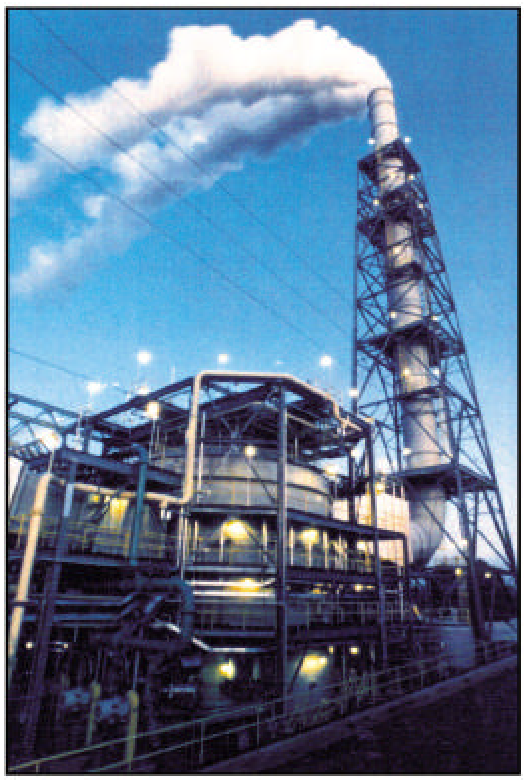
Demonstration of Innovative Applications of Technology for Cost Reductions to the CT-121 FGD Process

DOE ICCT PROJECT DE-FC22-90PC89650

FINAL REPORT

Volume 1 of 6: Executive Summary



Project Sponsors

Southern Company
US Department of Energy
Electric Power Research Institute

Issue Date: January 1997

DEMONSTRATION OF INNOVATIVE APPLICATIONS OF TECHNOLOGY FOR THE CT-121 FGD PROCESS

at

Georgia Power's

Plant Yates

Final Report

Volume 1
Executive Summary

DOE DE-FC22-90PC89650
SCS C-90-00284

Prepared by:

Southern Company Services, Inc.
42 Inverness Parkway, Suite 340
Birmingham, Alabama 35242

January 1997

DISCLAIMER / LEGAL NOTICE

Abstract

Final Results

The EPRI-DOE-SCS Chiyoda CT-121 Clean Coal Project

at

Georgia Power's Plant Yates

The EPRI-DOE-SCS Yates Project tested the operational limits of Chiyoda's CT-121 wet limestone S02 scrubbing system at Georgia Power's Plant Yates for twenty-seven months, between October 1992 and December 1994. Although the original test plan called for a rather straightforward assessment, the CT-121 system proved robust, so it was tested at widely varying conditions. Fuels ranged from 1.5 to 4.3 % sulfur, various limestone sources and grind sizes were used, particulate removal and air toxics performance were measured and gypsum soil amendment experimentation was conducted. In all cases, the CT- 121 system with Chiyoda's Jet Bubbling Reactor (JBR), gave encouraging results with predictably high S02 and particulate removals at all conditions with high reliability. Closed loop operations called for the extensive application of corrosion impervious, fiberglass reinforced plastics that was successful. Gypsum proved to be significant as a soil enhancement and was granted a plant food license by the State of Georgia. The Yates Project has received four awards from industry and environmental groups for its performance.

January 1997

Acknowledgments

The Yates CT-121 Scrubber Project has been a success by all measures and many who have been significant contributors to that. First, we must acknowledge Mr. Harry Ritz, formerly of the Department for Energy's Pittsburgh Energy Technology Center (PETC) before his recent retirement. Mr. Ritz shepherded this mammoth effort along from its infancy, through budget debates and test program modifications. It is safe to say that without his constant help and proactive assistance, the Yates Scrubber Project would have been significantly more difficult.... and less successful. Also, thanks to Paul Radcliffe and Jeff Stallings of the Electric Power Research Institute who allowed Project Management great latitude in decision-making while always bringing the electric utility industry perspective to the planning table.

A significant amount of the credit for day to day technical success is due to the efforts of Mr. Ira Pearl of Radian International's Atlanta, Georgia office who committed two years of his life to the plant and the CT- 121's success. Mr. Pearl guided the CT- 121 work like a worried parent and contributed an untold number of work-scope expansions that led us down the path of greater learning. Special thanks to Lamar Larrimore of SCS for the gypsum work and Pete Honeycutt of SCS who often responded to critical task requirements on a short time-line. Also, Buddy Hargrove of Radian laid out an excellent initial plan and got the project rolling as its Project Manager when he was with Southern Company Services.

Thanks to Mona Browning and Holly Roberson who both showed great patience in their daily on-site support of the ever-active Ira Pearl and Dave Burford while at Plant Yates. Also to Joe Lord of Monex; a man of abundant common sense, who passed away during the project.

Lastly, we must also thank Georgia Power Company and the Plant Yates staff who hosted our efforts for this project and saw us through difficult times with a technology that was initially totally unfamiliar to them. Georgia Power and *Southern Company* are always drawn to that future vision, no matter how challenging the requirement and how taxing the associated technology can be. Their willingness to host the Yates work was a pivotal event.

Points of Contact

for Sponsors, Participants and Host Site to the Yates CT-121 Clean Coal Project

Company / Person	***Office Telephone***	***FAX***	***Email***
Southern Company			southernco.com/site/home.asp
David P. Burford, Project Manager	(205) 992-6329	(205) 992-7535	dpburfor@southernco.com
C. Lamar Larrimore	(205) 257-6920	(205) 257-5367	cllarrim@southernco.com
Dan Warren	(205) 257-6947	(205) 257-7294	dhwarren@southernco.com
Pete Honeycutt	(205) 670-5875	(205) 670-5843	pmhoneyc@southrnco.com
Kamyar Vakhshoorzadeh *(departed SCS)*	-	-	-
Ed Healy	(205) 992-5212	(205) 992-7535	echealy@southernco.com
42 Inverness Parkway, Suite 340 *Birmingham, AL 35242*			
U.S. Department of Energy			www.doe.gov
Mr. Harry Ritz *(retired (1/96))*	-	-	-
Dr. Jim Watts	(412) 892-5991	(412) 892-4775	James.Watts@netl.doe.gov
Ms. Karen Khonsari *(departed DOE)*	-	-	-
Federal Energy Technology Center (FETC) *Technical Project Managers* *P. 0. Box 10940 / Wallace Road* *Pittsburgh, PA 15236*			
Electric Power Research Institute	800.313.3774		www.epri.com
Paul Radcliffe Jeff Stallings	650.855.2000 x2720 650.855.2000 x2721	- -	
3412 Hillview Avenue *Palo Alto, California 94304*			
Georgia Power Company			southernco.com/site/gapower/
Dean Dodgen George Goswick	(404) 506-7755 (404) 506-3906	(404) 506-7723 (404) 506-7723	hddodgen@southernco.com gmgoswic@southernco.com
Ralph-Magill Boulevard *Atlanta,, GA*			
Yates Electric Generating Station *Highway 27A /* ***708 Dyer Road*** *Newnan GA 30053*	(770) 252-0650	-	http://powergeneration. southernco.com/GPC-Yates/

Points of Contact *(continued)*

for Sponsors, Participants and Host Site to the Yates CT-121 Clean Coal Project

Company / Person	***Office Telephone***	***FAX***	***Email***
Radian International			www.radian.com
Ira Pearl *(departed Radian)*	-	-	-
Buddy Hargrove	(512) 419-5075	(512) 454-8807	Buddy_Hargrove@radian.com
Bob Wetherold	(512) 419-5265	(512) 454-8807	Bob_Wetherold@radian.com
8501 North MoPac Boulevard *Austin TX 78759*			
Chiyoda Corporation			
Paul Beddie *(departed Chiyoda)*	-	-	-
Environmental Business Development Department *31-19, Shiba 2-chome* *Minato-ku, Tokyo 105, Japan*	011-81-35-476-2601	011-81-33-456-1233	
Southern Research Institute			southern@sri.org
Whim Marchant	(205) 581-1713	(205) 581-2201	
2000 Ninth Avenue South *Birmingham AL 35205*	800-967-6774		
DynaFlow Systems, Inc. ***a Division of Acentech, Inc.***			
Dr. Lewis Maroti	(617) 499-8030		
99 Erie Street *Cambridge, MA 02139*			
Ershigs			
Robert B. Davis, Chief Engineer	(360) 733-2620		
742 Marine Dr, *Bellingham WA* 98226			
W.S. Pitts Consulting, Inc.			
Dr. Wallace Pitts	919-847-4800		
14 100 Allison Drive *Raleigh NC 27615*			

Points of Contact *(continued)*

for Sponsors, Participants and Host Site to the Yates CT-121 Clean Coal Project

University of Georgia			
Dr. William Miller Dr. Malcolm Sumner	706-542-2461 706-542-0899	(706) 542-0914 (706) 542-0914	bmiller@UGA.CC.UGA.EDU sumnerme@uga.edu
Department of Crop & Soil Sciences *3111 Plant Sciences Blg* *Athens, GA 30602-7272*			
Ardaman & Associates			ardaman@aol.com
Bill E. Jackson Robert J. Warner Tom Ingra	- - (407) 855-3860	(407) 859-8121	
8008 S. Orange Ave. PO Box 593003 Orlando,FL 32859-3003			
Monex Resources			
Charles Boykin Joe Lord *(deceased)*			
Newnan, GA	770-423-1883		
Physical Acoustics Corporation			
Jim Mitchell David Kesler Chris Barbour Bruce Gilbert	(230) 536-3380 - - (609) 844-0800	- - - (609) 716-0706	
15 Princess Road *Lawrence, NJ 08648*			sales@pacndt.com

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

Description	*Page*

List of Figures and Diagrams

List of Tables

Separate Volumes that make up the Yates Final Report

Volume 1 -- Executive Summary

Volume 2 -- Performance – Operations

Volume 3 -- Performance – Equipment

3a - Equipment, Materials and Maintenance

3b - Instrumentation and Controls / Data Acquisition System

3c - Materials Test and Evaluation Program

Volume 4 -- Gypsum Stacking and Byproduct Evaluation

Volume 5 -- Environmental Monitoring Plan

Volume 6a -- Data and Supplemental Testing Appendices

6b -- Data and Supplemental Testing Appendices

Abbreviations, Acronyms, Units of Measure and Terms of Reference

Can be found at the beginning of Volumes 2 and 4

The Yates Project, hosted by *Southern Company's* Georgia Power was a part of the U.S. Department of Energy's Innovative Clean Coal Technology initiative (ICCT) where government and the private sector join in partnerships to advance the use and efficacy of coal-oriented technologies.

The Yates work was an effort to demonstrate innovative improvements to an existing wet limestone sulfur dioxide ($S0_2$) scrubbing system called the CT-121 Jet Bubbling Reactor or "JBR", owned by Chiyoda Corporation of Japan. This device was retrofitted to Unit 1 at Georgia Power's Plant Yates just south of Atlanta, Georgia to perform flue gas desulfurization by exhaust gas clean-up. Over the length of the Yates demonstration site work from 1992 to 1994, the investigators also found that the CT-121 JBR device had unexpected promise as it showed high incidental removals for both fine particulate and air toxics.

The CT-121 process is a simplified wet scrubber that reduces capital costs by allowing the chemical reactions to occur in a single vessel at reaction rates, chemical conditions and times that encourage complete reaction efficiencies; meaning complete reactant usage's and complete product conversions to a usable byproduct. The mass contacting of SO_2-laden hot flue gases with the neutralizing limestone slurry is very unique in the JBR in that it relies on a "sparging" action; analogous to blowing through a straw into a soft drink. This neutralizing slurry was a massive quantity, contained and stirred in the reservoir of the JBR, acting to enable a complete conversion from sulfite reaction intermediaries to a more easily handled solid sulfate product, while encouraging this sulfate to undergo extended crystal growth. The CT-121's mechanical simplicity also reduced process control requirements, overall operational complexity and limited power requirements since extra vessels and extra support equipment were not needed (subsystem pumps, agitators, valves, etc.) as normally found in peer scrubber processes. The challenge was to ensure reliable, environmentally proficient, economically advantageous operations with a minimal set of equipment. The CT- 121 system did so, beyond expectations.

The major objectives of the Yates ICCT Project were originally five-fold:

- Construct major components from fiberglass reinforced plastics to avoid corrosion,
- Operate the CT-121 process without a spare absorber or prescrubber to reduce capital,
- Operate the CT- 121 process without reheat to reduce operating costs,
- Test simultaneous particulate / $S0_2$ removal by Chiyoda's JBR,
- Evaluate "stacking" of the gypsum byproduct as a disposal option.

The CT-121 process showed unexpected versatility in operating with reagent quality and inlet flue gas conditions well outside the design criteria. This project was also significant in that it indicated an unknown resilience of the CT-121 toward process upsets as the project staff often set operating conditions outside the owner’s recommendations in order to search for those limits of the CT-121’s operational envelope. The Project staff have dubbed this forgiving aspect as “chemical resiliency” and referred to it as “dial-a-removal” for the CT-121’s SO_2 removal performance.

Once through start-up, supplemental project objectives were added (air toxics testing, gypsum evaluation, etc.) that are discussed in detail in the accompanying volumes of this report. As the Yates Project testing progressed, the objectives again expanded to also include the measurement of incidental particulate collection across Chiyoda’s Jet Bubbling Reactor, the measurement of incidental air toxics removal across the JBR, experimentation on a wide range of limestones of various origins and the experimentation on a wide range of coals of various sulfur content.

The testing of the gypsum product proved that “gypsum stacking” is an excellent alternative to mechanical drying and also to landfill storage. Georgia Power has recently received a “plant food license” from the State of Georgia for the use of its scrubber-gypsum in agriculture.

