pH for lime and adipic acid enhancement systems (value is ignored for limestone system)	

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
8	IVPD	Venturi ΔP option	
		ΔP is input in in. H_2O	0
		Throat velocity (ft/sec) is input and the corresponding VPD is calculated	1
8	VPD	Value for either ΔP or throat velocity indicated by the IVPD option above	in. H_2O or (ft/sec)
8	DELTAP	Override ΔP for entire system	in. H_2O
8	PRES	Scrubber pressure	psia
8	IFAN	Fan option	
		Forced-draft fans	0
		Induced-draft fans	1
9	ISCRUB	Scrubbing option	
		Spray tower	1
		TCA	2
		Venturi-spray tower, two effluent tanks	3
		Venturi-spray tower, one effluent tank	4
		Venturi-TCA, two effluent tanks	5
		Venturi-TCA, one effluent tank	6
9	XNS	Number of TCA stages	
9	XNG	Number of TCA grids	
9	HS	Height of spheres per stage	in.
9	RAIN	Annual rainfall	in./yr
9	SEEPRT	Seepage rate	cm/sec
9	EVAPRT	Annual evaporation	in./yr
9	WINDEX	Limestone hardness work index factor value 5-15. (Example: 10)	wi
9	HPTONW	Fineness of grind index factor (see Table C-3)	hp/ton
9	NSPREP	Number of spare preparation units	(0-9)

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
9	NOTRAN	Number of operating scrubber trains	(1-10)
9	NOREDN	Number of spare scrubber trains	(0-10)
9	PCNTRN	Entrainment level as percentage of wet gas from scrubber (Example: 0.1)	wt %
10	ISLUDG	Sludge disposal option	
		Onsite ponding	1
		Thickener - ponding	2
		Thickener - fixation (fee)	3
		Thickener - filter - fixation (fee)	4
		Thickener - filter - landfill fixation fee	5
10	IFIXS	Sludge fixation option	
		No fixation specified	0
		Sludge - fly ash - lime fixation	1
10	SDFEE	Sludge disposal fee (Either an actual value or a zero value must be provided; refer to the ISLUDG option above.)	$/ton dry sludge
10	PSAMAX	Total available land for construction of pond	acres
10	ACRE$	Land cost	$/acre
10	PDEPTH	Final depth of sludge in pond (when ISLUDG = 1-4)	ft
10	PDEPTH	Uncompacted bulk density of waste (when ISLUDG = 5)	lb/ft3
10	PMXEXC	Maximum excavation depth (when ISLUDG = 1-4)	ft
10	PMXEXC	Compacted bulk density of waste (when ISLUDG = 5)	lb/ft3
10	DISTPD	Distance from scrubber area to disposal site	ft

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
10	ILINER	Disposal site lining option	
		Clay liner	1
		Synthetic liner	2
		No liner	3
		(Refer to the XLINA and XLINB variables that immediately follow.)	
10	XLINA	If ILINER = 1, XLINA = clay depth	in.
		If ILINER = 2, XLINA = material unit cost	$\$/yd^2$
		If ILINER = 3, XLINA = 0	
10	XLINB	If ILINER = 1, XLINB = clay cost	$\$/yd^3$
		If ILINER = 2, XLINB = labor unit cost	$\$/yd^2$
		If ILINER = 3, XLINB = 0	
11	ENGIN	Engineering design and supervision	%
11	ARCTEC	Architect and engineering contractor	%
11	FLDEXP	Construction field expenses	%
11	FEES	Contractor fees	%
11	CONT	Contingency	%
11	START	Allowance for startup and modifications	%
11	CONINT	Interest during construction	%
11	XINT	Cost of capital	%
11	PCTMNT	Maintenance rate, applied as percent of direct investment excluding disposal site cost	%
11	PDMNTP	Disposal site maintenance rate, applied as percent of direct disposal site investment	%
11	XINFLA	Inflation factor (used only when unlevelized lifetime revenue requirements are calculated, see Appendix B)	%

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
11	IECON	Economic premises option	
		Current premises	1
		Premises prior to 12/5/79	0
11	PCTOVR	Plant overhead rate, applied as percent of conversion costs less utilities	%
11	XLEVEL/ PCTADM	The use of this variable depends on the economic premises specified (IECON, line 11). If new premises are specified (IECON = 1), XLEVEL specifies the levelizing factor to be applied to first-year operating and maintenance cost to obtain levelized lifetime costs. If XLEVEL is set to zero, there is no levelizing and a lifetime revenue sheet is generated. If old premises are specified (IECON = 0), PCTADM specifies the administrative research and service overhead rate, applied as a percent of operating labor and supervision.	%
11	CAPCHG/ UNDCAP	If new premises are specified (IECON = 1) CAPCHG specifies levelized annual capital charges applied as a percent of total capital investment. If old economic premises are specified (IECON = 0), UNDCAP specifies the annual capital charge basis for undepreciated investment.	%
11	PCTMKT/ PCTINS	If new premises are specified (IECON = 1), PCTMKT specifies marketing costs applied as a percent of byproduct credit (applies only to processes with a salable byproduct). If old economic premises are specified (IECON = 0), PCTINS specifies the rate for insurance and interim replacements applied as a percent of total capital investment.	%

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
12	ITAXFR	Sales tax and freight option	
		No sales tax or freight	0
		Sales tax and freight rates as specified by TXRAT and FRRAT below	1
12	TXRAT	Sales tax rate (applied only when ITAXFR above set to 1)	%
12	FRRAT	Freight rate (applied only when ITAXFR above set to 1)	%
12	SERVRT	Services, utilities, and miscellaneous, applied as a percent of total process capital	%
12	ROYALT	Royalties, applied as a percent of total process capital	%
12	IOTIME	Overtime construction labor option	
		No overtime labor	0
		Overtime labor on 7% of total labor based on the OTRATE rate below	1
12	OTRATE	Overtime labor rate (applied to 7% of total labor). (Example: 1.5)	
12	INDPND	Separate indirect investment factors option for construction	
		No separate indirect factors for disposal waste site construction (same as process indirects)	0
		Separate indirects for waste site construction specified by PENGIN, PARCH, PFLDEX, PFEES, PCONT, and PSTART below	1
12	PENGIN	Disposal site construction engineering design and supervision expenses (applied only when INDPND above set to 1)	%

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
12	PARCH	Disposal site construction architect and engineering contractor expenses (applied only when INDPND above set to 1)	%
12	PFLDEX	Disposal site construction field expenses (applied only when INDPND above set to 1)	%
12	PFEES	Disposal site construction contractor fees (applied only when INDPND above set to 1)	%
12	PCONT	Disposal site construction contingency (applied only when INDPND above set to 1)	%
12	PSTART	Allowance for disposal site startup and modification (applied only when INDPND above set to 1)	%
13	UC (1)	Limestone unit cost	$/ton
13	UC (2)	Lime unit cost	$/ton
13	UC (3)	MgO unit cost	$/ton
13	UC (4)	Adipic acid unit cost	$/ton
13	UC (5)	Operating labor and supervision unit cost	$/man-hr
13	UC (6)	Landfill labor and supervision unit cost	$/man-hr
13	UC (7)	Steam unit cost	$/klb
13	UC (8)	Process water unit cost	$/kgal
13	UC (9)	Electricity unit cost	$/kWh
13	UC (10)	Diesel fuel cost	$/gal
13	UC (11)	Analyses unit cost	$/hr

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
13	XINDEX	*Chemical Engineering* material cost index (see premises)	
13	YINDEX	*Chemical Engineering* labor cost index see premises)	
13	INVYR	Investment year cost basis	yr
13	IREVYR	Revenue requirement year cost basis	yr
14	IOPSCH	Operating profile option	
		TVA profile	1
		FERC profile	2
		User input profile [Refer to the IYROP and IA(n) options on lines 14-17.]	3
		Levelized operating profile, 5,500 hr/yr	4
		Calculated input operating profile	5
14	ONCAP	Onstream capacity factor (Example .6)	decimal
14	IYROP	Years remaining life (lines 15 through 17 are needed only if the IOPSCH variable, line 14, is set to 3). Although only 30 years is shown, up to 50 years may be used.	
14	PNDCAP	Expected disposal site capacity (controls site design capacity; if 100% of sludge is to be disposed over the life of the unit, input 1.0; if 80% of sludge is to be disposed, input 0.80).	
14	BAGDLP	Baghouse pressure drop	in. H_2O
14	BAGRAT	Baghouse ratio (typically = 0.8)	$\frac{\text{open ft}^2}{\text{actual ft}^2}$
14	BGCOST	Bag cost	$/ft^2
14	BGLIFE	Bag life	yr

(Continued)

TABLE C-2. (Continued)

Line No.	Variable	Definition	Unit or value
14	EFFPS	ESP rectification efficiency (Example - .65)	decimal
14	ESPDLP	ESP pressure drop	in. H_2O
14	RESIST	Resistivity option (high or low)[a]	
		Assume ω = 20 ft/min	1
		Assume ω = 30	2
14	SCARAT	SCA ratio Contingency or safety factor (fractional) to apply to calculated collection area.	
14	ICEPYE	<u>Chemical Engineering</u> plant index year	yr
14	CEPNDX	<u>Chemical Engineering</u> plant index (see premises)	
15	IA(1) - IA(10)	Operating hr/yr (input only 10 years per line)	
16	IA(11) - IA(20)	Operating hr/yr (input only 10 years per line)	
17	IA(21) - IA(30)	Operating hr/yr (input only 10 years per line)	
18	END or NEXT	"END" terminates further execution. "NEXT" execution will continue with the next group of input variables. (If variable IOPSCH on line 14 is not equal to 3, line 15 will be the "END" or "NEXT" line.)	

a. Required for sizing hot ESP. Drift velocity (ω) is related to percent sulfur in the cold ESP model, but is an input for the hot ESP model.

TABLE C-3. LIMESTONE FINENESS OF GRIND INDEX FACTOR

Ground limestone product size distribution			Index factor (HPTONW)
80%- micron	% -200 mesh	% -325 mesh	hp/ton
129	60		1.11
113	65		1.22
98	70		1.35
85	75		1.51
74	80		1.72
62	85		2.04
58	86	70	2.19
51	90	75	2.54
44	93	80	3.04
40	95		3.40
37		85	3.64
31		90	4.44
24		95	5.70 base

Data from KVS Rock Talk Manual, Kennedy Van Saun Corporation, Danville, Pennsylvania, 1974. Total ball mill horsepower is calculated using the limestone hardness work index factor, wi, and the fineness of grind index factor as follows: hp = (ton/hr limestone)(wi)(fineness of grind index factor).

