United States
Environmental Protection
Agency

Air and Energy Engineering
Research Laboratory
Research Triangle Park NC 27711

Research and Development

EPA/600/S8-85/006 Sept. 1985

EPA

Project Summary

Shawnee Flue Gas Desulfurization Computer Model Users Manual

F. A. Sudhoff and R. L. Torstrick

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, liquid-to-gas 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 variations on a common design and costs basis.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

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 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 diposal. 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 treatment 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.

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 and texts 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 mathematic 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 in published literature 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:

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

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°; 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 Shawnee test facility reports and symposium proceedings.

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. Ranges for basic design parameters include:

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/aft^3 (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 manual 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 inprocess 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 of the raw material-handling area include 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 20-25% 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 weight 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

*1 ft = 30.48 cm; 1 gal. = 3.785 L; 1 ft^3 = 28.32 L; and °C = 5/9 (°F-32).

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 of 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 two-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. 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 MgO or 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 optional, providing 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)—is 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 (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) or (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 options (3) and (4), the fixation fee must include costs for transportation and disposal of the fixed sludge offsite. For options (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 option (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 area 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.

Process Equipment Design Basis

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 cost 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 crushers are used to reduce the inlet stone size from minus 1-1/2 in. to minus 3/4-in. 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 ft. 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 20-25% 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 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.

*1 HP = 9809.5 W; 1T = 907.2 kg.

Scrubbing Trains

The following procedures are used to determine 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. The number of scrubber grids and beds, and the 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 include:

Venturi: Carbon steel with acid-resistance lining.

Shell: Rubber-lined carbon steel.

Grids: Type 316L stainless steel.

Spheres: 1-1/2 in.-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 area 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, the diameter of each tank equals its height up to a maximum height of 60 ft. For tank diameters larger than 60 ft, tank height is fixed at 60 ft 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 on override to the calculated diameter, a minimum diameter equal to 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.

*1 ft^2 = 0.0929 m^2.

Agitators

All slurry tanks are equipped with a four-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 ft are provided for each 10,000 gpm of water required. The pumps are carbon steel spared.

Compressors

The compressors are sized to provide sufficient air (oxygen) for oxidizing the $CaSO_3 \cdot 1/2\ H_2O$ to $CaSO_4 \cdot 2\ H_2O$. 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-in.* tubes on a 2-in. square pitch.

Thickeners

The thickeners are constructed of carbon steel tank walls coated with epoxy paint and 1 ft 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 ft. 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.

*1 in. = 2.54 cm.

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-in.-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-in. diameter and rubber-lined strainers are used for 4-in.-diameter and larger pipes. For slurry lines less than 3-in. diameter, stainless steel plug valves are used. Eccentric plug valves are used for slurry lines between 3- and 20-in. diameter, and knife gate valves are used for valves greater than 20-in. diameter. Handwheel operators are used for valves less than 12-in. diameter and air cylinder actuators for larger valves. Typical piping layouts 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 ft 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-in. Cor-Ten with the exception of ductwork between the scrubber and reheater outlet which is 3/16-in. type 316 stainless steel. All ductwork is insulated with 2-in. 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 cost may depend on the number of scrubbing trains, ball mills, and 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. 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. The pond model is based on 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 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 achitectural 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 regulator 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 manual contains information required to run the overall computer model.

F. A. Sudhoff and R. L. Torstrick are with TVA, Office of Power, Muscle Shoals, AL 35660.

***J. David Mobley** is the EPA Project Officer (see below).*

The complete report, entitled "Shawnee Flue Gas Desulfurization Computer Model Users Manual," (Order No. PB 85-243 111/AS; Cost: $22.95, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

☆U. S. GOVERNMENT PRINTING OFFICE:1985/559-111/20693

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

U.S. OFFICIAL MAIL
U.S. POSTAGE

Official Business
Penalty for Private Use $300

EPA/600/S8-85/006

0000329 PS

U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604