Likewise, the widespread application of fiberglass reinforced plastic vessels was an enormous success. The limited repairs required were generally handled by onsite maintenance personnel and there were no catastrophic failures as some would have predicted.

The economics surrounding the Yates Project have made it difficult to separate the expenditures into capital costs versus testing expenditures as many “requirements” were mixed at the project’s outset and seem immune to accurate seperation. However, CT-121 is typically bid at under $100 per kW for capital and it proved to be remarkably inexpensive to operate. Economics improve if gypsum sales revenue are realized and included to defray O&M expenses.

The commercialization of the CT-121 process has begun as lesson-learned at Yates have been applied to subsequent applications of the CT-121 process worldwide. The new owners of these new CT-121 applications have frequently inquired as to the need for engineering improvements addressed to the staff that worked at the Yates CT-121 project.

During the last two years of the project, it received a number of awards from both industrial groups and environmental regulators. At the conclusion of the DOE-sponsored demonstration in 1994, Georgia Power asked to continue operation of CT-121 as part of Yates Unit 1 and has done so since January 1, 1995.

In summary, the CT-121 system met challenge after challenge, some far outside its original design parameters with a robust chemistry and impervious construction. Time and time again, it surprised its project staff as to its forgiving nature.

- **1994 Powerplant of the Year Award**

  Power Magazine - April 1994

- **Outstanding Achievement Award - 1994**

  Use of Innovative Technologies in Air Quality Control

  Air and Waste Management Association - Georgia Chapter

- **Air Quality Citizen of the Year - 1993**

  Georgia Chamber of Commerce

  Nominated by the State of Georgia's Environmental Protection Division

- **Design Award of Excellence - 1996**

  The Composites Institute

  Society of Plastics Industries

Demonstration of Innovative Applications of Technology for Cost Reductions to the CT-121 FGD Process

DOE ICCT PROJECT DE-FC22-90PC89650

FINAL REPORT

Volume 1 of 6: Executive Summary

Project Sponsors

Southern Company
US Department of Energy
Electric Power Research Institute

Issue Date: January 1997

1.0 INTRODUCTION

1.1 Project Overview

The Yates Project was proposed in Round II of the U.S. Department of Energy's Clean Coal Technology Initiative in 1989. [The Clean Coal Initiative was a Congressionally mandated program to entice research efforts in to the expanded uses of one of the United States' most abundant resources in terms of enhancements to efficiency and environmental performance. This Clean Coal work was not limited to environmental control work nor to electric utilities although the program received its biggest response from these sectors]. The Yates Project was one of sixteen winners in that Round and one of the four Southern Company proposals accepted in Round 11. Together, the Southern Company was proposing over $110 million in clean coal research in that round. The Yates Project was originally a $36 million, three -way partnership: Southern Company, the DOE and the Electric Power Research Institute. Before project end, this grew to almost $43 million through work-scope expansions and additional testing. The original concept was for a 110MW wet limestone sulfur dioxide (S02) scrubber, a Chiyoda Corporation CT-121 Jet Bubbling Reaction system, to be retrofitted to Unit I at Georgia Power's Plant Yates, just south of Atlanta, Georgia. Construction began in late 1990, startup was in the Fall of 1992 and testing continued through the end of 1994. Georgia Power elected to retain the equipment and continues to operate it today for compliance purposes. Over its course, the Yates Project gathered in four major awards; the largest of which was being named **1994 Powerplant of the Year** by Power magazine in April of 1994.

1.2 Purpose of the Final Report

The Final Report is intended to provide an unlimited cross-section of readers with access to the lessons learned during this large project. This allows them to make more educated decisions when in similar situations and circumstances.

1.3 Brief Description of the Project

The Yates Project was intended to experiment with innovative improvements to an existing wet limestone sulfur dioxide (S02) scrubbing system, Chiyoda Corporation's CT-121 Jet Bubbling Reactor, for coal combustion exhaust gas clean-up, retrofitted to Unit I at Georgia Power's Plant Yates, just south of Atlanta, Georgia. The process is a simplified wet scrubber that reduces capital costs by allowing the chemical reactions to occur in a single vessel at reaction rates and times that encourage complete reaction efficiencies (complete reactant usage, complete product conversion to a usable byproduct). It also indirectly reduces process control requirements, overall complexity and power requirements when extra vessels and associated support equipment are not needed (subsystem pumps, agitators, valves, etc.) as normally found in peer scrubber processes. The challenge was to ensure reliable, environmentally proficient, economically advantageous operations with a minimal set of equipment. The CT- 121 system did so admirably.

Chiyoda's Jet Bubbling Reactor

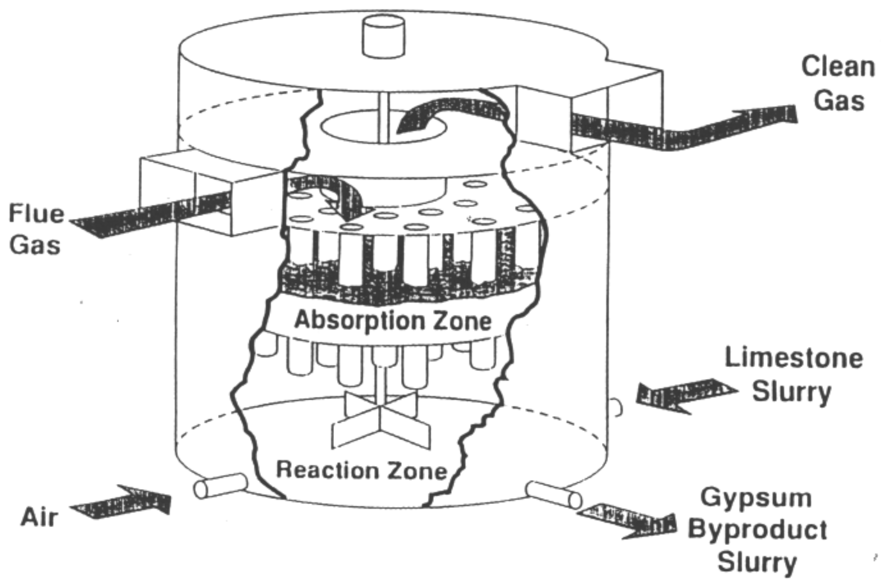


Figure 1-1

1.4 Objectives of the Project

The **major project objectives initially** were to:

- Make major cost reduction decisions (that normally increase operational risk)
- Eliminate the prescrubber from the original design
- Eliminate spare absorbers that normally improve reliability
- Maximize the use of corrosion impervious materials like
  fiberglass reinforced plastics (FRP)
- Operate closed loop
  (zero process liquids treated / zero discharge to the environment)
- Experiment with simultaneous particulate removal from the Jet Bubbling Reactor
- Evaluate possible uses and the markets for byproduct calcium sulfate (gypsum)

Later, the scope of the Yates Project was expanded to include:

- Evaluation of different limestone sources, types and grind sizes
- CT-121 operations at widely vary in sulfur dioxide flue gas
  (fuel sulfur content) significantly different from design expectations.
- Design and evaluate an energy-less, static droplet removal device in the chimney
- Evaluate the Jet Bubbling Reactor's potential for hazardous air pollutants removal
  (HAPs; air toxics measurement and removal calculations)

1.5 Significance of the Project

This project was significant in that it proved the unknown resilience of Chiyoda's CT-121 FGD process. The CT-21 system met challenge after challenge, far outside its original design parameters with a forgiving chemistry and impervious construction. Time and time again, it surprised its project staff as to its forgiving nature.

1.6 Conclusions

The major objectives of the Yates ICCT Project were five-fold:

- Construct major components of CT-121 of fiberglass reinforced plastics
- Operate the CT-121 process without a spare absorber
- Operate the CT- 121 process without reheat
- Test simultaneous particulate /S02 by Chiyoda's JBR
- Evaluate "stacking" of the gypsum byproduct as a disposal option.

Since Project start-up, other supplemental objectives were added (air toxics testing, gypsum wallboard evaluat ion, etc) that are discussed in detail in the accompanying volumes of this report.

1.6.1 Construct major CT -121 components of fiberglass reinforced plastics

The use of fiberglass reinforced plastics (FRP) for major process vessels and ductwork was successful with one qualification. Under full flyash loadings (almost 6 lb/MMBTU), FRP structures that have potential for erosion by high velocity flyash need extra abrasion protection. Materials evaluated at Yates were found that provided that needed degree of protection. A more thorough presentation on Yates FRP experience can be found in Volume 3 of this report.

1.6.2 Operate the CT -121 process without a spare absorber

The Chiyoda CT- 121 system at Plant Yates operated with high reliability without a spare scrubber module (no spare JBR) and without a prescrubber. This is to say that Chiyoda's process chemistry was reliable, controllable and forgiving to an extent that no spare module was needed and that mechanically, the aggressive environment resulting from closed lo op operations did not adversely impact performance (S02 removal) or operations (equipment).

1.6.3 Operate without reheat

Operating without reheat was entirely successful. The scrubber chimney was constructed of FRP to operate completely in the wet mode. Entrained moisture downstream of the mist eliminator was removed in a static stripping section, added to the chimney's 90' elbow, based on positive results from scale-model, Yates CT-121 flow investigations. No moisture stripping was observed from the Yates chimney.

1.6.4 Test simultaneous particulate / S02 by Chiyoda's JBR

Simultaneous S02 / particulate collection is possible with the CT - 121 JBR without any changes to normal, S02 removal proficiency and outlet values met NSPS requirements, in almost all cases. However, with flyash loading at the highest levels (6 lb/MMBTU), outlet particulate values climbed. Although the outlet amounts were well below Yates Unit I permit allowances, these outlets exceeded NSPS limitations. Design changes to the JBR and inlet d uctwork may reduce outlets at massive inlet loadings but this was not attempted at Yates.

1.6.5 Evaluate "stacking" of the gypsum byproduct as a disposal option.

This disposal option, borrowed from the other gypsum-producing industries, was successful and more fully described in the Byproducts Volume 4 to this report.

1.7 Lessons Learned

- **Chiyoda CT-121 has a very forgiving chemistry that does not operate close to the margin of inoperability.**

- **At low S02 inlet values, the operating pH set point is restricted by available alkalinity.**

As a result, the JBR can not reach the highest pH's available to the Chiyoda chemistry (e.g.: the highest pH's at the highest high $S0_2$ removals, limited to high limestone utilization). However, even this pH restriction did not effect S02 removal.

- **The Yates CT-121 JBR can be overwhelmed by inlet particulate loadings at the highest of inlet values (ESP not in operation).**

Modifications to the JBR's inlet plenum floor have been discussed to alleviate piling -up of collected ash and improving the deck wash system to supplement this added cleaning requirement.

- **CEM maintenance is <u>a continuous</u> resource vacuum.**

1.8 RECOMMENDATIONS

Several innovative design features, such as the widespread use of FRP, elimination of the prescrubber in a CT-121 design, and others, were first implemented in the Yates CT-121 demonstration project. Therefore, the effectiveness of many of these innovations was untested at the start of the demonstration. Not unexpectedly, some shortcomings in the design were identified, as well as areas of improvement for already satisfactory features. Some of these findings were discussed in Performance-Operations Volume 2 of this report. The following recommendations for improvements in future designs are detailed in this section, and include discussions of:

- Abrasion resistant material selection;
- Gas cooling system relocation;
- Cooling pump suction screens;
- Deck wash modifications;
- JBR level control;
- pH probe location and maintenance; and
- Process set point selection.

Note that some of these improvement recommendations have already been implemented in the Yates CT-121 process.

1.8.1 Abrasion Resistant Materials

To combat the problem of FRP erosion in the gas cooling duct, several possible solutions were identified:

- The use of an alternate material of construction for the walls of the transition duct;
- The use of abrasion-resistant materials to coat the transition duct walls (downstream of the gas cooling nozzles) and other wear prone surfaces; and
- The addition of stainless steel alloy wall paper, such as Hastelloy™ C-22 or 317-LM on the walls of the transition duct.

Alternate transition duct materials or wall paper made of exotic alloys would certainly offer improved erosion resistance over FRP. However, it would do so at a higher cost and provide less corrosion resistance than FRP, particularly in a high chloride environment such as that observed in the Yates CT-121 process.

The solution involving the use of abrasion resistant coating was implemented at Plant Yates mid-way through the process evaluation. Several types of erosion resistant materials were applied to the surfaces most susceptible to erosion to determine which was the most suitable for this application. Eventually, a material (Duromix™) was selected that appeared to offer the highest level of erosion resistance, without sacrificing cost or corrosion resistance. With the exception of some minor adherence problems (a result of misapplication), the use of this material to improve erosion resistance was successful and should be considered for all future CT-121 applications that widely use FRP materials of construction. Duromix™ was also applied to the upstream face of the vertical structures in the JBR inlet plenum, although erosion in this area would best be remedied by the recommendations provided in Volume 2, Section 6.2 (i.e., moving the gas cooling section further upstream of the JBR).

1.8.2 Relocation of Gas Cooling System

The gas cooling system in the Yates CT-121 design was located only 18 feet upstream of the JBR inlet plenum which resulted in two primary difficulties:

- Erosion damage to the inlet plenum; and
- Lower deck solids build-up.

A single solution is proposed that should alleviate these two problems. Relocating the gas cooling section of the transition duct further upstream of the process would minimize these adverse effects in future designs by:

- Allowing the slurry to fall to the floor of the duct well upstream of the JBR, thus reducing the deposition of solids on the lower deck resulting in decreased lower deck wash requirements;
- Reducing erosion in the JBR inlet plenum since the flue gas would no longer be laden with slurry prior to impacting the vertical surfaces of the JBR; and
- Increasing the gas cooling residence time, allowing more opportunity for flue gas cooling and decreasing the likelihood that a few plugged gas cooling nozzles would result in high temperature excursions in the JBR inlet plenum.