Appendix D

BASE CASE SHAWNEE COMPUTER MODEL INPUT AND PRINTOUT

TABLE D-1. BASE CASE SHAWNEE COMPUTER MODEL PRINTOUT

```
1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1
SHAWNEE COMPUTER USER MANUAL  BASE
2 500 9500 11700 39 300 2 1 0 90 0 84.14 12.162 .3 175 470 751.9
1 66.7 3.8 5.6 1.3 3.36 0.1 15.1 4.0 95 80 2 0.06 0.03
106 20 5 10 25 4 .6 8 0 1.40 1 0 .15 0.0 1500 3 4.85 5 0 0
8 85 0.0 40 2 95 2.5 85 1.2 5.2 0 9 0 14.7 1
1 0 3 0 35 .0000005 32 10 5.70 1 4 1 .1
5 0 0.0 9999 6000 75 95 5280 1 12 6
7 2 16 5 10 8 15.6 10 8 3 6 1 60 1.886 14.7 0.0
1 4 3.5 6 0 1 1.5 1 2 1 8 5 20 0
15.0 90 510 1500 19 24 4.0 .16 .055 1.6 26 366.8 292.2 1985 1987
4 .6 30 1 5 .8 1.0 3 .65 1 1 1.1 1985 363.4
END
```

(Continued)

TABLE D-1. (Continued)

TENNESSEE VALLEY AUTHORITY
SHAWNEE LIMESTONE OR LIME SCRUBBING PROCESS
COMPUTERIZED DESIGN-COST ESTIMATE MODEL

REVISION DATE OCTOBER 1, 1984

SHAWNEE COMPUTER USER MANUAL BASE

*** INPUTS ***

BOILER CHARACTERISTICS

MEGAWATTS = 500.

BOILER HEAT RATE = 9500. BTU/KWH

EXCESS AIR = 39. PERCENT, INCLUDING LEAKAGE

HOT GAS TEMPERATURE = 300. DEG F

COAL ANALYSIS, WT % AS FIRED :

C	H	O	N	S	CL	ASH	H2O
66.70	3.80	5.60	1.30	3.36	0.10	15.10	4.00

SULFUR OVERHEAD = 95.0 PERCENT

ASH OVERHEAD = 80.0 PERCENT

HEATING VALUE OF COAL = 11700. BTU/LB

FLYASH REMOVAL	EFFICIENCY, %	EMISSION, LBS/M BTU
UPSTREAM OF SCRUBBER	99.4	0.06
WITHIN SCRUBBER	50.0	0.03

(Continued)

TABLE D-1. (Continued)

EMISSION STANDARD

1979 NSPS
COST OF UPSTREAM FLYASH REMOVAL EXCLUDED

ALKALI

LIMESTONE :

CACO3 = 95.00 WT % DRY BASIS
SOLUBLE MGO = 0.15
INERTS = 4.85
MOISTURE CONTENT = 5.00 LB H2O/100 LBS DRY LIMESTONE
LIMESTONE HARDNESS WORK INDEX FACTOR = 10.00
LIMESTONE DEGREE OF GRIND FACTOR = 5.70

FLY ASH :

SOLUBLE CAO = 0.0 WT %
SOLUBLE MGO = 0.0
INERTS = 100.00

RAW MATERIAL HANDLING AREA

NUMBER OF REDUNDANT ALKALI PREPARATION UNITS = 1

SCRUBBER SYSTEM VARIABLES

NUMBER OF OPERATING SCRUBBING TRAINS = 4

NUMBER OF REDUNDANT SCRUBBING TRAINS = 1

SPRAY TOWER LIQUID-TO-GAS RATIO = 106. GAL/1000 ACF(SATD)

SPRAY TOWER GAS VELOCITY = 10.0 FT/SEC

INDUCED DRAFT SCRUBBER FAN OPTION

SCRUBBER PRESSURE = 14.7 PSIA

STOICHIOMETRY = 1.40 MOLE CACO3 ADDED AS LIMESTONE
PER MOLE (SO2+2HCL) ABSORBED

ENTRAINMENT LEVEL = 0.10 WT %

EHT RESIDENCE TIME = 8.0 MIN

SO2 OXIDIZED IN SYSTEM = 95.0 PERCENT

AIR STOICHIOMETRY = 2.50 G-ATOM O /G-MOLE SO2 ABSORBED

SOLIDS IN RECIRCULATED SLURRY = 8.0 WT %

(Continued)

TABLE D-1. (Continued)

SOLIDS DISPOSAL SYSTEM

COST OF LAND = 6000.00 DOLLARS/ACRE

SOLIDS IN SYSTEM SLUDGE DISCHARGE = 85.0 WT %

LANDFILL DISPOSAL OPTION

SOLIDS IN CLARIFIER DISCHARGE = 40.0 WT %

SOLIDS IN FILTER CAKE = 85.0 WT %

FILTRATION RATE = 1.20 TONS DRY SOLIDS/FT2 DAY

LANDFILL DISPOSAL OPTION

STEAM REHEATER (IN-LINE)

SATURATED STEAM TEMPERATURE = 470. DEG F

HEAT OF VAPORIZATION OF STEAM = 752. BTU/LB

OUTLET FLUE GAS TEMPERATURE = 175. DEG F

SUPERFICIAL GAS VELOCITY (FACE VELOCITY) = 25.0 FT/SEC

WATER BALANCE INPUTS

RAINFALL(IN/YEAR)	35.
POND SEEPAGE(CM/SEC)*10**8	50.
POND EVAPORATION(IN/YEAR)	32.

ECONOMIC PREMISES

1979 TVA-EPA ECONOMIC PREMISES

PROJECTED REVENUE REQUIREMENTS INCLUDE LEVELIZED OPERATING AND MAINTENANCE COSTS
RATE = 1.886 TIMES FIRST YEAR OPERATING AND MAINTENANCE COSTS

FREIGHT INCLUDED IN DIRECT INVESTMENT
FREIGHT RATE = 3.5 % OF EQUIPMENT COST

SALES TAX INCLUDED IN DIRECT INVESTMENT
SALES TAX RATE = 4.0 % OF EQUIPMENT COST

LABOR OVERTIME INCLUDED IN DIRECT INVESTMENT
OVERTIME RATE = 1.5

INFLATION RATE = 6.0 %

PROCESS MAINTENANCE = 8.0 % OF DIRECT PROCESS INVESTMENT

LANDFILL MAINTENANCE = 3.0 % OF LANDFILL DIRECT INVESTMENT

(Continued)

TABLE D-1. (Continued)

EMERGENCY BY-PASS
--------- -------

EMERGENCY BY-PASS DESIGNED FOR 50.0 %

HOT GAS TO SCRUBBER
--- --- -- --------

	MOLE PERCENT	LB-MOLE/HR	LB/HR
CO2	12.317	0.2255E+05	0.9923E+06
HCL	0.006	0.1145E+02	0.4175E+03
SO2	0.221	0.4042E+03	0.2589E+05
O2	5.553	0.1017E+05	0.3253E+06
N2	75.199	0.1377E+06	0.3857E+07
H2O	6.703	0.1227E+05	0.2211E+06

SO2 CONCENTRATION IN SCRUBBER INLET GAS = 2208. PPM
= 5.45 LBS / MILLION BTU

FLYASH EMISSION = 0.060 LBS/MILLION BTU TO BOILER
= 285. LB/HR

SOLUBLE CAO IN FLY ASH = 0. LB/HR
SOLUBLE MGO IN FLY ASH = 0.

HOT GAS FLOW RATE = .1156E+07 SCFM (60. DEG F, 14.7 PSIA)
= .1690E+07 ACFM (300. DEG F, 14.7 PSIA)

MW EQUIVALENT OF SCRUBBER = 500 MEGAWATTS

CORRESPONDING COAL FIRING RATE = .4060E+06 LB/HR

HOT GAS HUMIDITY = 0.043 LB H2O/LB DRY GAS

WET BULB TEMPERATURE = 124. DEG F

WET GAS FROM SCRUBBER
--- --- ---- --------

	MOLE PERCENT	LB-MOLE/HR	LB/HR
CO2	11.709	0.2292E+05	0.1009E+07
HCL	0.000	0.5726E+00	0.2088E+02
SO2	0.023	0.4449E+02	0.2850E+04
O2	5.106	0.9994E+04	0.3198E+06
N2	70.326	0.1377E+06	0.3857E+07
H2O	12.836	0.2512E+05	0.4526E+06

SO2 CONCENTRATION IN SCRUBBER OUTLET GAS = 227. PPM

FLYASH EMISSION = 0.030 LBS/MILLION BTU TO BOILER
= 143. LB/HR

TOTAL WATER PICKUP = 475. GPM
INCLUDING 11.3 GPM ENTRAINMENT

WET GAS FLOW RATE = .1236E+07 SCFM (60. DEG F, 14.7 PSIA)
= .1389E+07 ACFM (124. DEG F, 14.7 PSIA)

WET GAS SATURATION HUMIDITY = 0.087 LB H2O/LB DRY GAS

(Continued)

FLUE GAS TO STACK

	MOLE PERCENT	LB-MOLE/HR	LB/HR
CO2	11.690	0.2292E+05	0.1009E+07
HCL	0.000	0.5726E+00	0.2088E+02
SO2	0.023	0.4449E+02	0.2850E+04
O2	5.098	0.9994E+04	0.3198E+06
N2	70.214	0.1377E+06	0.3857E+07
H2O	12.975	0.2544E+05	0.4583E+06

CALCULATED SO2 REMOVAL EFFICIENCY = 89.0 %

CALCULATED SO2 EMISSION = 0.60 POUNDS PER MILLION BTU

CALCULATED SO2 CONCENTRATION IN STACK GAS = 227. PPM

CALCULATED HCL CONCENTRATION IN STACK GAS = 3. PPM

FLYASH EMISSION = 0.030 LBS/MILLION BTU TO BOILER
= 143. LB/HR

STACK GAS FLOW RATE = .1238E+07 SCFM (60. DEG F, 14.7 PSIA)
= .1512E+07 ACFM (175. DEG F, 14.7 PSIA)

STEAM REHEATER (IN-LINE)

SUPERFICIAL GAS VELOCITY (FACE VELOCITY) = 25.0 FT/SEC

SQUARE PIPE PITCH = 2 TIMES ACTUAL PIPE O.D.

SATURATED STEAM TEMPERATURE = 470. DEG F

OUTLET FLUE GAS TEMPERATURE = 175. DEG F

REQUIRED HEAT INPUT TO REHEATER = 0.7418E+08 BTU/HR

STEAM CONSUMPTION = 0.9866E+05 LBS/HR

OUTSIDE PIPE DIAMETER, IN.	PRESSURE DROP IN. H2O	HEAT TRANSFER COEFFICIENT, BTU/HR FT2 DEG F	NUMBER OF PIPES PER BANK PER TRAIN
1.00	0.75	0.2096E+02	92

	REHEATER OUTSIDE PIPE AREA, SQ FT PER TRAIN	NUMBER OF BANKS (ROWS) PER TRAIN
INCONEL	0.1531E+04	5
CORTEN	0.1223E+04	3
TOTAL	0.2754E+04	8

OUTLET SCRUBBER DUCTS ARE CORTEN

(Continued)

TABLE D-1. (Continued)

WATER BALANCE INPUTS

RAINFALL(IN/YEAR)	35.
POND SEEPAGE(CM/SEC)*10**8	50.
POND EVAPORATION(IN/YEAR)	32.