1.8.3 Gas Cooling Pump Suction Screens

The gas cooling nozzles, with a 3/8-inch free pass area, can become easily plugged with loosened scale and other debris from the JBR reaction zone. Several solutions to this problem were considered, including:

- Installing strainers upstream of the gas cooling pumps;
- Installing strainers downstream of the gas cooling pumps;

- Replacement of existing nozzles with ones with a larger free pass area; and
- Installing screens surrounding the suctions of the gas cooling pumps in the JBR reaction zone.

The cost of construction and installation of various types of strainers was evaluated, and it was determined that strainers that were easy to clean on-line and constructed of materials that were adequate to withstand the high chloride content of the scrubbing slurry would be cost-prohibitive. Alternate nozzle designs were investigated, but could not be implemented without increasing the size of the gas cooling pumps at a considerable expense.

The solution that was ultimately selected and implemented utilized a single "hockey net" style screen in the JBR at the location of the suctions of the three gas cooling pumps. The suction screen was designed with the following features:

- The screen was large enough so that all three gas cooling pump suctions were within the same screen;
- The free pass area of the screen was selected at 3/8" so that any object small enough to pass though the screen would also be able to pass through the nozzles;
- The screen was constructed of FRP and PVC for corrosion and erosion resistance and to be consistent with the materials of construction of the JBR; and
- Because of the "hockey net" style and large surface area of the screen, there was little danger of fouling the gas cooling pump intake and starving the pumps, therefore, no cleaning mechanism was required, as would have been in an in-line strainer.

Also installed at this time were similar, but smaller, screens for the gypsum slurry draw-off pump suctions. These pumps had not experienced any plugging due to foreign materials, but some damage to the rubber volute liner and impeller had been noted in previous inspections.

It is recommended that all future CT-121 designs include such a suction screening device to prevent plugging of gas cooling nozzles. These types of screens are both erosion- and corrosion-resistant, result in no additional pressure drop penalty, are unlikely to plug, and keep the gas cooling nozzles free of debris that otherwise might plug them. The screens installed at Plant Yates proved successful in eliminating further JBR temperature excursions due to gas cooling nozzle pluggage.

1.8.4 JBR Deck Wash Modification

Keeping the JBR lower deck and sparger tubes free of solids is critical to ensuring consistent performance of the CT-121 process. Lower deck solids build-up was effectively mitigated by increasing the number of deck drains and redesigning the deck wash system to ensure overlapping coverage was achieved. Unfortunately, this had little effect on abating the build-up of fly ash inside the sparger tubes during periods of elevated ash loading. This was a result of the design of the sparger tubes and mounting collars. The tops of the sparger tubes protrude approximately 4 inches above the deck. It would not be practicable to arrange the deck wash system so that the inside of each sparger tube was sprayed without adversely impacting the JBR water balance. To allow the sparger tubes to be washed, two solutions were devised:

- Install polystyrene-type foam on the lower deck, with cutouts for each of the sparger tube tops, effectively raising the lower deck surface and allowing each sparger tube to serve as a drain for the wash water; and
- Alter the design of the sparger tube mounting mechanism to allow the tops of the sparger tubes to remain flush with the lower deck, as shown in Figure 6-4.

The first proposed solution would be most practical for modifying the existing Yates CT-121 scrubber. Raising the deck flush with the sparger tube tops will allow the wash water to rinse the sparger tubes and keep them free of solids. It will also increase the effectiveness of the deck washing, since the solids that are resuspended by the wash water can more quickly drain to the JBR (before they settle on the deck again).

Redesigning the sparger tube mounting hardware will have the same effect as described for the retrofit recommendation: allowing the sparger tubes to serve as deck drains, effectively washing the sparger tube interior with the deck wash water.

1.8.5 JBR Level Control

One of the conclusions reached early in the process evaluation was the unsuitability of the differential-pressure type JBR level instruments selected for this application. Suggested methods for more reliable JBR level control include:

- Employing gas-side, differential pressure instruments as surrogates for level instrumentation and
- Using alternate kinds of liquid level -based differential pressure instruments.

The gas-side differential pressure instrument was used at Yates because of the difficulty in retrofitting an alternate technology. Although only a single ΔP instrument was used previously, consideration should be given to adding a second and third instrument for redundancy and to aid in detection of malfunction in any instrument.

A recommendation for future CT-121 designs would be to use a level indication system less prone to plugging than the original system (which used small gauge tubing for the indication and reference legs). One option that will allow level measurement with a decreased likelihood of fouling of the instrument is a diaphragm-type pressure sensor. The sensor can be mounted as an integral part of the JBR reaction zone wall. Because there is no opportunity for pluggage of sensing lines, this approach has a higher inherent reliability. Of course on-line instrument replacement would be difficult, if not impossible, but that inconvenience can be overcome by the installation of several redundant instruments. Scaling is not expected to be a problem because of the flexible nature of these types of devices.

1.8.6 pH Probes

Two pH measurement units were evaluated during the demonstration:

- A Rosemount transmitter coupled to a Van London pH probe; and
- A TBI-Bailey transmitter and probe arrangement.

Only the Rosemount transmitter and a Van London probe proved durable enough to last the entire demonstration project. This was because of the simplicity of design of the Rosemount instrument (the TBI-Bailey instrument was too easily short-circuited by slurry sprayed during sampling) and the durability of the Van London probe.

Based on experiences at Yates, the "hot-tapping" (i.e., the ability to remove and insert pH probes while on-line) of pH probes is highly recommended in all future applications. The hot taps allowed the pH probes to be removed for cleaning, bench calibration, and replacement. Because of the high suspended and dissolved solids content of the slurry, frequent preventive maintenance is required to ensure that the pH probes operate properly. The suggestedpreventative maintenance practices include:

- In-situ calibration checks at least twice daily;
- Weekly cleaning (with a soft brush) of the reference junction;
- Bi-monthly replacement of the probe (to circumvent end-of-life degradation, which is difficult to diagnose in its early stages); and
- Programmed, control system comparison of at least two redundant pH probes.

Based on lessons learned regarding pH probe placement, the following are recommended:

- Redundant pH probes be used;

- pH probes should be placed immediately adjacent to one another to mitigate the effects of incomplete mixing in the froth zone, which can lead to radial stratification;
- The sample (calibration) port should also be placed in close proximity to the probes - preferably between them; and
- pH probes should be placed at least 12 inches below the bottom of the sparger tube openings to provide more stable pH readings with less fluctuation due to localized low-pH areas in the turbulent froth zone.

1.8.7 Smart Process Set-Point Recommendations

The application of the types of regression models discussed in Volume 2, Section 4.8 of this report to distributed control systems (DCS) is an excellent way to ensure that SO_2 removal efficiency objectives are met. Forms of the regression models developed from parametric performance results can be entered into the DCS and a "smart" system can be used to make recommendations to the process operator to allow the target SO_2 removal efficiency to be achieved. Based on operating experience, a pH can be selected that provides for high SO_2 removal efficiency while maintaining high limestone utilization. Once the pH has been selected, the smart system can recommend JBR ΔP set points to achieve the target level of performance.

It is not recommended, however, that a smart system be used to automatically adjust the operating parameters of the scrubber without operator action. Instrument errors, transients, or CEM calibration cycles could have a deleterious impact on the selected operating parameters, and human intervention is important to "filter" all recommended process parameter changes to confirm that they make sense and are necessary. For example, a known, short-duration load transient may not necessitate any process changes. An informed operator can decide whether or not to alter process parameters based on his knowledge of the brevity of such a transient.

2.0 Project History

The *Southern Company* has had an interest in flue gas desulfurization research for a number of years as well as being involved in other en vironmental control research for other emissions-of-interest. The Project at Plant Yates follows the five scrubber systems built and operated at Gulf Power's Plant Scholz in the late 1970's. These indicated that wet limestone scrubbing and gypsum-producing system were most likely to satisfy the *Southern Company's* needs for both new-build and retrofit SO2 environmental control technology. However, the size of the Scholz work was limited to 23MW and all were slip -stream operation (only taking a portion of the flue gas flow from a single unit). The Yates work was envisioned to fill the two gaps;

- A full-scale flue gas system application to a coal fired unit
- Handling full flue gas flow; including the following of unit load.

Of course, this was only the beginning … a number of key scrubber questions were raised during the course of test work and addressed during the Yates Project.

The technology of CT-121 ("Chiyoda Thoroughbred 121") was invented and vested in the Chiyoda Corporation of Japan, using their massive chemical engineering staff (that is primarily oriented toward their numerous projects in the petroleum industry). The predecessor technology many think, to be Chiyoda's CT-101 of the mid 1970's vintage but this is not the case. The CT-101 was an iron-catalyzed, sulfuric acid SO_2 removal system relying on a counter current spray tower mass contactor. The CT-121 is a lower pH, limestone slurry device that radically changes the gas-liquid contacting by sparging the hot flue gases underneath the surfa ce of a massive, turbulently stirred limestone slurry reservoir that has an in situ oxidation subsystem.

The project participation matrix did not include Chiyoda however, as they declined to be a financial participant. As a result the Southern Company pu rchased the rights to engineer, procure, erect, test, own and operate the 100MW system at Plant Yates.

Chiyoda does ask however, for the following to be included in the Final Report:

"The test program at Yates was developed and conducted almost exclusively by SCS without interference by Chiyoda Corporation, the owner and developer of the CT-121 FGD Process. Chiyoda did assist SCS in a limited manner when requested to do so, however, the data design parameters and operating conditions used to produce this data were generated by SCS.

The Yates CT-121 planet was operated as a test bed facility by SCS during the DOE test period. During this period, the plant was often operated under conditions that were outside, sometimes radically so, of the design parameters determined and guaranteed by the process owner and developer, Chiyoda Corporation. It was generally under these radical conditions when any failures that occurred did so. However, in general the CT-121 process performed remarkably well, even under these radical conditions."

Note: The SCS project management onsite every day at Yates took full responsibility for extending the operational envelope of the CT-121 process, feeling that the owner's concerns were reasonable when the intent is to sustain statistics for operations and reliability. However, for demonstrating a technology for commercial application, the project management felt that these constraints were very conservative. Therefore, in the interests of finding the 'operational limits' of the Yates CT-121 system, conditions were occasionally set that intentionally put CT-121 'at risk' for reduced reliability, in order to seek the exact cusp or point of process failure.

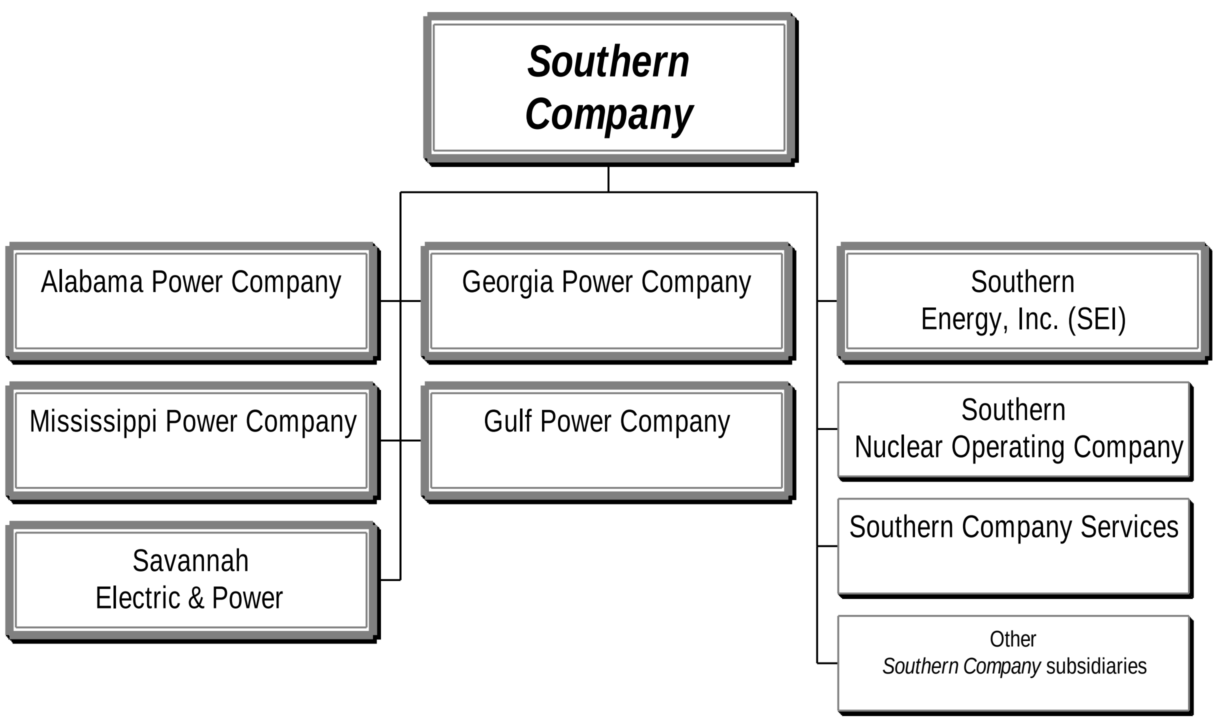
2.1. *Southern Company's* Corporate Structure

Southern Company is an electric utility holding company headquartered in the southeastern United States that is comprised of various subsidiaries; five are large traditional electric utility companies, others are for subsidiary support and still others are for investment or provide alternative services. *Southern Company* also has holdings in ten countries spread across four continents; *Southern Company* is the largest producer of electricity in the United States.

Figure 2-1

Southern Company

Corporate structure and subsidiaries



Southern Company has a "large central generation station" philosophy resulting in over 18,000MW of pulverized coal units in its traditional five electric utilities alone and thus has an ongoing interest in researching and demonstrating innovative technologies that serve this base. The Yates Project built on *Southern's* previous experiences with flue gas desulfurization efforts at Gulf Power's Plant Scholz and was an opportunity to build its largest demonstration system to date.

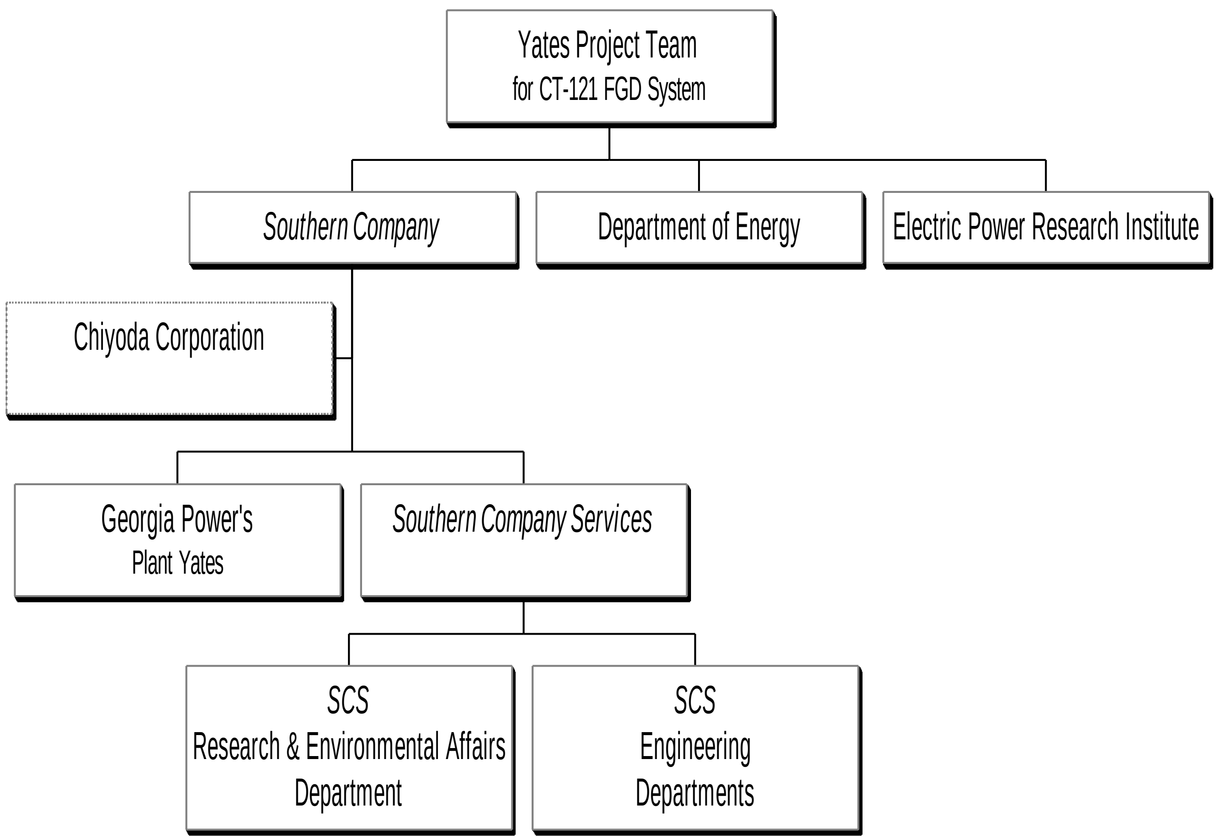
2.2. Management Arrangement of the Yates Project

Principals to the project were the U.S. Department of Energy, the Electric Power Research Institute and the *Southern Company*. Further, Chiyoda Corporation acted as a vendor and consultant in agreeing to a "for-fee" use of the CT-121 technology at Georgia Power.

Figure 2-2

Yates Scrubber Project

General Project Management Arrangement



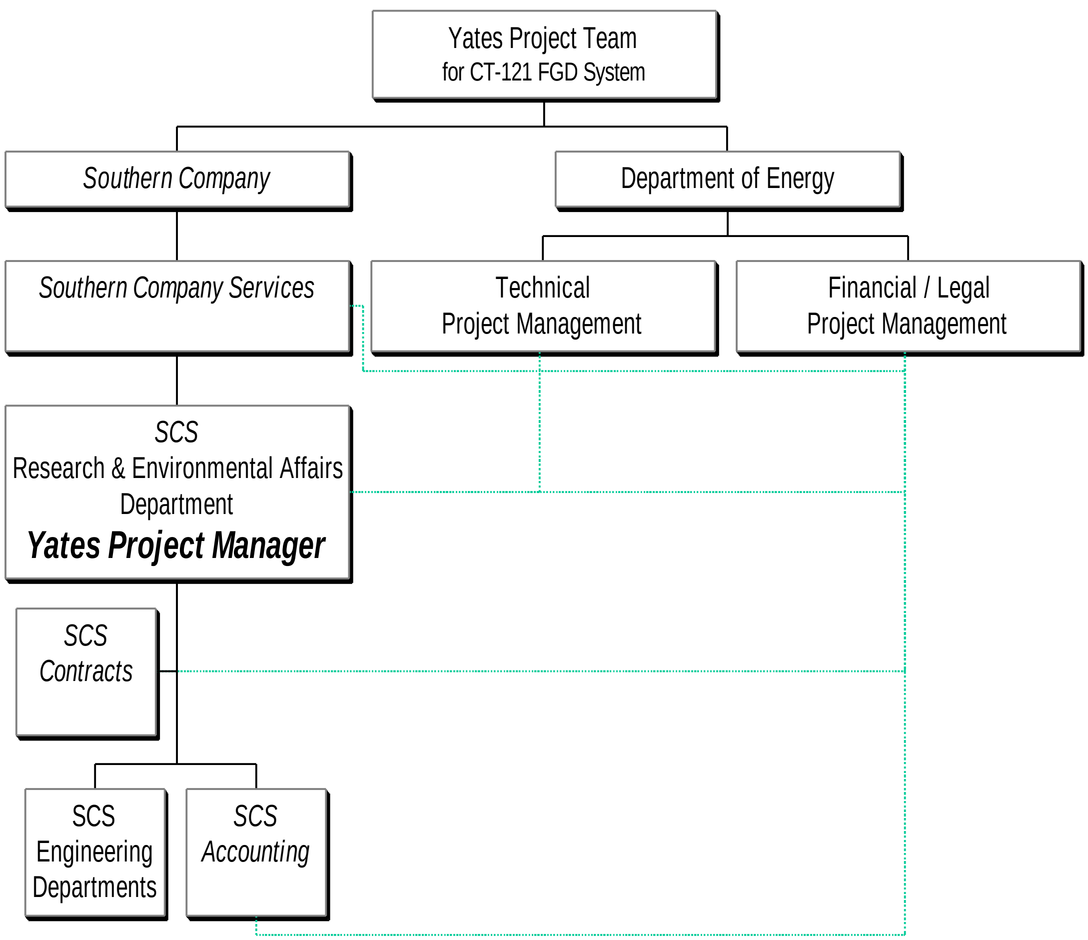
2.3. DOE's Role in the Project

The DOE provided 49% of the project's funding but also its project management expertise through almost continuous contacts with the project management, attendance at meetings and an enormous positive element of support and understanding to the Yates Project. Outside of the funding, the DOE Project Managers were insightful, cooperatively oriented and always receptive to a new concept for added validity of the testing. Likewise, the DOE brought the opportunity for Yates to take some of the first ever, real data on the air toxics issue that has served as a benchmark effort. Specifically, the DOE provided project management directly into the *Southern Company*-led project management structure:

Figure 2-3

Yates Scrubber Project

Project Management interface with the DOE

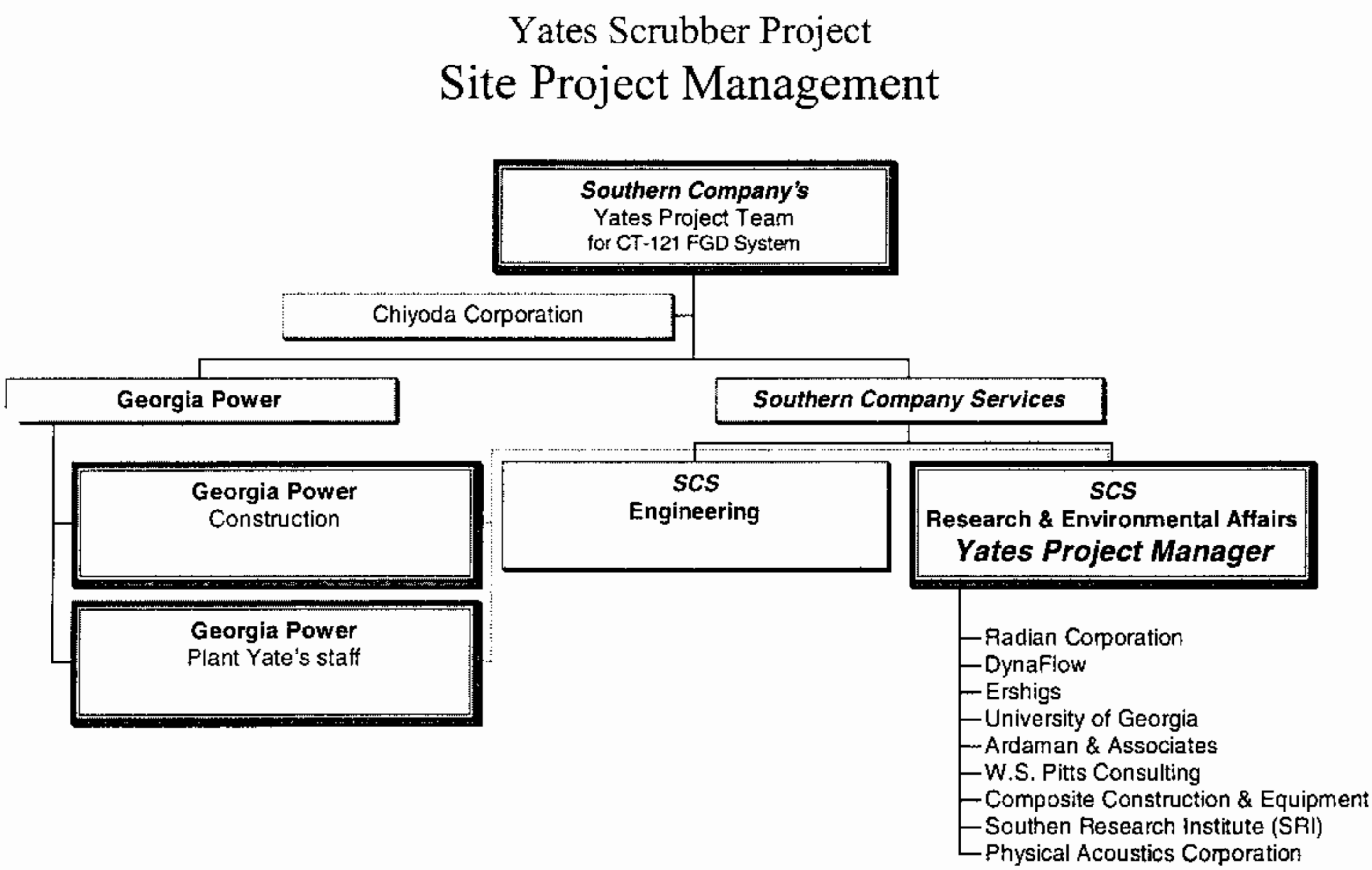


Legend:
Reporting relationships ________
Direct coordination …………..

2.4. Site Project Management – Construction through Testing

For the Yates Project's construction, operations and testing; the organizational ties expand through the Project Manager to Georgia Power, the vendors providing materials or expertise and the various testing contractors:

Figure 2-4

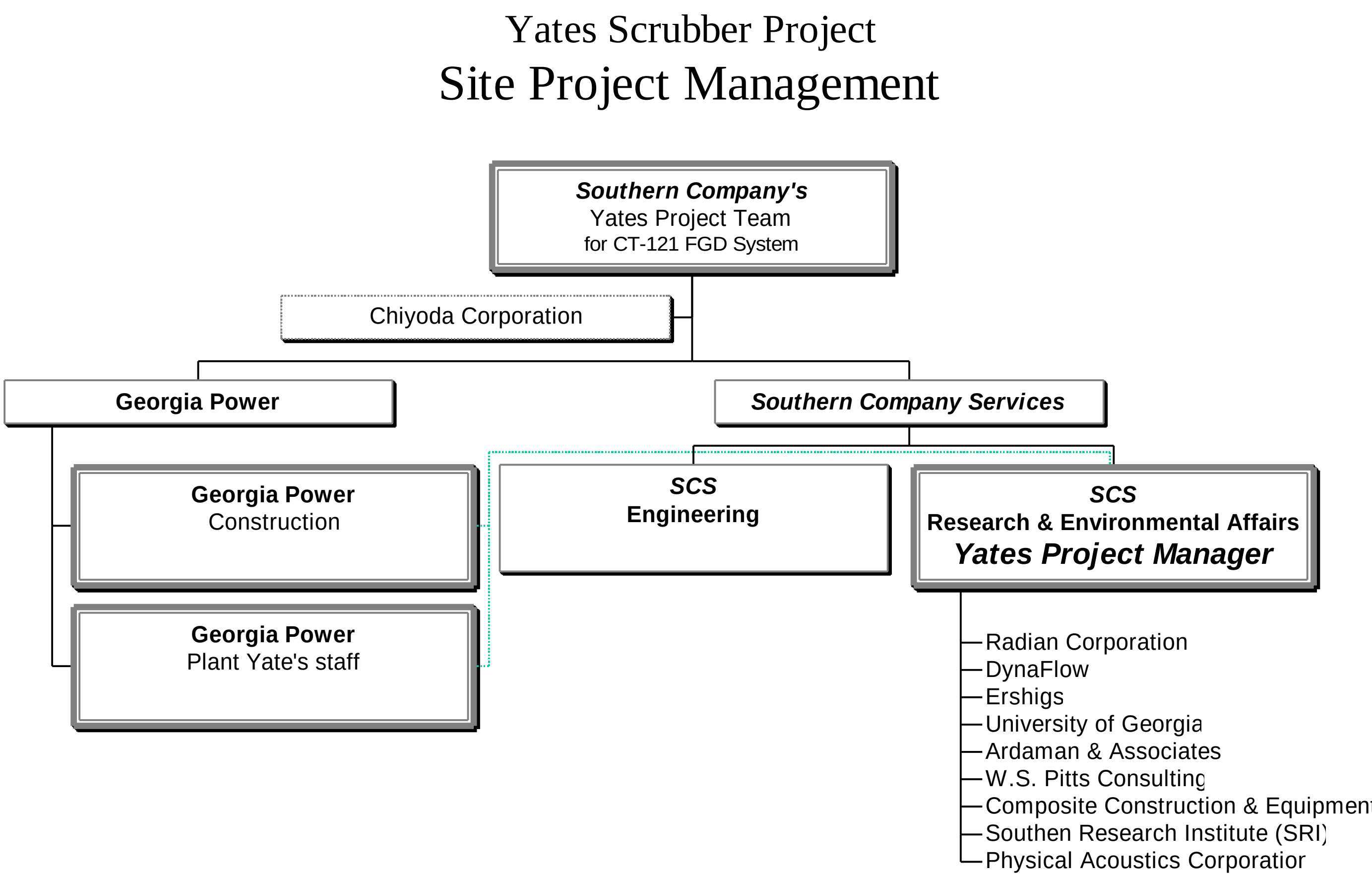


Legend:
Reporting relationships ________
Direct coordination ....