WATER BALANCE OUTPUTS

WATER AVAILABLE		
RAINFALL	0. GPM	38. LB/HR
ALKALI	5. GPM	2691. LB/HR
TOTAL	5. GPM	2730. LB/HR
WATER REQUIRED		
HUMIDIFICATION	463. GPM	231586. LB/HR
ENTRAINMENT	11. GPM	5634. LB/HR
DISPOSAL WATER	27. GPM	13274. LB/HR
HYDRATION WATER	25. GPM	12471. LB/HR
CLARIFIER EVAPORATION	55. GPM	27728. LB/HR
POND EVAPORATION	0. GPM	0. LB/HR
SEEPAGE	0. GPM	0. LB/HR
TOTAL WATER REQUIRED	582. GPM	290693. LB/HR
NET WATER REQUIRED	576. GPM	287963. LB/HR

SCRUBBER SYSTEM

TOTAL NUMBER OF SCRUBBING TRAINS (OPERATING+REDUNDANT) = 5

SO2 REMOVAL = 89.0 PERCENT

PARTICULATE REMOVAL IN SCRUBBER SYSTEM = 50.0 PERCENT

SPRAY TOWER PRESSURE DROP = 2.6 IN. H2O

TOTAL SYSTEM PRESSURE DROP = 7.9 IN. H2O

SPECIFIED SPRAY TOWER L/G RATIO = 106. GAL/1000 ACF(SATD)

LIMESTONE ADDITION = 0.5383E+05 LB/HR DRY LIMESTONE

SPECIFIED LIMESTONE STOICHIOMETRY = 1.40 MOLE CACO3 ADDED AS LIMESTONE PER MOLE (SO2+2HCL) ABSORBED

SOLUBLE CAO FROM FLY ASH = 0.0 MOLE PER MOLE (SO2+2HCL) ABSORBED

TOTAL SOLUBLE MGO = 0.01 MOLE PER MOLE (SO2+2HCL) ABSORBED

TOTAL STOICHIOMETRY = 1.41 MOLE SOLUBLE (CA+MG) PER MOLE (SO2+2HCL) ABSORBED

MAKE UP WATER = 576. GPM

OXIDATION AIR RATE = 0.4972E+05LB/HR
= 0.1083E+05 SCFM (60 DEG F,14.7 PSIA)

CROSS-SECTIONAL AREA PER SCRUBBER = 579. SQ FT

(Continued)

TABLE D-1. (Continued)

SOLIDS DISPOSAL SYSTEM

TOTAL CLARIFIER(S) CROSS-SECTIONAL AREA = 1843. SQ FT

SYSTEM SLUDGE DISCHARGE

SPECIES	LB-MOLE/HR	LB/HR	SOLID COMP, WT %	LIQUID COMP, PPM
CASO3 .1/2 H2O	0.1797E+02	0.2320E+04	2.95	
CASO4 .2H2O	0.3416E+03	0.5879E+05	74.72	
CACO3	0.1481E+03	0.1482E+05	18.83	
INSOLUBLES	----------	0.2753E+04	3.50	
H2O	0.7368E+03	0.1327E+05		
CA++	0.3799E+01	0.1523E+03		10966.
MG++	0.2069E+01	0.5031E+02		3623.
SO3--	0.2415E-01	0.1933E+01		139.
SO4--	0.2237E+00	0.2148E+02		1547.
CL-	0.1088E+02	0.3857E+03		27776.

TOTAL DISCHARGE FLOW RATE = 0.9257E+05 LB/HR
= 88. GPM

TOTAL DISSOLVED SOLIDS IN DISCHARGE LIQUID = 44037. PPM

DISCHARGE LIQUID PH = 7.08

CLARIFIER SOLIDS SETTLING RATE = 8.54 FT/HR

(Continued)

TABLE D-1. (Continued)

SCRUBBER SLURRY BLEED

SPECIES	LB-MOLE/HR	LB/HR
CASO3 .1/2 H2O	0.1797E+02	0.2320E+04
CASO4 .2H2O	0.3416E+03	0.5879E+05
CACO3	0.1481E+03	0.1482E+05
INSOLUBLES	----------	0.2753E+04
H2O	0.4813E+05	0.8671E+06
CA++	0.2400E+03	0.9620E+04
MG++	0.1307E+03	0.3178E+04
SO3--	0.1526E+01	0.1221E+03
SO4--	0.1413E+02	0.1357E+04
CL-	0.6874E+03	0.2437E+05
AD--	0.0	0.0

TOTAL FLOW RATE = 0.9845E+06 LB/HR
= 1873. GPM

TOTAL SUPERNATE RETURN

SPECIES	LB-MOLE/HR	LB/HR
H2O	0.4581E+05	0.8253E+06
CA++	0.2362E+03	0.9467E+04
MG++	0.1287E+03	0.3128E+04
SO3--	0.1501E+01	0.1202E+03
SO4--	0.1391E+02	0.1336E+04
CL-	0.6764E+03	0.2398E+05
AD--	0.0	0.0

TOTAL FLOW RATE = 0.8633E+06 LB/HR
= 1727. GPM

SUPERNATE TO WET BALL MILL

SPECIES	LB-MOLE/HR	LB/HR
H2O	0.1772E+04	0.3192E+05
CA++	0.9134E+01	0.3661E+03
MG++	0.4976E+01	0.1210E+03
SO3--	0.5806E-01	0.4649E+01
SO4--	0.5378E+00	0.5166E+02
CL-	0.2616E+02	0.9273E+03
AD--	0.0	0.0

TOTAL FLOW RATE = 0.3339E+05 LB/HR
= 67. GPM

(Continued)

TABLE D-1. (Continued)

LIMESTONE SLURRY FEED
--------- ------ ----

SPECIES	LB-MOLE/HR	LB/HR
CACO3	0.5109E+03	0.5114E+05
SOLUBLE MGO	0.2003E+01	0.8074E+02
INSOLUBLES	----------	0.2611E+04
H2O	0.1904E+04	0.3430E+05
CA++	0.9134E+01	0.3661E+03
MG++	0.4976E+01	0.1210E+03
SO3--	0.5806E-01	0.4649E+01
SO4--	0.5378E+00	0.5166E+02
CL-	0.2616E+02	0.9273E+03
AD--	0.0	0.0

TOTAL FLOW RATE = 0.8971E+05 LB/HR
= 113. GPM

SUPERNATE RETURN TO SCRUBBER OR EHT
--------- ------ -- -------- -- ---

SPECIES	LB-MOLE/HR	LB/HR
H2O	0.4404E+05	0.7934E+06
CA++	0.2271E+03	0.9101E+04
MG++	0.1237E+03	0.3007E+04
SO3--	0.1443E+01	0.1156E+03
SO4--	0.1337E+02	0.1284E+04
CL-	0.6503E+03	0.2305E+05
AD--	0.0	0.0

TOTAL FLOW RATE = 0.8299E+06 LB/HR
= 1660. GPM

RECYCLE SLURRY TO SPRAY TOWER
------- ------ -- ----- -----

SPECIES	LB-MOLE/HR	LB/HR
CASO3 .1/2 H2O	0.1414E+04	0.1826E+06
CASO4 .2H2O	0.2589E+05	0.4627E+07
CACO3	0.1165E+05	0.1166E+07
INSOLUBLES	----------	0.2167E+06
H2O	0.3779E+07	0.6808E+08
CA++	0.1889E+05	0.7571E+06
MG++	0.1029E+05	0.2502E+06
SO3--	0.1201E+03	0.9613E+04
SO4--	0.1112E+04	0.1068E+06
CL-	0.5410E+05	0.1918E+07
AD--	0.0	0.0

TOTAL FLOW RATE = 0.7741E+08 LB/HR
= 147261. GPM

(Continued)

TABLE D-1. (Continued)

FLUE GAS COOLING SLURRY

SPECIES	LB-MOLE/HR	LB/HR
CASO3 .1/2 H2O	0.5337E+02	0.6890E+04
CASO4 .2H2O	0.1015E+04	0.1746E+06
CACO3	0.4397E+03	0.4401E+05
INSOLUBLES	----------	0.8177E+04
H2O	0.1426E+06	0.2569E+07
CA++	0.7128E+03	0.2857E+05
MG++	0.3883E+03	0.9440E+04
SO3--	0.4531E+01	0.3628E+03
SO4--	0.4197E+02	0.4031E+04
CL-	0.2041E+04	0.7237E+05
AD--	0.0	0.0

TOTAL FLOW RATE = 0.2921E+07 LB/HR
= 5557. GPM

CLARIFIER UNDERFLOW SLURRY

SPECIES	LB-MOLE/HR	LB/HR
CASO3 .1/2 H2O	0.1797E+02	0.2320E+04
CASO4 .2H2O	0.3416E+03	0.5879E+05
CACO3	0.1481E+03	0.1482E+05
INSOLUBLES	----------	0.2753E+04
H2O	0.6126E+04	0.1104E+06
CA++	0.3159E+02	0.1266E+04
MG++	0.1721E+02	0.4183E+03
SO3--	0.2008E+00	0.1608E+02
SO4--	0.1860E+01	0.1786E+03
CL-	0.9046E+02	0.3207E+04
AD--	0.0	0.0

TOTAL FLOW RATE = 0.1941E+06 LB/HR
= 293. GPM

SUPERNATE FROM CLARIFIER

SPECIES	LB-MOLE/HR	LB/HR
CASO3 .1/2 H2O	0.0	0.0
CASO4 .2H2O	0.0	0.0
CACO3	0.0	0.0
INSOLUBLES	----------	0.0
H2O	0.4045E+05	0.7288E+06
CA++	0.2086E+03	0.8360E+04
MG++	0.1136E+03	0.2762E+04
SO3--	0.1326E+01	0.1062E+03
SO4--	0.1228E+02	0.1180E+04
CL-	0.5974E+03	0.2118E+05
AD--	0.0	0.0

TOTAL FLOW RATE = 0.7624E+06 LB/HR
= 1525. GPM

(Continued)

TABLE D-1. (Continued)

FILTER CAKE SLURRY

SPECIES	LB-MOLE/HR	LB/HR
CASO3 .1/2 H2O	0.1797E+02	0.2320E+04
CASO4 .2H2O	0.3416E+03	0.5879E+05
CACO3	0.1481E+03	0.1482E+05
INSOLUBLES	----------	0.2753E+04
H2O	0.7368E+03	0.1327E+05
CA++	0.3799E+01	0.1523E+03
MG++	0.2069E+01	0.5031E+02
SO3--	0.2415E-01	0.1933E+01
SO4--	0.2237E+00	0.2148E+02
CL-	0.1088E+02	0.3857E+03
AD--	0.0	0.0

TOTAL FLOW RATE = 0.9257E+05 LB/HR
= 88. GPM

FILTRATE FROM FILTER

SPECIES	LB-MOLE/HR	LB/HR
CASO3 .1/2 H2O	0.0	0.0
CASO4 .2H2O	0.0	0.0
CACO3	0.0	0.0
INSOLUBLES	----------	0.0
H2O	0.5354E+04	0.9646E+05
CA++	0.2761E+02	0.1106E+04
MG++	0.1504E+02	0.3656E+03
SO3--	0.1755E+00	0.1405E+02
SO4--	0.1625E+01	0.1561E+03
CL-	0.7906E+02	0.2803E+04
AD--	0.0	0.0

TOTAL FLOW RATE = 0.1009E+06 LB/HR
= 202. GPM

(Continued)

TABLE D-1. (Continued)

LANDFILL DESIGN

LANDFILL DIMENSIONS

HEIGHT OF LANDFILL	112.27	FT
HEIGHT OF LANDFILL CAP	92.27	FT
SLOPE OF LANDFILL CAP	6.	DEGREES
LENGTH OF LANDFILL DISPOSAL SIDE	1856.	FT
LENGTH OF LANDFILL TRENCH	7569.	FT
LENGTH OF PERIMETER FENCE	9657.	FT
SURFACE AREA OF LANDFILL	3495.	THOUSAND FT2
FILL AREA LAND EXPOSED TO RAIN	3673.	THOUSAND FT2
SURFACE AREA OF RECLAIM STORAGE	520.	THOUSAND FT2
DISPOSAL LAND AREA OF LANDFILL	3444.	THOUSAND FT2
LAND AREA OF LANDFILL SITE	4930.	THOUSAND FT2
LAND AREA OF LANDFILL SITE	113.	ACRES
VOLUME OF EXCAVATION	301.	THOUSAND YD3
VOLUME OF RECLAIM STORAGE	300.	THOUSAND YD3
VOLUME OF SLUDGE TO BE	5955.	THOUSAND YD3
DISPOSED OVER LIFE OF PLANT	3691.	ACRE FT
DENSITY OF DISCHARGE CAKE	75.00	LBS/FT3
DENSITY OF COMPACTED CAKE	95.00	LBS/FT3
DEPTH OF CATCHMENT POND	24.44	FT
LENGTH OF CATCHMENT POND	373.33	FT
VOLUME OF CATCHMENT POND	96.	THOUSAND YD3

(Continued)

TABLE D-1. (Continued)

LANDFILL COSTS (THOUSANDS OF DOLLARS)

LANDFILL EQUIPMENT			1189.
TAX AND FREIGHT			87.
LANDFILL EQUIPMENT TOTAL			1277.
	LABOR	MATERIAL	TOTAL
CLEARING LAND	249.		249.
EXCAVATION	596.		596.
DISCHARGE TRENCH	25.		25.
GRAVEL	56.	65.	121.
LINING(12. IN. CLAY)	932.		932.
DRAINAGE LANDFILL	10.	102.	113.
SEEDING LANDFILL SITE	89.	53.	142.
ROAD CONSTRUCTION	81.	47.	128.
PERIMETER COSTS, FENCE	66.	74.	140.
RECLAMATION EXPENSE	281.		281.
RECLAMATION CLAY COVER	439.		439.
MONITOR WELLS	6.	5.	11.
SUBTOTAL DIRECT	2830.	347.	3177.
TAX AND FREIGHT		26.	26.
TOTAL DIRECT LANDFILL INVESTMENT	2830.	373.	3203.
ENGINEERING DESIGN AND SUPERVISION (2.0)			64.
ARCHITECT AND ENGINEERING CONTRACTOR(1.0)			32.
CONSTRUCTION EXPENSES (8.0)			256.
CONTRACTOR FEES (5.0)			160.
CONTINGENCY (20.0)			998.
TOTAL FIXED INVESTMENT			5990.
LAND COST			679.

REVENUE QUANTITIES

LANDFILL LABOR	29120.	MAN-HRS
DIESEL FUEL	103596.	GALLONS
ELECTRICITY	145178.	KWH
WATER	3867.	K-GALLONS
ANALYSIS	42.	MAN-HRS

(Continued)

TABLE D-1. (Continued)

PARTICULATE REMOVAL INVESTMENT AND OPERATING COST

WPSUL CONTENT (%):	3.36	PARTICULATE EMISSION REGULATION (LB ASH/MILLION BTU):	0.06
ASH CONTENT (%):	15.10	FLUE GAS TEMPERATURE (COLD) (F):	300.0
BTU RATING:	11700	FLUE GAS TEMPERATURE (HOT) (F):	700.0
BOILER TYPE:	DRY PULVERIZED COAL	COST OF ELECTRICITY ($/KWHR):	0.06
NO. OF SCRUBBERS:	4	COST OF STEAM ($/THOUSAND LB):	4.00
SCRUBBER VELOCITY (FT/M):	600.0	FIRST YEAR CAPITAL CHARGE FACTOR:	0.18
PLANT SIZE (MW):	500	BAGHOUSE RATIO (OPER. SQ.FT./ACTUAL SQ.FT.):	0.80
OPERATING HRS/YR:	5500	BAG COST ($/SQ.FT.):	1.00
PUMPING RATE (GAL/1000 ACF):	20.00	BAG LIFE(YEARS):	3.00
SCA RATIO: (ACTUAL SQ.FT./CALC. SQ.FT.)	1.100	FLUE GAS REHEAT TEMPERATURE (F):	175.00
		CHEMICAL ENGINEERING PLANT INDEX:	346.0

	ELECTROSTATIC PRECIPITATORS COLD	HOT	BAGHOUSE FABRIC FILTERS	SCRUBBE
REQUIRED REMOVAL EFFICIENCY (%):	99.42	99.42	99.42	99.42
DRIFT VELOCITY (FT/M):	27.19	20.00		
SPECIFIC COLLECTION AREA (SQ.FT./ACFM):	208.27	283.14		
COLLECTION AREA (SQ.FT.):	351952.9	730312.4	768846.0	
TOTAL CORONA POWER (KW):	460.1	702.2		
AUXILIARY POWER (KW):	296.6	666.3	490.8	
FAN POWER (KW):	264.5	403.7	1322.3	8480.6
PUMP POWER (KW):				6022.8
TOTAL POWER (KW):	1021.1	1772.2	1813.1	14503.5
OPERATING AIR/CLOTH RATIO:			2.7	
INSTALLED AIR/CLOTH RATIO:			2.2	
REQUIRED PRESSURE DROP (INCHES):	1.0	1.0	5.0	32.1
DIAMETER (FEET):				34
REQUIRED REHEAT (BTU/HR):				64377216.0
STEAM SUPPLY/YR (THOUSAND LB):				393416.2
INSTALLED COST (1985 DOLLARS):	$ 6653621	$ 12334274	$ 19279280	$ 29723120
FIRST YEAR CAPITALIZED COST:	$ 1199869	$ 2224280	$ 3476696	$ 5360068
ANNUAL POWER COST:	$ 308892	$ 536086	$ 548457	$ 4387298
ANNUAL OPERATING AND MAINTENANCE COST (1985 DOLLARS):	$ 125718	$ 188652	$ 96338	$ 2036472
REPLACEMENT COST (1985 DOLLARS):			$ 439978	
ANNUAL REHEAT COST:				$ 1573665
TOTAL ANNUAL COST:	$ 1634479	$ 2949018	$ 4560469	$ 13357503
ANNUALIZED COST OF POWER(MILLS/KWHR):	0.59	1.07	1.66	4.86

(Continued)

TABLE D-1. (Continued)

RAW MATERIAL HANDLING

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
CAR SHAKER AND HOIST	20HP SHAKER 7.5HP HOIST	1	85232.	14392.
CAR PULLER	25HP PULLER, 5HP RETURN	1	70391.	21586.
UNLOADING HOPPER	16FT DIA, 10FT STRAIGHT INCLUDES 6 IN SQ GRATING	1	16566.	6837.
UNLOADING VIBRATING FEEDER	3.5 HP	1	6987.	588.
UNLOADING BELT CONVEYOR	20FT HORIZONTAL, 5HP	1	11490.	1639.
UNLOADING INCLINE BELT CONVEYOR	310 FT, 50 HP	1	85641.	5521.
UNLOADING PIT DUST COLLECTOR	POLYPROPYLENE BAGTYPE, INCLUDES DUST HOOD	1	10835.	5922.
UNLOADING PIT SUMP PUMP	60 GPM, 70 FT HEAD, 5 HP	1	4476.	870.
STORAGE BELT CONVEYOR	200 FT, 5 HP	1	73387.	4521.
STORAGE CONVEYOR TRIPPER	30 FPM, 1 HP	1	27264.	10443.
MOBILE EQUIPMENT	SCRAPPER TRACTOR	1	166916.	0.
RECLAIM HOPPER	7FT WIDE, 4.25FT HT, 2FT WIDE BOTTOM, CS	2	2576.	1876.
RECLAIM VIBRATING FEEDER	3.5 HP	2	13973.	1175.
RECLAIM BELT CONVEYOR	200 FT, 5 HP	1	42182.	3277.
RECLAIM INCLINE BELT CONVEYOR	193 FT, 40 HP	1	60587.	3842.
RECLAIM PIT DUST COLLECTOR	POLYPROPYLENE BAG TYPE	1	7511.	2961.
RECLAIM PIT SUMP PUMP	60GPM, 70 FT HEAD, 5 HP	1	4476.	870.
RECLAIM BUCKET ELEVATOR	90 FT HIGH, 25 HP	1	54294.	7606.
FEED BELT CONVEYOR	60 FT HORIZONTAL 7.5 HP	1	21091.	1639.
FEED CONVEYOR TRIPPER	30 FPM, 1 HP	1	27264.	10443.
FEED BIN	13FT DIA, 21FT STRAIGHT SIDE HT, COVERED, CS	3	46096.	27734.
			---------	---------
TOTAL RAW MATERIAL HANDLING EQUIPMENT COST			839234.	133741.

(Continued)

TABLE D-1. (Continued)

RAW MATERIAL PREPARATION

INCLUDING 2 OPERATING AND 1 SPARE PREPARATION UNITS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
BIN WEIGH FEEDER	14 FT PULLEY CENTERS, 2HP	3	63437.	2661.
GYRATORY CRUSHERS	75 HP	3	402825.	7374.
BALL MILL DUST COLLECTORS	POLYPROPYLENE BAG TYPE 2200 CFM, 7.5 HP	3	28820.	8883.
BALL MILL	CYLINDRICAL 13.5TPH, 767.HP	3	1724395.	114997.
MILLS PRODUCT TANK	5500 GAL 10FT DIA, 10FT HT, FLAKEGLASS LINED CS	3	17963.	13257.
MILLS PRODUCT TANK AGITATOR	7.5 HP	3	38317.	4069.
MILLS PRODUCT TANK SLURRY PUMP	57.GPM, 60 FT HEAD, 2 HP, 2 OPERATING AND 1 SPARE	3	7240.	3051.
SLURRY FEED TANK	59803.GAL, 21.7FT DIA, 21.7 FT HT, FLAKEGLASS-LINED CS	1	24050.	20132.
SLURRY FEED TANK AGITATOR	50 HP	1	49744.	4120.
SLURRY FEED TANK PUMPS	28 GPM, 60 FT HEAD, 1 HP, 4 OPERATING AND 4 SPARE	8	18858.	8137.
			---------	---------
TOTAL FEED PREPARATION EQUIPMENT COST			2375647.	186681.

(Continued)

TABLE D-1. (Continued)

GAS HANDLING

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
I.D. FANS	7.9IN H2O, WITH 664. HP MOTOR AND DRIVE	5	3490060.	63725.
			---------	---------
TOTAL GAS HANDLING EQUIPMENT COST			3490060.	63725.