2.4. Site Project Management – Construction through Testing

For the Yates Project's construction, operations and testing; the organizational ties expand through the Project Manager to Georgia Power, the vendors providing materials or expertise and the various testing contractors:

Figure 2-4



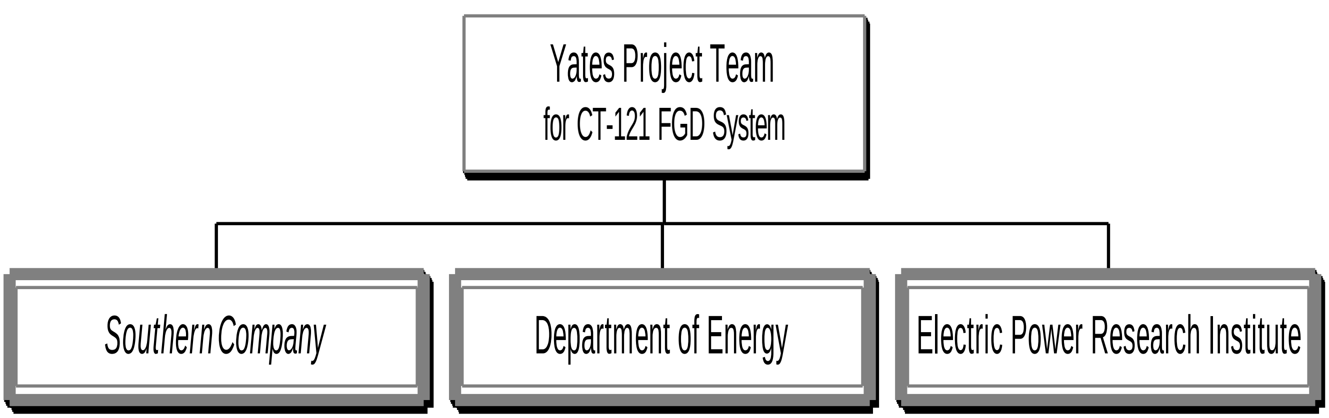
Legend:
Reporting relationships ________
Direct coordination …………..

3.0 Project Finances

The initial total funding for the Yates project was $35,843,678. In keeping with the DOE's Clean Coal program guidelines, more that 50% had to be from private sector source or sources. For the Yates work, only Southern Company and the Electric Power Research Institute were "private sector" contributors. Chiyoda Corporation was not a project contributor. At the DOE's later consideration, additional monies were added to the project. However the $50\%^{+}$ / $50^{\%-}$ split to meet DOE's Clean Coal program guidelines had to be maintained although the Electric Power Research Institute declined to participate in the added test costs. Funding responsibilities are shown in the table(s) below.

Figure 3-1

Yates Scrubber Project
Financial Participation



The funding for the project changed just before operations began with a consensus to increase authorizations and expand the testing from $35,843,678 by $7,231,318 to a project total of $43,074,996.

However, the funding levels never exceeded the DOE's objective of contributing less than 50% from the public sector and gathering in the support for greater than 50% from the private sector:

Tables 3-3a – 3-3e **<u>Project Financial Breakdown and Summaries … by participant</u>**

Table 3-3a ---- Initial funding

Yates Project Participants	Commitment in $	Commitment by %	
US DOE	$ 17,546,646	49.0%	>
Southern Company	$ 11,297,032	31.5%	
Electric Power Research Institute	$ 7,000,000	19.5%	
Total project	***$ 35,843,678***	*100%*	

Table 3-3b ---- Initial Summary

Public sector funding	$ 17,546,646	49.0%
Private sector funding	*$ 18,297,032*	*51.0%*
	$ 35,843,678	

Table 3-3c ---- Final funding / ***Table 3-3d ---- Added funding***

Yates Project Participants	Commitment in $	Commitment by %		Added funding	
US DOE	$ 21,085,211	49.0%	>	*$ 3,538,565*	>
Southern Company	$ 14,989,785	34.8%	>	*$ 3,692,753*	>
Electric Power Research Institute	$ 7,000,000	16.3%	-	-	
Total project	***$ 43,074,996***	*100%*		***$ 7,231,318***	

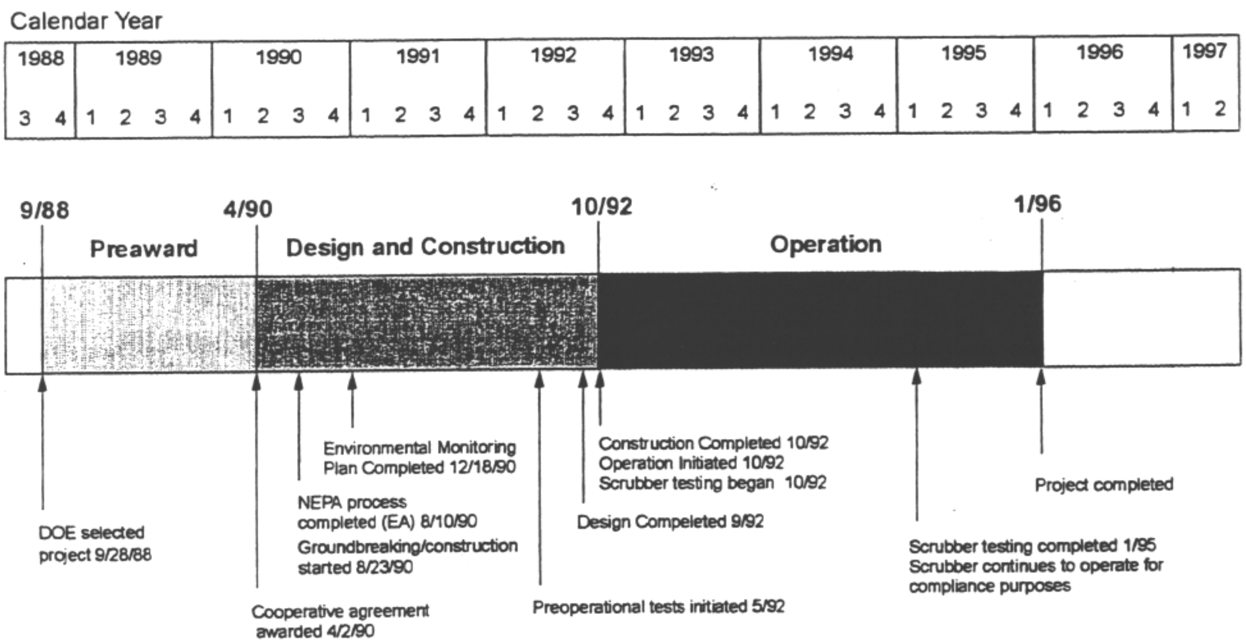
Table 3-3e ---- Final Summary

Public sector funding	$ 21,085,211	49.0%
Private sector funding	*$ 21,989,785*	*51.0%*
	$ 43,074,996	

4.0 Project Schedule 1988 - 1997

The schedule as shown below, carries from the selection of the Project in Round II of the DOE's Clean Coal Technology Initiative, the thirty months of design and construction , to start-up in October of 1992, through two years of demonstration testing that ended the last day of December 1994.

Figure 4-1



5.0 PROJECT OVERVIEW

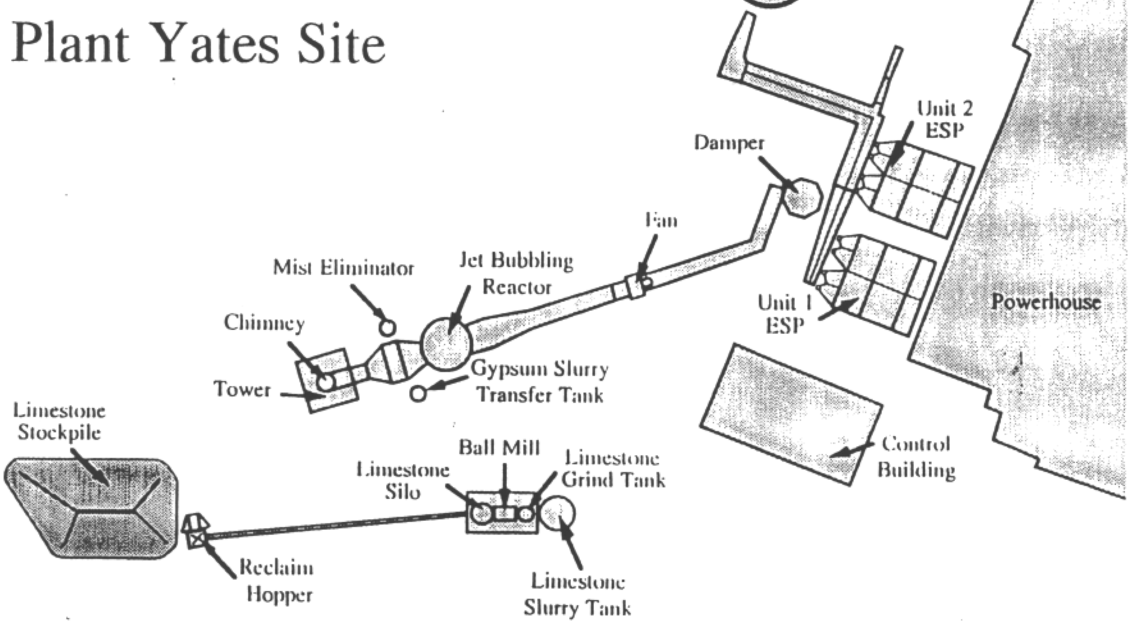
5.1 Purpose of the Final Report

The purpose of the Final Report for the Yates Project is to convey to the public the nature, objectives and experimental findings of the demonstration of the Chiyoda CT-121 wet limestone flue gas desulfurization system, built at full scale, retrofit to an existing coal fired unit taking 100% of it exhaust flue gases at Georgia Power's Plant Yates in a cooperative effort between the U.S. Department of Energy and the private sector.

5.2 Description of the Plant and the Project

The Yates Project involved an environmental control system, specifically a wet limestone flue gas desulfurization system, built as a retrofit to treat the exhaust flue gases from a 110MW pulverized coal fired boiler at Georgia Power's Plant Yates just south of Atlanta, Georgia. The test program was originally intended to include the use of innovative materials of construction, the reliance on this CT-121 system's inherent reliability by not providing much spare capacity and the production of a possible by-product of gypsum as opposed to the usual scrubber waste produced by limestone scrubbing. This original test program was expanded into additional avenues of investigation just after start-up in 1992.