SO2 SCRUBBING

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
SHELL			2341328.	
NEOPRENE LINING			1928600.	
MIST ELIMINATOR			383686.	
SLURRY HEADER AND NOZZLES			938730.	
GRIDS			627930.	
TOTAL SPRAY SCRUBBER COSTS		5	6220272.	507083.
SOOTBLOWERS	AIR-FIXED	40	174667.	27123.
EFFLUENT HOLD TANK	323974.GAL, 38.0FT DIA, 38.0FT HT, FLAKEGLASS-LINED CS	5	419706.	347464.
EFFLUENT HOLD TANK AGITATOR	66.HP	5	457885.	37922.
COOLING SPRAY PUMPS	1389.GPM 100FT HEAD, 61.HP, 4 OPERATING AND 6 SPARE	10	113911.	36076.
RECIRCULATION PUMPS	18408.GPM, 100FT HEAD, 814.HP, 8 OPERATING AND 7 SPARE	15	2085846.	167399.
MAKEUP WATER PUMPS	3473.GPM, 200.FT HEAD, 293.HP, 1 OPERATING AND 1 SPARE	2	26754.	4155.
			---------	---------
TOTAL SO2 SCRUBBING EQUIPMENT COST			9499038.	1127220.

(Continued)

TABLE D-1. (Continued)

OXIDATION

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
RECIRCULATION TANK	202484.GAL 30.1FT DIA, 38.0FT HT, FLAKEGLASS-LINED CS	5	319840.	264831.
RECIRCULATION TANK AGITATOR	59.HP	5	342708.	28383.
OXIDATION BLEED PUMPS	468.GPM, 60 FT HEAD 12.HP, 4 OPERATING AND 4 SPARE	8	47202.	17942.
OXIDATION AIR BLOWER	2708.SCFM, 267.HP	6	204276.	5425.
OXIDATION SPARGER	19.0 FT DIA RING	5	66414.	42697.
TOTAL FORCED OXIDATION EQUIPMENT COST			980440.	359277.

REHEAT

INCLUDING 4 OPERATING AND 1 SPARE SCRUBBING TRAINS

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
REHEATERS		5	2964017.	184909.
SOOTBLOWERS	AIR-RETRACTABLE	20	327500.	22603.
TOTAL REHEAT EQUIPMENT COST			3291516.	207512.

(Continued)

TABLE D-1. (Continued)

SOLIDS SEPARATION

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
ABSORBER BLEED RECEIVING TANK	80905.GAL. 19.0FT DIA. 39.0FT HT, FLAKGLASS-LINED CS	1	33857.	28353.
ABSORBER BLEED TANK AGITATOR	41 HP	1	37036.	3067.
THICKENER FEED PUMP	1873.GPM, 60FT HEAD, 50.HP, 1 OPERATING AND 1 SPARE	2	23292.	8221.
THICKENER	1843.SQ.FT., 48.FT DIA, 5.5TANK FT HT 1. RAKE HP	1	88611.	69845.
THICKENER UNDERFLOW SLURRY PUMPS	293.GPM, 9.4 FT HEAD, 2 HP , 1 OPERATING AND 1 SPARE	2	9657.	3654.
THICKENER OVERFLOW PUMPS	1525.GPM, 75.0FT HEAD, 48.HP, 1 OPERATING AND 1 SPARE	2	10517.	1633.
THICKENER OVERFLOW TANK	25169.GAL, 28.0FT DIA, 5.5FT HT	1	7223.	5475.
FILTER FEED TANK	4832.GAL, 9.4FT DIA, 9.4 FT HT, FLAKEGLASS-LINED CS	1	4496.	3763.
FILTER FEED TANK AGITATOR	7 HP	1	8443.	699.
FILTER FEED SLURRY PUMP	146.GPM, 50FT HEAD, 4.HP, 2 OPERATING AND 1 SPARE	3	11201.	4049.
FILTER	393.SQ FT FILTRATION AREA, 49. VACUUM HP 2 OPERATING AND 1 SPARE	3	511867.	77905.
FILTRATE PUMP (PER FILTER)	101.GPM, 20.0FT HEAD, 1.HP, 2 OPERATING AND 2 SPARE	4	13939.	2165.
FILTRATE SURGE TANK	3331.GAL, 8.3FT DIA, 8.3FT HT	1	1848.	1400.
FILTRATE SURGE TANK PUMP	202.GPM, 85.0FT HEAD, 7.HP, 1 OPERATING AND 1 SPARE	2	7496.	1164.
FILTER CAKE CONVEYOR	75 FT. HORIZONTAL 100 FT. INCLINE 1.5 HP	1	42066.	3592.
			----------	----------
TOTAL EQUIPMENT COST			811550.	214986.

(Continued)

TABLE D-1. (Continued)

LANDFILL DISPOSAL

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
TRUCKS	16.0 CU YD, 1 SPARE	3	152435.	0.
WHEEL LOADER	7.0 CU YDS-BUCKET	1	385265.	0.
TRACK-DOZER	133.HP,STRAIGHT-BLADE	1	154103.	0.
COMPACTOR	SHEEP-FOOT	1	195749.	0.
WHEEL LOADER	3.5 CU YDS BUCKET,CLEANUP	1	138423.	0.
WATER TRUCK	1500 GALLON TANK AND SPRAY HEADERS	1	37990.	0.
SERVICE TRUCK	WRECKER RIG, TOOLS	1	54649.	0.
TRAILER	12 FT X 30 FT, OFFICE, BREAKROOM,FACILITIES	1	10917.	1130.
WATER TREATMENT SYSTEM	PUMPS, TANKS		32861.	25947.
			----------	----------
TOTAL EQUIPMENT COST			1162389.	27077.

(Continued)

TABLE D-1. (Continued)

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP
PROJECTED CAPITAL INVESTMENT REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL BASE

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 SCRUB	OXID	REHEAT	SOLID SEP	TOTAL	DOLLARS PER KW
EQUIPMENT									
MATERIAL	839.	2376.	3490.	9499.	980.	3292.	812.	21287.	42.57
LABOR	134.	187.	64.	1127.	359.	208.	215.	2293.	4.59
PIPING									
MATERIAL	37.	416.	0.	5723.	25.	559.	851.	7611.	15.22
LABOR	17.	192.	0.	735.	57.	263.	271.	1536.	3.07
DUCTWORK									
MATERIAL	0.	0.	2918.	0.	102.	0.	0.	3020.	6.04
LABOR	0.	0.	2424.	0.	182.	0.	0.	2606.	5.21
FOUNDATIONS									
MATERIAL	215.	114.	49.	103.	45.	0.	35.	561.	1.12
LABOR	524.	219.	88.	208.	90.	0.	69.	1197.	2.39
STRUCTURAL									
MATERIAL	142.	67.	0.	393.	0.	0.	0.	602.	1.20
LABOR	36.	124.	0.	722.	0.	0.	0.	882.	1.76
ELECTRICAL									
MATERIAL	171.	178.	338.	437.	202.	66.	250.	1641.	3.28
LABOR	540.	365.	1103.	780.	226.	67.	529.	3610.	7.22
INSTRUMENTATION									
MATERIAL	1.	167.	60.	942.	69.	32.	54.	1325.	2.65
LABOR	0.	24.	12.	127.	10.	7.	72.	252.	0.50
BUILDINGS									
MATERIAL	0.	161.	0.	0.	34.	0.	61.	256.	0.51
LABOR	0.	166.	0.	0.	34.	0.	61.	260.	0.52
SALES TAX (4.0 %) AND FREIGHT (3.5 %)	105.	261.	514.	1282.	109.	296.	155.	2723.	5.45
TOTAL PROCESS CAPITAL	2762.	5015.	11059.	22079.	2525.	4790.	3434.	51665.	103.33
SERVICES AND MISCELLANEOUS (6.0 %)	166.	301.	664.	1325.	152.	287.	206.	3100.	6.20
TOTAL DIRECT PROCESS INVESTMENT	2927.	5316.	11723.	23403.	2677.	5077.	3640.	54764.	109.53
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	1189.	1189.	2.38
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	3177.	3177.	6.35
LANDFILL SALES TAX (4.0 %) AND FREIGHT (3.5 %)	0.	0.	0.	0.	0.	0.	113.	113.	0.23
TOTAL DIRECT INVESTMENT	2927.	5316.	11723.	23403.	2677.	5077.	8120.	59244.	118.49
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	205.	372.	821.	1638.	187.	355.	255.	3834.	7.67
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	59.	106.	234.	468.	54.	102.	73.	1095.	2.19
CONSTRUCTION EXPENSES (15.0 %)	468.	851.	1876.	3745.	428.	812.	582.	8762.	17.52
CONTRACTOR FEES (5.0 %)	146.	266.	586.	1170.	134.	254.	182.	2738.	5.48
CONTINGENCY (10.0 %)	381.	691.	1524.	3042.	348.	660.	473.	7119.	14.24
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	1511.	1511.	3.02
SUBTOTAL FIXED INVESTMENT	4186.	7602.	16764.	33467.	3828.	7261.	11196.	84303.	168.61
STARTUP & MODIFICATION ALLOWANCE (8.0, 0.0 %)	335.	608.	1341.	2677.	306.	581.	416.	6265.	12.53
INTEREST DURING CONSTRUCTION (15.6 %)	653.	1186.	2615.	5221.	597.	1133.	1747.	13151.	26.30
ROYALTIES (0.0 %)	0.	0.	0.	0.	0.	0.	0.	0.	0.0
LAND ($ 6000. ACRE)	15.	1.	2.	1.	1.	0.	684.	704.	1.41
WORKING CAPITAL	192.	349.	769.	1535.	176.	333.	533.	3885.	7.77
TOTAL CAPITAL INVESTMENT	5381.	9745.	21491.	42901.	4908.	9307.	14576.	108309.	216.62

(Continued)

TABLE D-1. (Continued)

LIMESTONE SLURRY PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS - SHAWNEE COMPUTER USER MANUAL BASE

DISPLAY SHEET FOR YEAR= 1
ANNUAL OPERATION KW-HR/KW = 5500

39.38 TONS PER HOUR DRY SLUDGE
TOTAL CAPITAL INVESTMENT 108308000

	ANNUAL QUANTITY	UNIT COST,$	TOTAL ANNUAL COST,$
DIRECT COSTS			
RAW MATERIAL			
LIMESTONE	148.0 K TONS	15.00/TON	2220400
SUBTOTAL RAW MATERIAL			2220400
CONVERSION COSTS			
OPERATING LABOR AND SUPERVISION	43860.0 MAN-HR	19.00/MAN-HR	833400
LANDFILL LABOR AND SUPERVISION	29120.0 MAN-HR	24.00/MAN-HR	698900
UTILITIES			
STEAM	542640.0 K LB	4.00/K LB	2170500
PROCESS WATER	194000.0 K GAL	0.16/K GAL	31000
ELECTRICITY	56943180.0 KWH	0.055/KWH	3131900
DIESEL FUEL	103600.0 GAL	1.60/GAL	165800
MAINTENANCE			
LABOR AND MATERIAL			4515500
ANALYSES	4990.0 HR	26.00/HR	129700
SUBTOTAL CONVERSION COSTS			11676700
SUBTOTAL DIRECT COSTS			13897100
INDIRECT COSTS			
OVERHEADS			
PLANT AND ADMINISTRATIVE (60.0% OF CONVERSION COSTS LESS UTILITIES)			3706500
FIRST YEAR OPERATING AND MAINTENANCE COSTS			17603600
LEVELIZED CAPITAL CHARGES(14.70% OF TOTAL CAPITAL INVESTMENT)			15921400
FIRST YEAR ANNUAL REVENUE REQUIREMENTS			33525000
EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)			12.19
LEVELIZED OPERATING AND MAINTENANCE (1.886 TIMES FIRST YEAR OPER. & MAIN.)			33200400
LEVELIZED CAPITAL CHARGES(14.70% OF TOTAL CAPITAL INVESTMENT)			15921400
LEVELIZED ANNUAL REVENUE REQUIREMENTS			49121800
EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)			17.86

HEAT RATE 9500. BTU/KWH - HEAT VALUE OF COAL 11700 BTU/LB - COAL RATE 1116500 TONS/YR

Appendix E

ADIPIC ACID INTERACTIVE MODEL

ADIPIC ACID INTERACTIVE MODEL

The adipic acid computerized model in the Shawnee computer model is available as an interactive model that allows the user to optimize the adipic acid enhanced flue gas desulfurization (FGD) system by calculating operating conditions at various input conditions. The optimized values can then be input to the Shawnee model and executed in "forced-through mode" to determine the entire system design and cost.