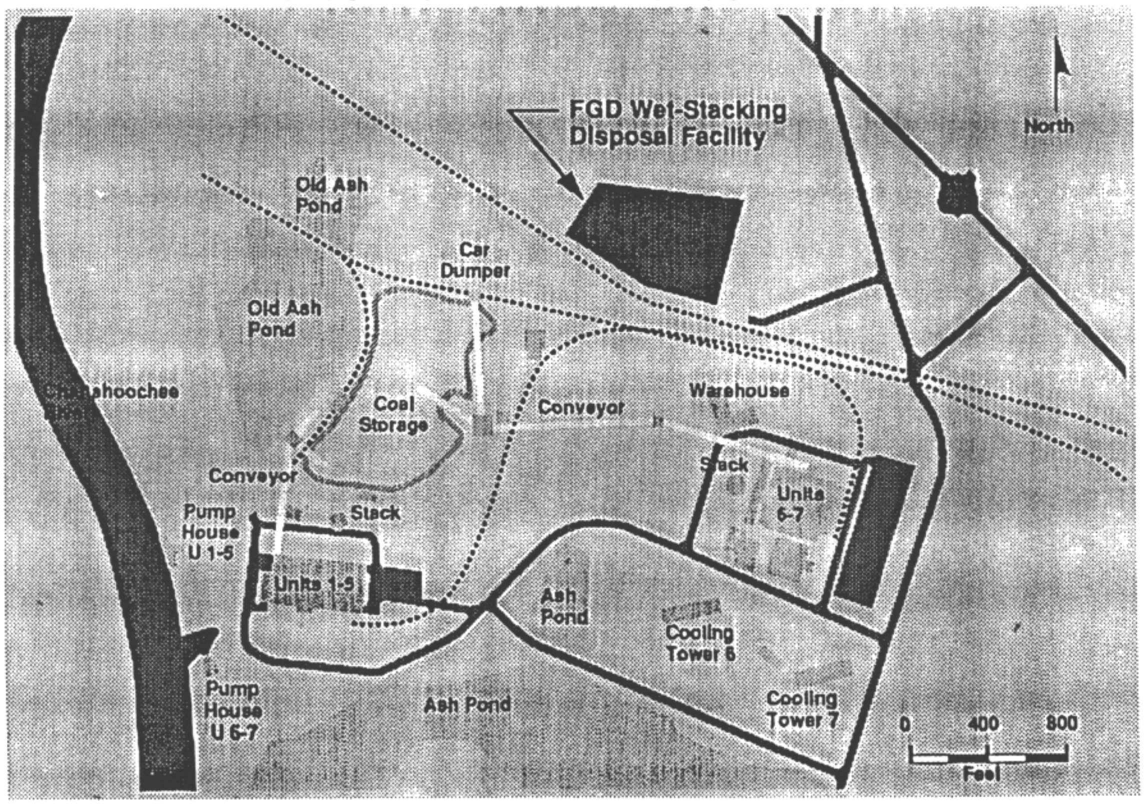
Figure 5-1



Plant Yates is a seven-unit station of pulverized coal fired units with a site capacity of ~1,250MW, located on the banks of the Chattahoochee River, about 45 miles south of Atlanta, Georgia. The original five units (Units 1-5) are small Combustion Engineering tangential boilers (100-125MW) built in the 1950's; Units 6 and 7 are also Combustion Engineering tangential boilers (350MW each) added to the site in the 1970's. All units have electrostatic precipitators for particulate control and share a single coal pile but Units 1-5 use once-through cooling from the river while Units 6 and 7 both have a dedicated mechanical draft cooling tower. Coal is delivered to the site by train. Units 1-5 share a single, dual-flue chimney; Units 6 and 7 also share a single dual-flue chimney. Some flyash is sold from the site but most is landfilled on Georgia Power property. The scrubber project used about 20+ acres of existing plant property north of the coal pile for its gypsum stacking landfill.

Figure 5-2

Plant Yates Site Plan



The onsite Project Management was provided by Southern Company's Research & Environmental Affairs Department out of Birmingham, Alabama who relied on Georgia Power's existing plant staff at PlantYates for scrubber operations, maintenance, laboratory support and emissions monitor support (CEM's). The Unit 1 boiler-turbine operator is also the scrubber operator, with DCS scrubber controls located at his fingertips and the maintenance personnel simply include the CT-121 system in their walk-down and maintenance scheduling.
Under SCS Project Management, Radian Corporation provided an onsite chemical engineer from its Atlanta, Georgia office for the duration of operations; 1992-1994.

The Yates scrubber Project was not built in response to any specific environmental requirement placed on Georgia Power at the inception nor during the duration of the project. At the conclusion of the experimental period in December of 1994, Georgia Power chose to assume responsibility for the cost and operation of the CT-121 flue gas desulfurization system on their own, in order to preserve the scrubber's contribution to Georgia Power's overall commitment to environmental excellence. The original project plan had called for its demolition following the conclusion of testing.

The project schedule spanned a period of some 60 months from groundbreaking in 1989, to placing the scrubber online in October of 1992 through the conclusion of the demonstration period on the last day of 1994. The testing matrix was a "factorial" design fashioned to recover the intricacies of various influences on operations, operational predictability and reliability. It was also important to the demonstration team to "push the envelope" of operational boundaries in order to better understand the limitations of this CT-121 system. Test periods included a short shakedown period, comparative runs on alternative fuels and comparative runs alternative limestones as well as high particulate loading periods and periods of substantially level duration runs following unit load.

As the Yates Project testing progressed, the objectives expanded into include the measurement of incidental particulate collection across Chiyoda's Jet Bubbling Reactor, the measurement of incidental air toxics removal across the JBR, the experimentation on a wide range of limestones of various origins and the experimentation on a wide range of coals of various sulfur content. As of the writing of this report, the CT-121 system at Plant Yates continues to operate as required by the normal operations of Unit 1, serviced by the dedicated manpower of that unit.

5.3. Significance of the Project

The Yates Project provided a demonstration of several innovative ideas. First, it was a successful application of he corrosion-independent use of fiberglass reinforced plastics (FRP) that many traditionalists did n ot support. Second, it was a significant finding for the operational resilience and "robustness" of the chemistry of the CT -121 … by operating at a lower pH with in-situ oxidation and massive residence times in the slurry reservoir, one could almost elimi nate the gypsum scaling inherent to so many other limestone scrubbers, without relying on additive for assistance. It was also a triumph of the personnel, who were trained onsite from the existing rolls to operate and maintain the scrubber.

5.4. Block Flow Diagram

The CT-121 system is not as mechanically complex as many other competitive flue gas desulfurization systems.

Figure 5-3

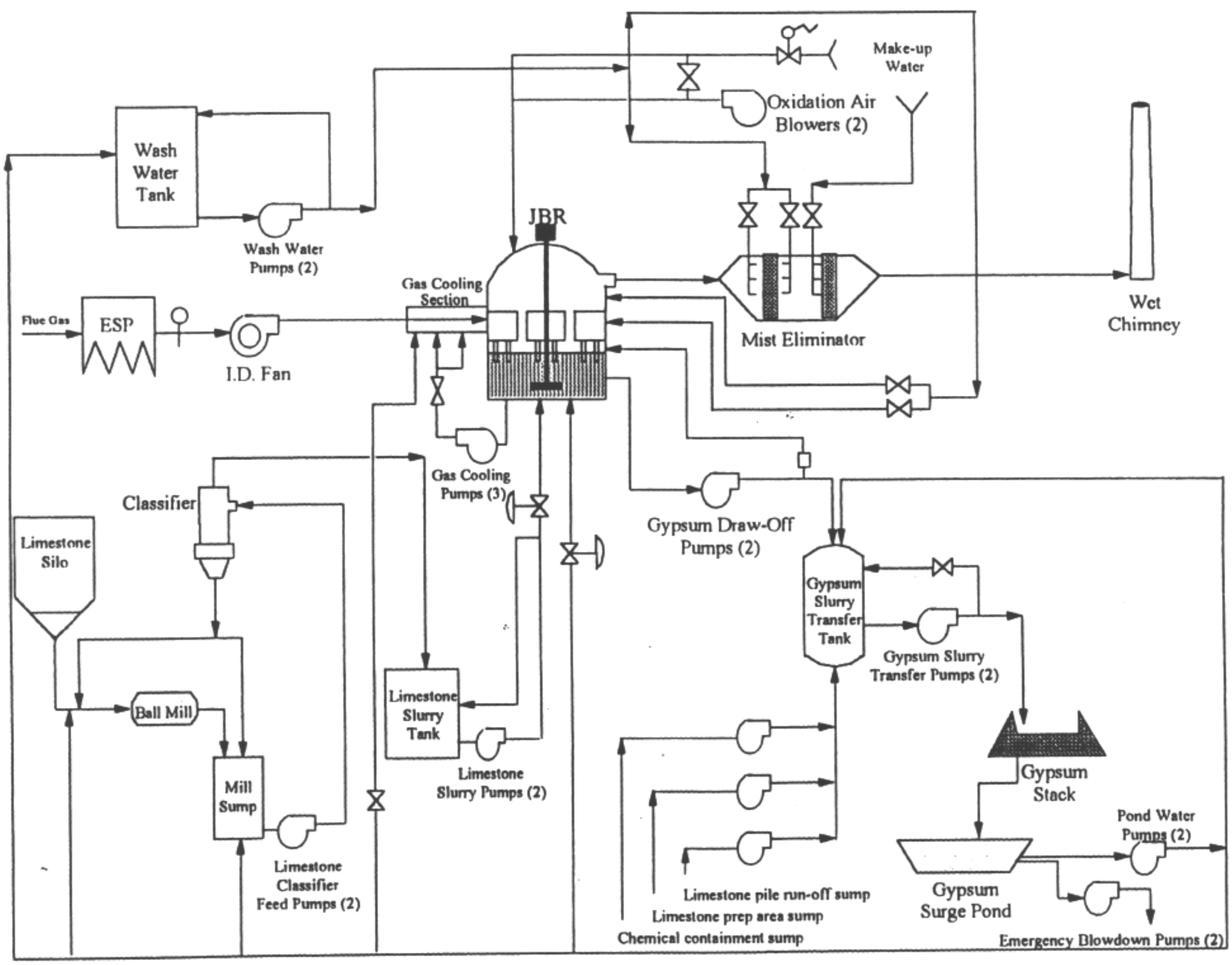


Table 5-1 Process Design Criteria for Yates CT-121

** Operation at 110MW on 2.68% sulfur coal*

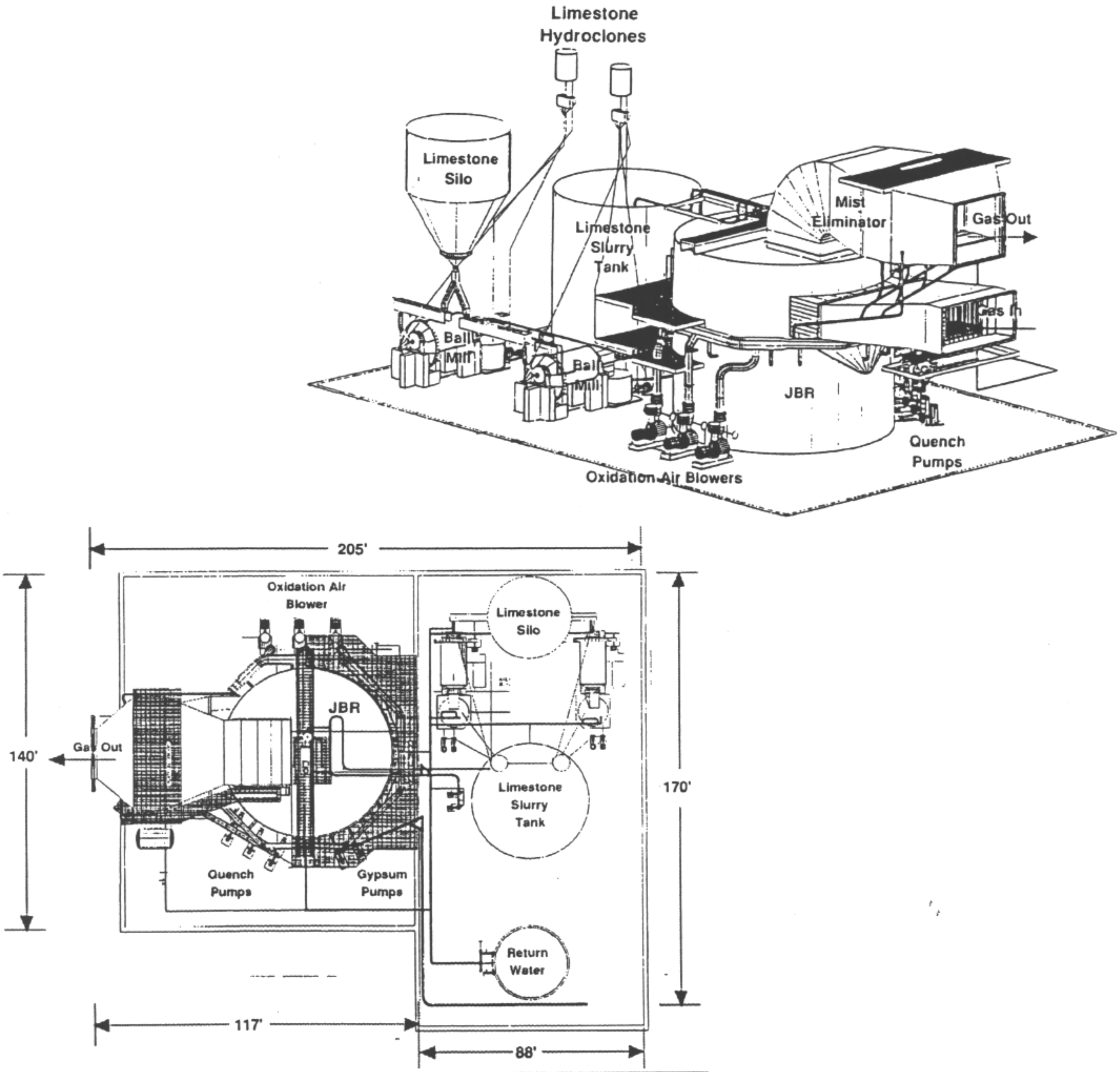
Process Area	**Design Criteria**	**Information***
Flue gas handling	Flue Gas Flow Rate	316,000scfm
	Pressure drop	21” water column
	Inlet SO_2	~1900 ppm (vol-wet)
	Inlet particulate	~175 mg / Nm^3 dry (0.151 lb/10^6BTU)
	Cooling section inlet	276ºF inlet
	JBR inlet	165ºF continuous / 250ºF excursion
	JBR outlet	~126ºF
SO_2 removal	Percent SO_2 reduction	90% - 95%
	Absorber module	1ea - Jet Bubbling Reactor (no spare)
	Volumetric scrubbing intensity	N/A in a Jet Bubbling Reactor
	Reagent feed ratio	Ca to S molar feed ratio of 1
	Gas contacting	Flue gas sparged into slurry reservoir
	Absorber reservoir	12-24 hours gypsum residence time
	Oxidation rate	100% sulfite to sulfate conversion
	Pressure drop (JBR only)	12-14” water column
Reagent feed	Total limestone storage	Outdoor pile @ 30 days
	Limestone day bin	36 hours days at max output
	Limestone slurry tank	24 hours at max output @ 20 % solids
Waste handling	Absorber underflow	15 to 30% solids in JBR reservoir
	Slurry transport to gypsum	Diluted to 10% solids for transport
	Sulfate / sulfite ratio in solids	~100% sulfate
	Water treatment requirement	None (closed loop)
	Leachate water	95% returned, 5% in solids (long term)
Balance of plant	Makeup water	Return flow from gypsum area
	Seal water	Constant flow from existing plant

5.5. Commercialization of CT-121 systems

The CT-121 system has been applied in a number of countries on different fuels and at many different sizes, rangunig up to 750MW in a single module. One example of a CT-121 system that gained insight from the work at Plant Yates was a 350MW application that was designed and began construction while the Yates Project was still in the demonstration phase.

Figure 5-4a & 5-4b

350 MW CT-121 Compact Design



6.0 PROCESS CAPITAL COSTS

Table 6-1

Yates DOE Project - CT-121 Scrubber

Final Actual Costs

ACCOUNT & DESCRIPTION		Element Cost
ENGINEERING & CONSTRUCTION MANAGEMENT		
	Preliminary Engineering	$101,564
	Detailed Design Engineering	$3,756,722
	Construction Management	$2,219,415

TOTAL ENGINEERING & CONSTRUCTION MGMT		$6,077,701
LIMESTONE PREPARATION		
	Limestone Truck Scales	$22,672
	Structural Steel	$39,936
	Limestone Handling	$152,198
	Limestone Storage Silo	
	Limestone Handling	$117,429
Limestone Pulverizer System		
	Ball Mill	$808,456
	Limestone Handling	$95
Limestone Slurry Storage Tank & Feed System		
	Structural Steel	$14,006
	Pumps	$23,830
	Agitators	$19,356
	Tanks	$198,022
Limestone Area Chemical Containment System		
	Pumps	$45,562
	Agitators	$7,173
	Limestone Preparation - Construction	$787,955

	TOTAL LIMESTONE PREPARATION	$2,236,690

PROCESS CAPITAL COSTS (continued)

ACCOUNT & DESCRIPTION		Element Cost
S02 CONTROL		
Jet Bubbling Reactor		
	Structural Steel	$34,989
	Agitators	$98,679
	Reactor (JBR)	$2,823,748
Mist Eliminator		
	Ductwork	$4,655
	Structural Steel	$75,323
	Pumps	$24,235
	Mist Eliminator	$428,460
	Tanks	$26,112
Oxidation Air System		
	Blowers	$59,197
Prescrubber System		
	Piping	$139,835
	Pumps	$88,973
Absorber Area Chemical Containment System		
	Pumps	$24,517
	Agitators	$7,173

S02 Control -Construction		$1,831,082

	TOTAL S02 CONTROL	$5,666,978

PROCESS CAPITAL COSTS (continued)

ACCOUNT & DESCRIPTION		Element Cost
WASTE DISPOSAL		
Gypsum Slurry Tank and Pump		
	Structural Steel	$5,678
	Tanks	$2,911
Waste Gypsum System		
	Misc. Electrical	$6,593
	Pumps	$62,510
	Agitators	$6,367
	Tanks	$37,080
Gypsum Stack Initial Construction		
	Misc. Electrical	$91
Gypsum Liquor Return System		
	Structural Steel	$91,038
	Pumps	$112,950
Waste Disposal - Construction		$1,401,552

	TOTAL WASTE DISPOSAL	$1,726,770
FLUE GAS HANDLING		
Dry Booster Fan		
	Fans	$731,690
Flue Gas Duct - Existing ID Fan Discharge to Dry Booster Fan		
	Ductwork	$347,374
	Structural Steel	$150,656
	Misc. I & C	$3,981
	Dampers	$60,490
FRP Ductwork From Dry Booster Fan to Chimney		
	Ductwork	$298,793
	Structural Steel	$14,719
Chimney		
	Elevator	$121,119
	Structural Steel	$146,224
	Chimney	$912,216
Flue Gas Flow Model		
	Flow Model	$125,839
Flue Gas Handling - Construction		$1,384,144

	TOTAL FLUE GAS HANDLING	$4,297,245

PROCESS CAPITAL COSTS (continued)

ACCOUNT & DESCRIPTION		Element Cost
GENERAL SUPPORT (BALANCE OF PLANT)		
Control and Service Air System		
	Air Compressors	$114,141
Scrubber Control Building		
	Control Building	$76,996
Area Lighting		
	Cable	$1,819
	Lighting	$35,919
	Misc. Electrical	$4,603
Communication System		
	Communication System	$4,718
	Misc. Electrical	$1,079
Digital Data Acquisition System		
	Control System	$104,490
	Misc. I & C	$265
Plant Control System		
	Cable	$45,378
	Misc. Electrical	$1,484
	Control System	$165,264
	Misc. I & C	$11,734
B.O.P. Instruments and Controls		
	Cable	$582
	Misc. Electrical	$15,294
	Misc. I & C	$203,474
Continuous Emissions Monitoring System		
	Structural Steel	$1,235
	Emissions Monitoring System	$315,435
	Misc. I & C	$823
Freeze Protection System		
	Misc. Electrical	$18,261

PROCESS CAPITAL COSTS (continued)

ACCOUNT & DESCRIPTION		Element Cost
GENERAL SUPPORT (BALANCE OF PLANT) - continued		
115 KV System		
	Breakers	$36,420
	Misc. Electrical	$23,945
	Transformers	$237,933
4160 Volt System		
	Structural Steel	$7,156
	Cable	$135,770
	Distribution Panels	$1,832
	Misc. Electrical	$26,176
	Motor Control Centers	$78,741
	Switchgear	$43,606
480 Volt System		
	Cable	$137,045
	Distribution Panels	$8,527
	Misc. Electrical	$8,750
	Motor Control Centers	$92,009
	Switchgear	$57,232
	Transformers	$46,857
208/120 Volt System		
	Misc. Electrical	$4,908
125 Volt D.C. Distribution System		
	Distribution Panels	$6,382
	Misc. Electrical	$801
Area Conduit & Cable Tray		
	Cable	$62,512
	Communication System	$5,087
	Grounding	$1,996
	Misc. Electrical	$20,651
	Local Control Stations	$180
General Support (Balance of Plant) - Construction		$3,364,104

TOTAL GENERAL SUPPORT (BALANCE OF PLANT)		$5,531,614

PROCESS CAPITAL COSTS (continued)

ACCOUNT & DESCRIPTION	Element Cost
PROCESS ENGINEERING	
Process Engineering	$383,673
FRP Evaluation	$40,411
Strain Gauge Support	$74,340
Corrosion/Abrasion Support	$5,154
Acoustic Emissions Support	$46,852
Radian Process Engineering Support	$83,186

TOTAL PROCESS ENGINEERING	$633,616
OPERATING COMPANY ENGINEERING COORDINATION	
GPC Engineering Coordination	
Plant	$20,582

TOTAL OPERATING COMPANY ENGINEERING COORDINATION	$20,582
TEST PLAN DEVELOPMENT	
Test Plan Development	$15,520

TOTAL TEST PLAN DEVELOPMENT	$15,520
TRAINING OF OPERATIONS & MAINTENANCE PERSONNEL	
Training of Operations & Maintenance Personnel	$158,918

TOTAL TRAINING OF OPERATIONS & MAINTENANCE PERSONNEL	$158,918
START-UP	
Start-up	$1,230,047

TOTAL START-UP	$1,230,047
BASELINE GROUNDWATER MONITORING	
Baseline Groundwater Monitoring	$10,200
Groundwater Monitoring	$90,225
Chemical Analysis	$16,971
SCS R&EA Review & Supt of Groundwater Monitoring	$8,474

TOTAL BASELINE GROUNDWATER MONITORING	$125,870

PROCESS CAPITAL COSTS (continued)

ACCOUNT & DESCRIPTION	Element Cost
ENVIRONMENTAL DATA MANAGEMENT & REPORTING	
Environmental Data Management Reporting	$55,923

TOTAL ENVIRONMENTAL DATA MANAGEMENT & REPORTING	$55,923
PROJECT MANAGEMENT & REPORTING	
Project Management & Reporting	$460,899
Compliance Charges	$5,470
DOE Non-Billable Expenses	$6,867

TOTAL PROJECT MANAGEMENT & REPORTING	$473,236
PHASE 11 GYPSUM STACK DESIGN & BYPRODUCT STUDIES	
Phase 11 Gypsum Stack Design and Byproduct Studies	$45,840
Ardaman - Site Evaluation	$47,432
Ardaman - Design & Construction Recommendations	$84,362
Ardaman - Construction of Stacking Areas	$106,697
Ardaman - Stack Operation & Evaluation	$9
Univ. of Georgia - Agronomic Response	$95,389
Univ. of Georgia - Environmental Aspects	$140,880
Univ. of Georgia - Crop Rotation & Deep Rooting	$27,092
Univ. of Georgia - Revegetation of Stacks	$15,465
Univ. of Georgia - Reporting of Results	$13,731
System Gypsum Stack Management	$94,426

TOTAL PHASE 11 GYPSUM STACK DESIGN & BYPRODUCT STUDIES	$671,323
CHIYODA TASKS	
Chiyoda Tasks	$413,946

TOTAL CHIYODA TASKS	$413,946
GRAND TOTAL	**$29,335,979**
Project Total	**$43,074,996**

Table 6-2

Annual Fixed Operating Costs *Base year 1994*

	Number of operators per shift	1
Operating Cost details *	Number of Shifts per week	21
	Operating pay per hour	~$26.00
		Cost / year *
Total Annual Operating Cost		$512,000
Total Annual Maintenance Labor Cost		$257,000
Total Annual Maintenance Material Cost		$47,000
Total Annual Admin and Support Labor Cost		$50,000
Total Annual Fixed O&M Cost		$354,000

** 1994 dollars*

Table 6-3

Summary of estimated start -up costs *Start-Up Oct-1992*

Start-up element		***Cost***
Operating labor cost		
Maintenance and materials cost		
Admin and support costs		
Training		$158,918
Commodity costs:		
Limestone		$15 per ton
Water for the JBR		$0 *(ash pond water)*
Gypsum seed crystals		$0 *(donated)*
Total		$1,230,047

** Start-up at Yates made an unprecedented transition directly into operations. Start-up costs can not be broken down into categories.*

Table 6-4a

Sampling of Measured Variable Operating Cost Factors

Test #	**ID Fan HP *kW***	**ID Fan HP costs *$/ton SO2 removed***	**All other power costs *$/ton SO2 removed***	**Reagent Use *(lb/hr)***	**Reagent Costs *$/ton SO2 removed***	**Total Var cost *$/ton SO2 removed***
AC2-5R	408	$4.40	$7.90	5334	$22.30	$34.00
P1-1	487	$5.00	$7.40	5513.0	$30.60	$43.60
L1-3	711	$6.40	$6.50	149.2	$30.20	$43.70
HR1-2	623	$6.20	$7.40	5645	$30.70	$44.20
AL2-9	467	$10.20	$17.90	2584	$21.80	$49.90
HR2-1	934	$18.80	$15.60	2730	$29.10	$63.5

Date taken from Appendix D, Volume 2   Performance –Operation,

Table 6-4b

Test Condition Descriptions for

Sampling of Me asured Variable Operating Costs Factors

Testing sequence number	**Test Description**
AC2-5R	High particulate alternate coal tests
P1-1	Low particulate parametric testing
L1-3	Low particulate long term testing
HR1-2	Low particulate high removal testing
AL2-9	High particulate alternate limestone testing
HR2-1	High particulate high removal testing

It is interesting that the $ per ton removed figures are low and vary only moderately.

It seems safe to say that reagent cost are almost constant with an FGD pr ocess that uses a stoichiometric amount (or molar ratio near 1) and that the real difference in the $ per ton removed is in the horsepower demands of the flue gas handling and in the auxiliary power required to meet SO_2 removal objectives.

7.0 FACILITY DESCRIPTION

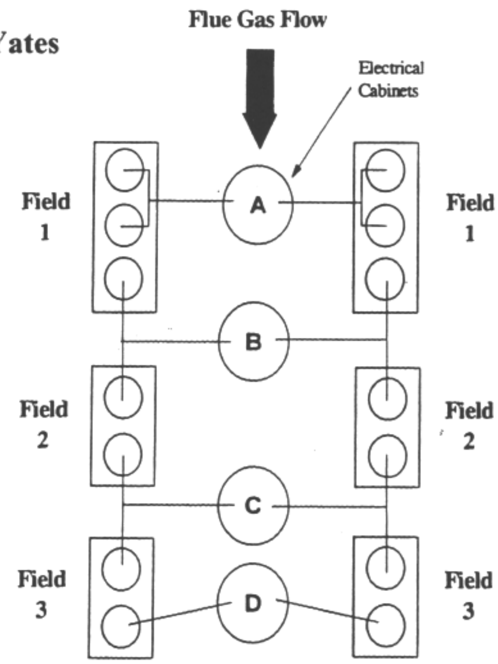
The equipment comprising the demonstration facility can be divided into four major systems: boiler/ESP, CT-121 scrubber/wet chimney, limestone preparation circuit, and byproduct gypsum stack. Additionally, many control systems were required to maintain proper operation of the scrubber. Each of these systems is described below.

7.1 Boiler / Electrostatic precipitator (ESP)

Plant Yates has seven operating pulverized-coal-fired generating units located in two separate buildings. Unit 1, with a rated capacity of 100 MWe, was used to supply flue gas for the demonstration program. The flue gas passes through an electrostatic precipitator to remove fly ash particulate prior to entering the scrubber (a "cold side" ESP). All of the flue gas from this unit is treated by the CT-121 wet FGD process and there is no provision to bypass the scrubber. The flue gas from Unit 1 is vented through a wet chimney downstream of the CT-121 process.