Adipic acid is an organic acid which serves to buffer the pH of the limestone slurry in the range of 4.6-5.8, thus maintaining a higher driving force for SO_2 removal while operating at a lower limestone stoichiometry. It has been found at the Shawnee test facility at TVA's Shawnee Steam Plant that a stoichiometric ratio of 1.07 mol $CaCO_3$/mol (SO_2 + 2HCl) absorbed provides the optimum conditions. Higher stoichiometric ratios have little effect on SO_2 removal, can cause scaling, and will increase operating costs.

The data generated at the test facility have been reduced to mathematical equations that project a material balance based on input L/G, SO_2 removal, adipic acid concentration, and pH. It is recommended that both pH and limestone stoichiometries be input with the values described above. The model projects the remaining condition when any two of the values for L/G, SO_2 removal, or adipic acid concentration are input.

The adipic acid model requires user knowledge of adipic acid-enhanced systems. Unless L/G, SO_2 removal, or adipic acid concentrations are known or specified, it is recommended that the model be executed several times to optimize conditions.

The FORTRAN variable names are presented in Table E-1 and they are defined in Table E-2. An example COMMAND procedure to interactively execute only the adipic acid model is presented in Table E-3. The results of an interactive computer run are illustrated in Table E-4.

TABLE E-1. FORTRAN VARIABLE NAMES FOR ADIPIC ACID INTERACTIVE MODEL

Line					
1	SR	LG	PH	ISR	ISCRUB
2	SO2R	AD	OX		
3A	VLG	VPD			
3B	V				
3C	V	NSTAGE	NGRID	HS	
4	IREAD				

TABLE E-2. ADIPIC ACID INTERACTIVE MODEL INPUT DEFINITIONS

Line	Variable	Definition	Unit or value
1	SR	Stoichiometry (see ISR option below)	mols $CaCO_3$ added as limestone per mol SO_2 + 2HCl absorbed
1	LG	L/G ratio (see ISR option below)	gal/kaft3
1	PH	Scrubbing liquid pH	
1	ISR	This option controls the method of determining L/G ratio, SO_2 removal, and adipic acid concentration.	
		LG, SO2R, and AD will be processed as input values (there will be no check for validity and consistency).	0
		LG and SO2R will be processed as input values and AD will be calculated by the model.	1
		AD and SO2R will be processed as input values and LG will be calculated by the model.	2
		LG and AD will be processed as input values and SO2R will be calculated by the model.	3
1	ISCRUB	Absorber type	
		Spray tower	1
		TCA	2
		Venturi-spray tower, two effluent tanks	3
		Venturi-spray tower, one effluent tank	4
		Venturi-TCA, two effluent tanks	5
		Venturi-TCA, one effluent tank	6
2	SO2R	SO_2 removal	%
2	AD	Adipic acid in the scrubbing liquid	ppm (wt)
2	OX	Oxidation of sulfite in the scrubbing liquid	mol %

(Continued)

TABLE E-2. (Continued)

Line	Variable	Definition	Unit or value
3A	VLG	L/G ratio in venturi	gal/kaft3
3A	VPD	Venturi throat velocity	ft/sec
3B	V	Spray tower superficial gas velocity	ft/sec
3C	V	TCA superficial gas velocity	ft/sec
3C	NSTAGE	Number of TCA stages	
3C	XGRID	Number of TCA grids	
3C	HS	Height of TCA sphere bed per stage	in.
4	IREAD	Terminate model program Continue with next case	0 1

TABLE E-3. EXAMPLE COMMAND PROCEDURE FOR EXECUTING THE ADIPIC ACID MODEL INTERACTIVELY

```
10  FREE FI(FT03F001,FT05F001,FT06F001)
20  ALLOC FI(FT03F001) DA(*)
30  ALLOC FI(FT05F001) DA(*)
40  ALLOC FI(FT06F001) DA(*)
50  CALL '$LALQ01.INVEST.LOAD(ADIPIC)'
```

TABLE E-4. EXAMPLE RESULTS ILLUSTRATING INTERACTIVE ADIPIC ACID MODEL OUTPUT

```
                                                    TENNESSEE VALLEY AUTHORITY
                                                   COMPUTERIZED ADIPIC ACID MODEL
                                                   REVISION DATE APRIL 08, 1982

USER SHOULD VARY PH, L/G,AND ADIPIC ACID CONCENTRATION
IN ATTEMPS TO IMPROVE SO2 REMOVALS


SEE USER MANUAL FOR VARIABLE DEFINITIONS


       *** VALUES ARE CALCULATED FOR SPRAY TOWER ***

(1)  ENTER SR, LG, PH, ISR, ISCRUB

(2)  ENTER  SO2R, AD, OX

(3B)  ENTER SCRUBBER VELOCITY

INPUT VALUES  SR=  1.070 LG= 80.000 REMOVAL= 90.000 PH=  5.200 AD= 1500.00 VEL=  10.

OUTPUT VALUES  SR=  1.070 LG= 80.000 REMOVAL= 94.800 PH=  5.200 AD= 1500.00 VEL=  10.

(4)  ENTER 1 TO CONTINUE OR 0 TO STOP

     *** VALUES BELOW ARE FOR TCA SCRUBBER ***

(1) ENTER SR, LG, PH, ISR, ISCRUB

(2) ENTER  SO2R, AD, OX

(3C) ENTER TCA SCRUB VEL, STAGES, GRIDS, SPHERE HT

INPUT VALUES  SR=  1.070 LG= 45.000 REMOVAL= 90.000 PH=  5.200 AD= 1500.00 VEL=  10.

OUTPUT VALUES  SR=  1.070 LG= 45.000 REMOVAL= 93.741 PH=  5.200 AD= 1500.00 VEL=  10.

(4) ENTER 1 TO CONTINUE OR 0 TO STOP

    *** VALUES BELOW ARE FOR VENTURI-SPRAY TOWER ***

(1) ENTER SR, LG, PH, ISR, ISCRUB

(2) ENTER  SO2R, AD, OX

(3A) ENTER VLG,VPD

INPUT VALUES  SR=  1.070 LG= 40.000 REMOVAL= 90.000 PH=  5.200 AD= 1500.00 VEL=  10.

OUTPUT VALUES  SR=  1.070 LG= 40.000 REMOVAL= 95.176 PH=  5.200 AD= 1500.00 VEL=  10.

(4) ENTER 1 TO CONTINUE OR 0 TO STOP
```

Appendix F

POND INTERACTIVE MODEL

POND INTERACTIVE MODEL

The pond model in the Shawnee computer model can be executed in an interactive mode to project pond designs and costs independent of the scrubbing model. In this mode, the pond design is based on the final volume of the waste, which is specified by the GPMSS and THRS input variables. GPMSS specifies the waste input rate in gal/min using the final dry bulk density and THRS specifies the lifetime hours of pond disposal site operation.

The FORTRAN variable names are presented in Table F-1 and they are defined in Table F-2. An example COMMAND procedure to interactively execute only the pond model is presented in Table F-3. The results of an interactive computer run are illustrated in Table F-4.

TABLE F-1. FORTRAN VARIABLE NAMES FOR

POND INTERACTIVE MODEL

Line	
1	IOTIME OTRATE
2	UA RMI RLI
3	IECON
4	PENGIN PARCH PFLDEX PFEES PCONT PSTART PCONIN
5	ITAXER TXRAT FRRAT
6	GPMSS THRS
7	EMAX AMAX
8	LINER
9	XLINA XLINB
10A	No entry
10B	PDEPTH
10C	DBEG DEND DINC
10D	VBEG VEND VINC
11	PCLEAR PDEXEC SODM SODL PERIMM PERIML ROADMM ROADLL
12	WELLM WELLL RECLAM

TABLE F-2. POND INTERACTIVE MODEL INPUT DEFINITIONS

Line	Variable	Definition	Unit or value
1	IOTIME	Overtime construction labor option	
		No overtime labor	0
		Overtime labor on 7% of total labor based on the OTRATE rate below	1
1	OTRATE	Overtime labor rate (applied to 7% of total labor) Example: 1.5	
2	UA	Land cost	$/acre
2	RMI	_Chemical Engineering_ material cost index (see premises)	
2	RLI	_Chemical Engineering_ labor cost index (see premises)	
3	IECON	Economic premises option	
		Current premises	1
		Premises prior to 12/5/79	0
4	PENGIN	Pond construction engineering design and supervision expenses	%
4	PARCH	Pond construction architect and engineering contractor expenses	%
4	PFLDEX	Pond construction field expenses	%
4	PFEES	Pond construction contractor fees	%
4	PCONT	Pond construction contingency	%
4	PSTART	Allowance for pond startup and modification	%
4	PCONIN	Interest during construction	%
5	ITAXFR	Sales tax and freight option	
		No sales tax or freight	0
		Sales tax and freight rates specified by TXRAT and FRRAT below	1
5	TXRAT	Sales tax rate (applied only when ITAXFR above set to 1)	%

(Continued)

TABLE F-2. (Continued)

Line	Variable	Definition	Unit or value
5	FRRAT	Freight rate (applied only when ITAXFR above set to 1)	%
6	GPMSS	Accumulation rate of settled sludge (settled bulk density)	gpm
6	THRS	Total lifetime disposal operating time	hr
7	EMAX	Maximum excavation depth	ft
7	AMAX	Maximum site area	acres
8	LINER	Pond lining option	
		Clay liner	1
		Synthetic liner	2
		No liner	3
		(Refer to the XLINA and XLINB variables that immediately follow.)	
9	XLINA	If LINER = 1, XLINA = clay depth	in.
		If LINER = 2, XLINA = material unit cost	$\$/yd^2$
		If LINER = 3, XLINA = 0	
9	XLINB	If LINER = 1, XLINB = clay cost	$\$/yd^3$
		If LINER = 2, XLINB = labor unit cost	$\$/yd^2$
		If LINER = 3, XLINB = 0	
10A	-	Not required, optimum pond	
10B	PDEPTH	Pond depth (fixed-depth option)	ft
10C	DBEG	Minimum pond depth (pond depth table option)	ft
10C	DEND	Maximum pond depth (pond depth table option)	ft
10C	DINC	Pond depth increment (pond depth table option)	ft
10D	VBEG	Minimum pond volume (pond volume table option)	Mgal
10D	VEND	Maximum pond volume (pond volume table option)	Mgal
10D	VINC	Pond volume increment (pond volume table option)	Mgal

(Continued)

TABLE F-2. (Continued)

Line	Variable	Definition	Unit or value
11	PCLEAR	Clearing cost	\$/acre
11	PDEXEC	Excavation cost	\$/yd3
11	SODM	Revegetation material cost	\$/yd^2
11	SODL	Revegetation labor cost	\$/yd^2
11	PERIMM	Perimeter fence and lights material	\$/ft
11	PERIML	Perimeter fence and lights labor	\$/ft
11	ROADMM	Road construction material cost	\$/yd3
11	ROADLL	Road construction labor cost	\$/yd3
12	WELLM	Monitor well, material cost (60 ft of 4-in.-diameter pipe)	\$
12	WELLL	Monitor well, labor cost	\$
12	RECLAM	Reclamation cost	\$/acre

TABLE F-3. EXAMPLE COMMAND PROCEDURE FOR EXECUTING THE POND MODEL INTERACTIVELY

```
FREE FI(FT03F001,FT05F001,FT06F001)
ALLOC FI(FT03F001) DA(*)
ALLOC FI(FT05F001) DA(*)
ALLOC FI(FT06F001) DA(*)
CALL '$LALQ01.INVEST.LOAD(PND)'
```

TABLE F-4. EXAMPLE RESULTS ILLUSTRATING INTERACTIVE POND MODEL OUTPUT

```
                              TENNESSEE VALLEY AUTHORITY
                      POND COMPUTERIZED DESIGN-COST ESTIMATE MODEL

                             REVISION DATE APRIL 14, 1983

ENTER TYPE OF RUN:
   1 - OPTIMUM POND
   2 - FIXED DEPTH POND
   3 - POND DEPTH TABLE
   4 - POND CAPACITY TABLE
   5 - TERMINATE

(1) ENTER OVERTIME FLAG AND RATE.
     IF UNKNOWN USE 1, 1.5

(2) ENTER COST OF LAND AND MATERIAL AND LABOR INDEXES, FOR DESIRED YEA R
     IF UNKNOWN USE 6000, 366.8, 292.2

(3) ENTER ECONOMIC PREMISES FLAG (NEW=1, OLD=0)

(4) ENTER OVERHEAD PERCENTAGES ENGIN, ARCTEC, FLDEXP, FEES,CONT, START , AND CONINT
     IF UNKNOWN ENTER 2, 1, 8; 5, 10, 8, 15.6

(5) ENTER TAX AND FREIGHT FLAG AND RATES AS A PERCENTAGES
     IF UNKNOWN USE 1, 4, 3.5

(6) ENTER NET ACCUMULATION OF SETTLED SLUDGE IN GPM  AND TOTAL EQUIV.  POND LIFE IN HOURS
     IF UNKNOWN USE 88, 165000

(7) ENTER MAX. EXCAVATION IN FEET AND MAX. ACREAGE.
     IF UNKNOWN USE 9999, 9999

(8) ENTER 1 IF CLAY LINING DESIRED; ENTER 2 IF SYNTHETIC LINING DESIRE D; OR ENTER 3 FOR NO LINING

(9) ENTER CLAY LINING DEPTH IN INCHES AND UNIT COSTS IN DOLLARS PER CUBIC YARD
     IF UNKNOWN USE 12.0, 6.15

(10) NO ENTRY FOR THIS OPTION

(11) ENTER CLEARING COSTS/ACRE, EXCAVATION COSTS/YD3,SEED-FERTILIZER COSTS/YD2 M&L,
     PERIMETER M&L COSTS/FT, ROAD COST,S/YD3 M&L
      IF UNKNOWN USE : 1950,1.75,.3,.49,7.0,6.05,6.0,8.5

(12) ENTER MATERIAL AND LABOR COST MONITOR WELLS $ RECLAIMATION COSTS/ ACRE
      IF UNKNOWN USE: 5000,5100,3100
```

(Continued)

TABLE F-4. (Continued)

POND DESIGN

OPTIMIZED TO MINIMIZE TOTAL COST PLUS OVERHEAD

POND DIMENSIONS

DEPTH OF POND	20.29	FT
DEPTH OF EXCAVATION	3.84	FT
LENGTH OF DIVIDER DIKE	1797.	FT
LENGTH OF POND PERIMETER DIKE	9962.	FT
LENGTH OF POND PERIMETER FENCE	10968.	FT
SURFACE AREA OF BOTTOM	589.	THOUSAND YD2
SURFACE AREA OF INSIDE WALLS	96.	THOUSAND YD2
SURFACE AREA OF OUTSIDE WALLS	70.	THOUSAND YD2
SURFACE AREA OF RECLAIM STORAGE	57.	THOUSAND YD2
LAND AREA OF POND	678.	THOUSAND YD2
LAND AREA OF POND SITE	881.	THOUSAND YD2
LAND AREA OF POND SITE	182.	ACRES
VOLUME OF EXCAVATION	815.	THOUSAND YD3
VOLUME OF RECLAIM STORAGE	255.	THOUSAND YD3
VOLUME OF SLUDGE TO BE	4314.	THOUSAND YD3
DISPOSED OVER LIFE OF PLANT	2674.	ACRE FT

(Continued)

TABLE F-4. (Continued)

POND COSTS (THOUSANDS OF DOLLARS)

	LABOR	MATERIAL	TOTAL
CLEARING LAND	401.		401.
EXCAVATION	1616.		1616.
DIKE CONSTRUCTION	1938.		1938.
LINING(12. IN. CLAY)	1405.		1405.
SEEDING DIKE WALLS	123.	73.	202.
ROAD CONSTRUCTION	16.	22.	37.
PERIMETER COSTS, FENCE	66.	76.	142.
RECLAMATION EXPENSE	543.		543.
MONITOR WELLS	5.	5.	10.
SUBTOTAL DIRECT	6114.	176.	6289.
TAX AND FREIGHT		13.	13.
TOTAL DIRECT POND INVESTMENT	6114.	189.	6302.
ENGINEERING DESIGN AND SUPERVISION (2.0)			126.
ARCHITECT AND ENGINEERING CONTRACTOR(1.0)			63.
CONSTRUCTION EXPENSES (8.0)			504.
CONTRACTOR FEES (5.0)			315.
CONTINGENCY (10.0)			731.
TOTAL FIXED INVESTMENT			8042.
LAND COST			1092.

MORE? NO

ENTER TYPE OF RUN:
1 - OPTIMUM POND
2 - FIXED DEPTH POND
3 - POND DEPTH TABLE
4 - POND CAPACITY TABLE
5 - TERMINATE

Appendix G

LANDFILL INTERACTIVE MODEL

G·

LANDFILL INTERACTIVE MODEL

The landfill model in the Shawnee computer model can be executed in an interactive mode to project landfill designs and costs independent of the scrubbing model. In this mode, the landfill design is based on the final volume of the waste, which is specified by the GPMSS and TOPHRS input variables. GPMSS specifies the waste input rate in yd^3/hr at the compacted volume and TOPHRS specifies the lifetime hours of landfill disposal site operation.

The FORTRAN variable names are presented in Table G-1 and they are defined in Table G-2. An example COMMAND procedure to interactively execute only the landfill model is presented in Table G-3. The results of an interactive computer run are illustrated in Table G-4.

TABLE G-1. FORTRAN VARIABLE NAMES FOR

LANDFILL INTERACTIVE MODEL

Line	
1	IOTIME OTRATE
2	ACRE$ RATMAT RATLAB
3	IECON
4	PENGIN PARCH PFLDEX PFEES PCONT PSTART PCONIN
5	ITAXFR TXRAT FRRAT
6	GPMSS TOPHRS OPP DISTPD STORM
7	A1 HLIFT SW(3)
8	DEND DENS
9	ILINER
10A	CLAYIN CLAYUC
10B	ULFC(1) ULFC(2)
11	ULFC(3) ULFC(4) ULFC(5)
12	ULFC(6) ULFC(7)
13	PCLEAR PDEXEC SODM SODL PERIMM PERIML ROADMM ROADML
14	WELLM WELLL RECLAM
15	UC(6) UC(10) CAP CAPS
16	INEXT

TABLE G-2. LANDFILL INTERACTIVE MODEL INPUT VARIABLE DEFINITIONS

Line	Variable	Definition	Unit or value
1	IOTIME	Overtime construction labor option	
		No overtime labor	0
		Overtime labor on 7% of total labor	1
1	OTRATE	Overtime labor rate (times standard rate) Example: 1.5	
2	ACRE$	Land cost	$/acre
2	RATMAT	_Chemical Engineering_ material cost index (see premises)	
2	RATLAB	_Chemical Engineering_ labor cost index (see premises)	
3	IECON	Economic premises option	
		Current premises	1
		Premises prior to 12/5/79	0
4	PENGIN	Landfill construction engineering design and supervision expenses	%
4	PARCH	Landfill construction architect and engineering contractor expenses	%
4	PFLDEX	Landfill construction field expenses	%
4	PFEES	Landfill construction contractor fees	%
4	PCONT	Landfill construction contingency	%
4	PSTART	Allowance for landfill startup and modifications	%
4	PCONIN	Interest during construction	%
5	ITAXFR	Sales tax and freight option	
		No sales tax or freight	0
		Sales tax and freight rates as specified by TXRAT and FRRAT	1
5	TXRAT	Sales tax rate (applied only when ITAXFR above set to 1)	%

(Continued)

TABLE G-2. (Continued)

Line	Variable	Definition	Unit or value
5	FRRAT	Freight rate (applied only when ITAXFR above set to 1)	%
6	GPMSS	Waste disposal rate (compacted volume)	yd^3/hr
6	TOPHRS	Total lifetime disposal operating time	hr
6	OPP	First-year operating hours	hr/yr
6	DISTPD	Transportation distance from scrubber area to landfill site	ft
6	STORM	Rainfall for 10-year storm, 24-hour period	in.
7	A1	Landfill cap slope	degrees
7	HLIFT	Landfill height at perimeter	ft
7	SW(3)	Offset width	ft
8	DEND	Uncompacted bulk density of waste	lb/ft3
8	DENS	Compacted bulk density of waste	lb/ft3
9	ILINER	Landfill liner option	
		Clay liner	1
		Synthetic liner	2
		No liner	3
10A	CLAYIN	Clay liner thickness (if ILINER = 1)	in.
10A	CLAYUC	Clay cost (if ILINER = 1)	$/yd3
10B	ULFC(1)	Synthetic liner unit material cost (if ILINER = 2)	$\$/yd^2$
10B	ULFC(2)	Synthetic liner unit labor cost (if ILINER = 2)	$\$/yd^2$
11	ULFC(3)	8-inch drain, material and labor cost	$/ft
11	ULFC(4)	4-inch drain, material and labor cost	$/ft

(Continued)

TABLE G-2. (Continued)

Line	Variable	Definition	Unit or value
11	ULFC(5)	Drain pipe, 8-inch to 4-inch tees, material and labor	$/each
12	ULFC(6)	Gravel material cost	$/ft3
12	ULFC(7)	Gravel labor cost	$/ft3
13	PCLEAR	Clearing cost	$/acre
13	PDEXEC	Excavation cost	$/yd3
13	SODM	Revegetation material cost	$/yd2
13	SODL	Revegetation labor cost	$/yd2
13	PERIMM	Perimeter fence and lights material costs	$/ft
13	PERIML	Perimeter fence and lights labor costs	$/ft
13	ROADMM	Road gravel material cost	$/yd3
13	ROADML	Road gravel labor cost	$/yd3
14	WELLM	Monitor well material cost, 60 feet of 4-inch pipe	$
14	WELLL	Monitor well labor cost	$
14	RECLAM	Reclamation cost	$/acre
15	UC(6)	Landfill transportation and operating labor	$/hr
15	UC(10)	Diesel fuel	$/gal
15	CAP	Final soil cover, material and labor	$/yd3
15	CAPS	Synthetic cover, material and labor	$/yd2
16	INEXT	Terminate program Continue with next case	0 1

TABLE G-3. EXAMPLE COMMAND PROCEDURE FOR EXECUTING THE LANDFILL MODEL INTERACTIVELY

```
10  FREE FI(FT03F001,FT05F001,FT06F001)
20  ALLOC FI(FT03F001) DA(*)
30  ALLOC FI(FT05F001) DA(*)
40  ALLOC FI(FT06F001) DA(*)
50  CALL '$LALQ01.INVEST.LOAD(LANDF)'
```

TABLE G-4. EXAMPLE RESULTS ILLUSTRATING INTERACTIVE LANDFILL MODEL OUTPUT

```
                                    TENNESSEE VALLEY AUTHORITY
                            LANDFILL COMPUTERIZED DESIGN-COST ESTIMATE MODEL

                                  REVISION DATE APRIL 14, 1983


   ALL UNIT COSTS MUST BE IN OPERATIONAL YEAR DOLLARS,
   THOSE LISTED 1985; INDEX ONLY APPLIES TO EQUIPMENT. IF
   SPECIFIED, OVERTIME DOLLARS ARE INCLUDED IN LABOR COSTS

(1) ENTER OVERTIME FLAG AND RATE.
     IF UNKNOWN USE 1,1.5

(2) ENTER COST OF LAND AND MATERIAL AND LABOR INDEXES FOR DESIRED YEAR
     IF UNKNOWN USE 6000, 366.8, 292.2

(3) ENTER ECONOMIC PREMISES FLAG (NEW=1, OLD=0)

(4) ENTER OVERHEAD AND PERCENTAGES ENGIN, ARCTEC,FLDEXP,FEES,CONT,START,AND CONINT
     IF UNKNOWN ENTER 2, 1, 8, 5, 20, 0, 15.6

(5) ENTER TAX AND FREIGHT FLAG AND RATES AS A PERCENTAGE
     IF UNKNOWN ENTER 1, 4, 3.5

(6) ENTER NET ACCUMULATION OF COMPACTED SLUDGE IN YD3/HR AND TOTAL EQUIV. LANDFILL LIFE IN HOURS
    FIRST YEAR OPERATING, AND DISTANCE TO SITE,STORM INCHES,
     IF UNKNOWN USE 36.1, 165000, 5500, 5280, 8

(7) ENTER CAP SLOPE IN DEGREES, LIFT HEIGHT AND OFFSET WIDTH IN FEET
     IF UNKNOWN USE 6, 20, 10

(8) ENTER DISCHARGE AND COMPACT DENSITY IN LBS/FT3.
     IF UNKNOWN USE 75 ,95 FOR OXIDIXED SLUDGE

(9) ENTER 1 IF CLAY LINING DESIRED; ENTER 2 IF SYNTHETIC LINING DESIRED; OR 3 FOR NO LINING

(10A) ENTER CLAY LINING DEPTH IN INCHES AND UNIT COSTS IN DOLLARS PER CUBIC YARD
       IF UNKNOWN USE 12.0, 6.72

(11) ENTER DRAIN INVESTMENT 8 INCH, 4 INCH, TEES M &L
      IF UNKNOWN USE 5.16, 2.25, 13.12

(12) ENTER GRAVEL COST PER CUBIC FOOT  M + L
      IF UNKNOWN USE 0.31, 0.25

(13) ENTER CLEARING COSTS/ACRE, EXCAVATION COSTS/YD3, SEED-FERTILIZER COSTS/YD2 M & L,
     PERIMETER M & L COSTS/FT,ROAD COSTS/YD3 M & L.
      IF UNKNOWN USE: 2130,1.91,.33,.54,7.64,6.61,6.55,9.28

(14) ENTER MATERIAL AND LABOR COSTS MONITOR WELLS $, RECLAIMATION COST $/ACRE :
      IF UNKNOWN USE : 5400, 5550, 3385

(15) ENTER LABOR IN $/HR AND FUEL IN $/GALLON,RECAP IN $/YD3 CLAY AND $/YD2 SYNTHETIC M+L
      IF UNKNOWN USE 26.20, 1.75, 6.72, 5.25
```

(Continued)

TABLE G-4. (Continued)

LANDFILL DESIGN

LANDFILL DIMENSIONS

HEIGHT OF LANDFILL	112.28	FT
HEIGHT OF LANDFILL CAP	92.28	FT
SLOPE OF LANDFILL CAP	6.	DEGREES
LENGTH OF LANDFILL DISPOSAL SIDE	1856.	FT
LENGTH OF LANDFILL TRENCH	7570.	FT
LENGTH OF PERIMETER FENCE	9658.	FT
SURFACE AREA OF LANDFILL	3496.	THOUSAND FT2
FILL AREA LAND EXPOSED TO RAIN	3674.	THOUSAND FT2
SURFACE AREA OF RECLAIM STORAGE	520.	THOUSAND FT2
DISPOSAL LAND AREA OF LANDFILL	3445.	THOUSAND FT2
LAND AREA OF LANDFILL SITE	4931.	THOUSAND FT2
LAND AREA OF LANDFILL SITE	113.	ACRES
VOLUME OF EXCAVATION	301.	THOUSAND YD3
VOLUME OF RECLAIM STORAGE	300.	THOUSAND YD3
VOLUME OF SLUDGE TO BE	5957.	THOUSAND YD3
DISPOSED OVER LIFE OF PLANT	3692.	ACRE FT
DENSITY OF DISCHARGE CAKE	75.00	LBS/FT3
DENSITY OF COMPACTED CAKE	95.00	LBS/FT3
DEPTH OF CATCHMENT POND	24.44	FT
LENGTH OF CATCHMENT POND	373.36	FT
VOLUME OF CATCHMENT POND	96.	THOUSAND YD3

(Continued)

TABLE G-4. (Continued)

LANDFILL COSTS (THOUSANDS OF DOLLARS)

LANDFILL EQUIPMENT			1190.
TAX AND FREIGHT			87.
LANDFILL EQUIPMENT TOTAL			1277.
	LABOR	**MATERIAL**	**TOTAL**
CLEARING LAND	250.		250.
EXCAVATION	596.		596.
DISCHARGE TRENCH	25.		25.
GRAVEL	55.	66.	122.
LINING(12. IN. CLAY)	956.		956.
DRAINAGE LANDFILL	10.	102.	113.
SEEDING LANDFILL SITE	90.	53.	143.
ROAD CONSTRUCTION	81.	47.	128.
PERIMETER COSTS, FENCE	66.	74.	140.
RECLAMATION EXPENSE	281.		281.
RECLAMATION CLAY COVER	450.		450.
MONITOR WELLS	6.	5.	11.
SUBTOTAL DIRECT	2866.	348.	3214.
TAX AND FREIGHT		26.	26.
TOTAL DIRECT LANDFILL INVESTMENT	2866.	374.	3241.
ENGINEERING DESIGN AND SUPERVISION (2.0)			65.
ARCHITECT AND ENGINEERING CONTRACTOR(1.0)			32.
CONSTRUCTION EXPENSES (8.0)			259.
CONTRACTOR FEES (5.0)			162.
CONTINGENCY (20.0)			1007.
TOTAL FIXED INVESTMENT			6043.
LAND COST			679.

REVENUE QUANTITIES

LANDFILL LABOR	29120.	MAN-HRS
DIESEL FUEL	103600.	GALLONS
ELECTRICITY	145202.	KWH
WATER	3867.	K-GALLONS
ANALYSIS	42.	MAN-HRS

(Continued)

TABLE G-4. (Continued)

LANDFILL EQUIPMENT

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
TRUCKS	16.0 CU YD,1 SPARE	3	152435.	0.
WHEEL LOADER	7.0 CU YDS-BUCKET	1	385265.	0.
TRACK-DOZER	133.HP,STRAIGHT-BLADE	1	154134.	0.
COMPACTOR	SHEEP-FOOT	1	195801.	0.
WHEEL LOADER	3.5 CU YDS BUCKET CLEANUP	1	138423.	0.
WATER TRUCK	1500 GALLON TANK AND SPRAY HEADERS	1	37990.	0.
SERVICE TRUCK	WRECKER RIG, TOOLS	1	54661.	0.
TRAILER	12 FT X 30 FT, OFFICE BREAKROOM-FACILITIES	1	10917.	1130.
WATER TREATMENT SYSTEM	PUMPS, TANKS		32867.	25952.
			--------	--------
EQUIPMENT TOTAL			1162489.	27082.

(16) ENTER 1 TO CONTINUE , 0 TO STOP

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/8-85-006	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Shawnee Flue Gas Desulfurization Computer Model Users Manual		5. REPORT DATE March 1985
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) F. A. Sudhoff and R. L. Torstrick		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS TVA, Office of Power, Division of Energy Demonstrations and Technology, Muscle Shoals, Alabama 35660		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. EPA IAG-79-D-X0511
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 10/81 - 1/85
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES AEERL project officer is J. David Mobley, Mail Drop 61, 919/541-2612.

16. ABSTRACT The manual describes a Shawnee flue gas desulfurization (FGD) computer model and gives detailed instructions for its use. The model, jointly developed by Bechtel National, Inc. and TVA (in conjunction with the EPA-sponsored Shawnee test program), is capable of projecting preliminary design and economics for lime- and limestone-scrubbing FGD systems, including spray tower, turbulent contact absorber (TCA), and venturi/spray-tower scrubbing options. It may be used to project the effect on system design and economics of variations in required SO2 removal, scrubber operating parameters (gas velocity, liquid/gas ratio, alkali stoichiometry, and liquor holdtime in slurry recirculation tanks), reheat temperature, and scrubber bypass. It may also be used to evaluate alternative waste disposal methods or additives (MgO or adipic acid) on costs for the selected process. Although the model is not intended to project the economics of an individual system to a high degree of accuracy, it allows prospective users to quickly project comparative design and costs for limestone and lime case variations on a common design and cost basis. The manual describes and explains the user-supplied input data which are required (e.g., boiler size, coal characteristics, and SO2 removal requirements). Outputs include a material balance, equipment list, and capital investment/annual revenue needs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Scrubbers	Pollution Control	13B	13I
Mathematical Models		Stationary Sources	12A	
Flue Gases	Calcium Oxides		21B	07B
Desulfurization	Limestone		07A,07D	08G
Design	Waste Disposal		14G	
Economics			05C	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 273
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)