The ESP has three fields (numbered 1 through 3), powered by a total of four electrical cabinets (A through D). Depending on the desired particulate loading to the scrubber (i.e., low-, mid-, or high-ash loading), each cabinet could be fully or partially deenergized to achieve the target loading.

Figure 7-1 **Fields of the Unit 1 ESP at Plant Yates**



7.2 CT-121 Wet FGD System

The general chemistry of mass transfer involved in wet SO_2 scrubbing is shown below. A simplified process flow diagram for the CT-121 process is presented on the next page. The CT-121 employs a unique absorber design, called a jet bubbling reactor (JBR), to combine SO_2 absorption, neutralization, sulfite oxidation, and gypsum crystallization in one reaction vessel. The process is designed to operate in a pH range (3 to 5) where the driving force for limestone dissolution is high, resulting in nearly complete reagent utilization. Oxidation of sulfite to sulfate is also promoted at the lower pH because of the increased solubility of naturally occurring catalysts such as iron. Because the process is designed for forced oxidation, there is sufficient surface area for gypsum crystal growth to prevent the system from becoming significantly supersaturated with respect to calcium sulfate. This significantly reduces the potential for gypsum scaling, a problem that frequently occurs in natural-oxidation FGD systems and many conventional forced oxidation systems. Since much of the crystal attrition and secondary nucleation associated with the large centrifugal pumps in conventional systems is eliminated in the CT-121 design, large, easily dewatered gypsum crystals can be produced.

Figure 7-2

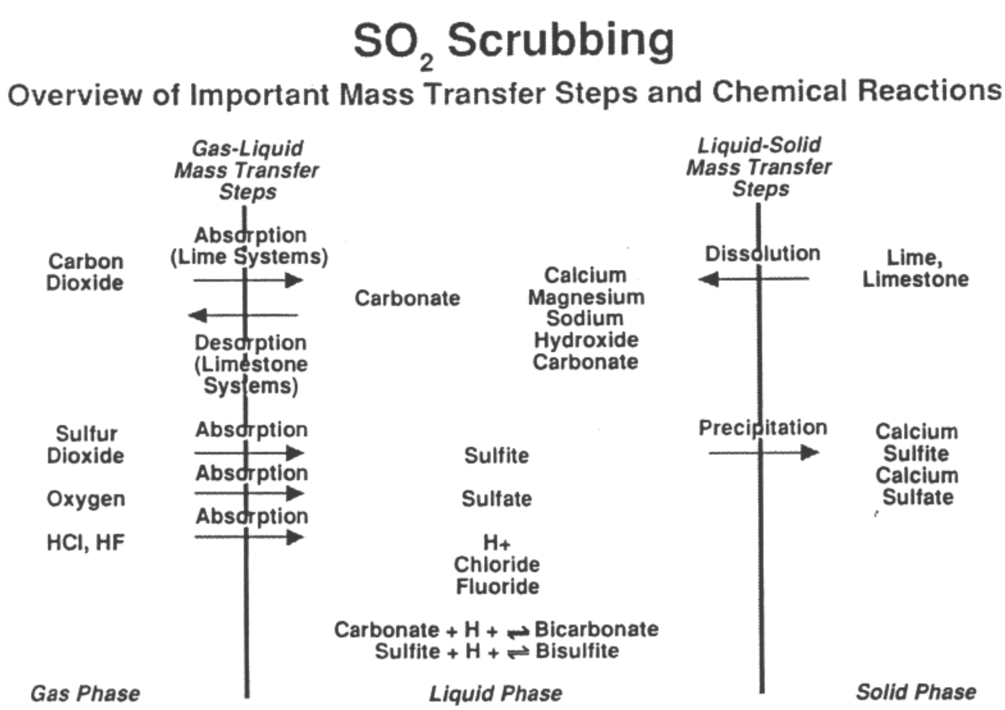
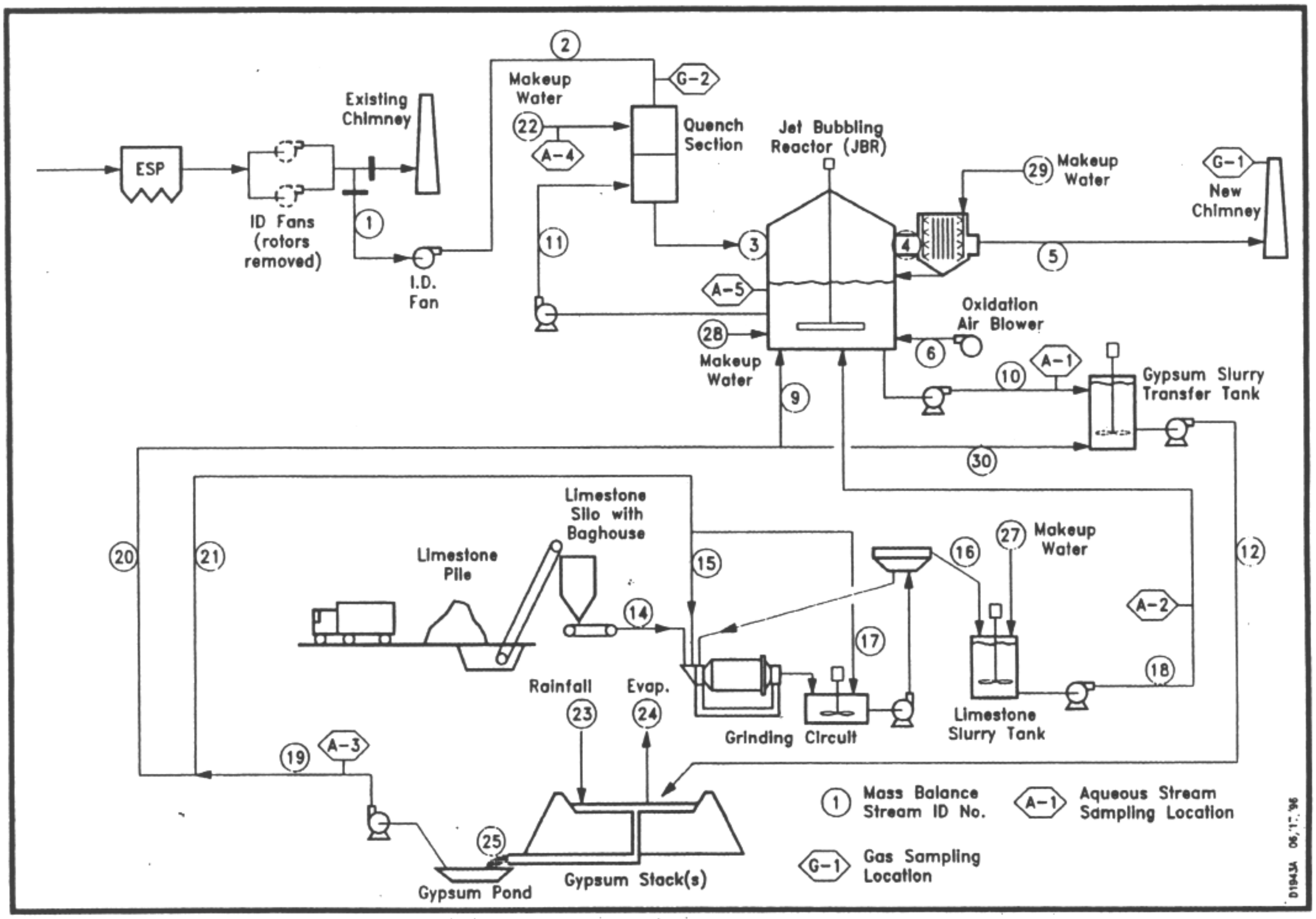


Figure 7-3 **Process Flow Diagram for CT-121**



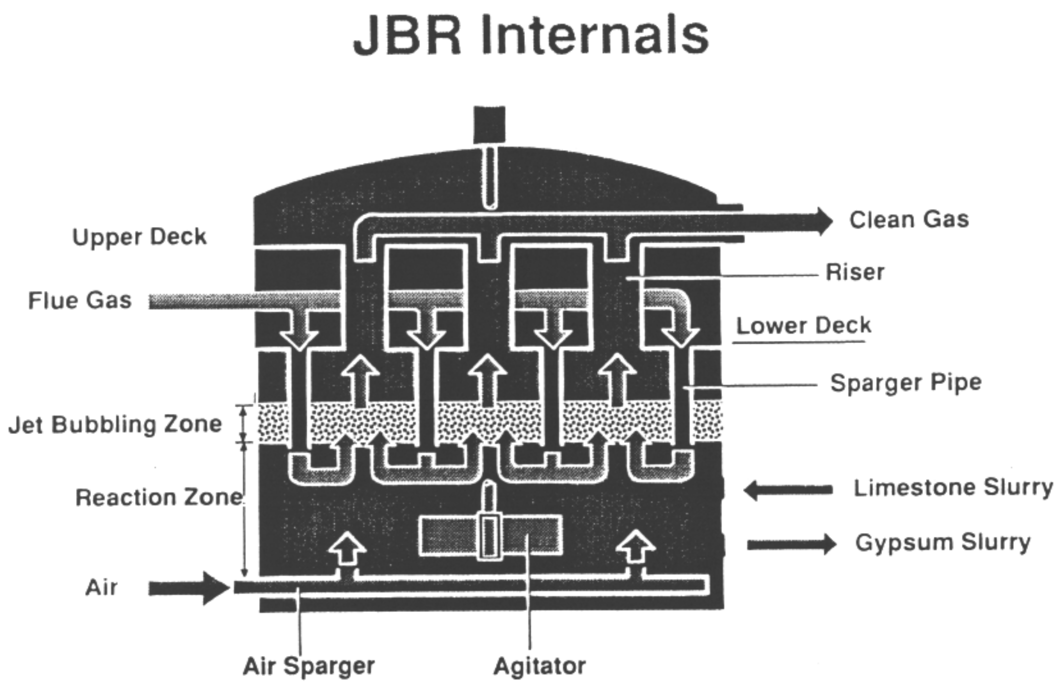
7.3 Gas Cooling System

Flue gas from the boiler passes through the ESP and is pressurized by the Unit 1 induced draft (I.D.) and scrubber booster fan (The retrofit project replaced the two existing boiler I.D. fans with one combination I.D./booster fan). From the fan, the flue gas enters the gas cooling section, also referred to as the transition duct. Here the flue gas is cooled with gypsum recycle pond water at a liquid-to-gas ratio of 0.25 gal/1000 acf to prevent a wet-dry interface from occurring between the slurry and flue gas. The gas is then completely saturated with JBR slurry. The slurry is sprayed cocurrently into the gas at a liquid-to-gas ratio of about 10 gal/1000 acf at full boiler load using two of three installed centrifugal gas cooling pumps. The suction for the slurry gas cooling pumps is located near the bottom of the JBR. Suction screens were added late in the demonstration project to prevent the gas cooling nozzles from being plugged by foreign material entering the gas cooling pump suctions.

7.4 JBR

From the gas cooling section, the flue gas enters the JBR. The JBR is the central feature of the CT-121 process. A simplified cross-section of this vessel is shown in Figure 7-2. The gas enters an enclosed plenum chamber formed by an upper deck plate and a lower deck plate. Sparger tube openings in the lower deck plate force the gas into the slurry contained in the jet bubbling (froth) zone of the JBR vessel. After bubbling through the slurry, the gas flows upward through gas risers which pass through both the lower and upper deck plates.

Figure 7-4

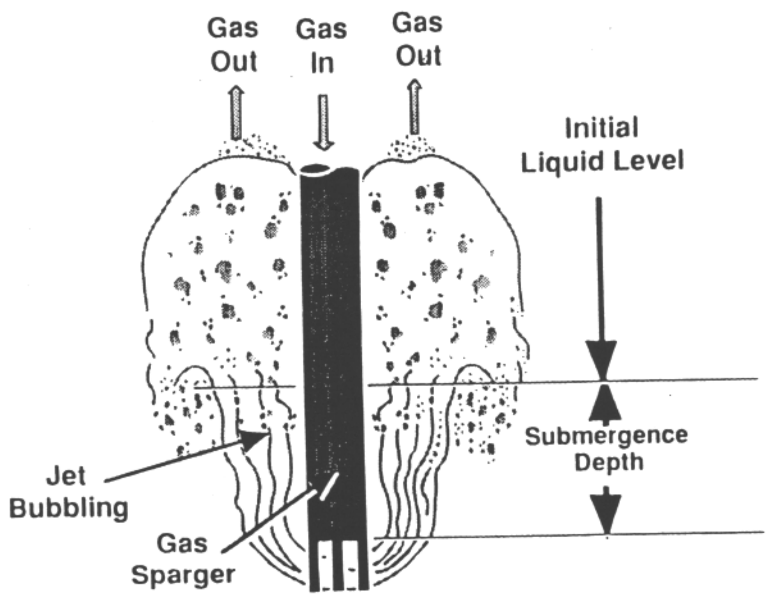


Entrained liquor in the gas disengages in a second plenum above the upper deck plate, and the cleaned gas passes to the mist eliminator.

The slurry in the JBR can be divided into two zones: the jet bubbling or froth zone, and the reaction zone. SO_2 absorption occurs in the froth zone, while neutralization, sulfite oxidation, and crystal growth occur in both the froth and reaction zones. The froth zone is formed when the untreated gas is accelerated through hundreds of sparger tubes in the lower deck and bubbled beneath the surface of the slurry at a depth of 8 to 20 inches. The froth zone provides the gas-liquid interfacial area for SO_2 mass transfer to the slurry, as well as particulate removal. The bubbles in the froth zone are continually collapsing and reforming to generate new and fresh interfacial areas and to transport reaction products away from the froth zone to the reaction zone. The amount of interfacial area can be varied by changing the level in the JBR, and consequently, the injection depth of flue gas.

Figure 7-5

CT-121 Gas Sparger Action

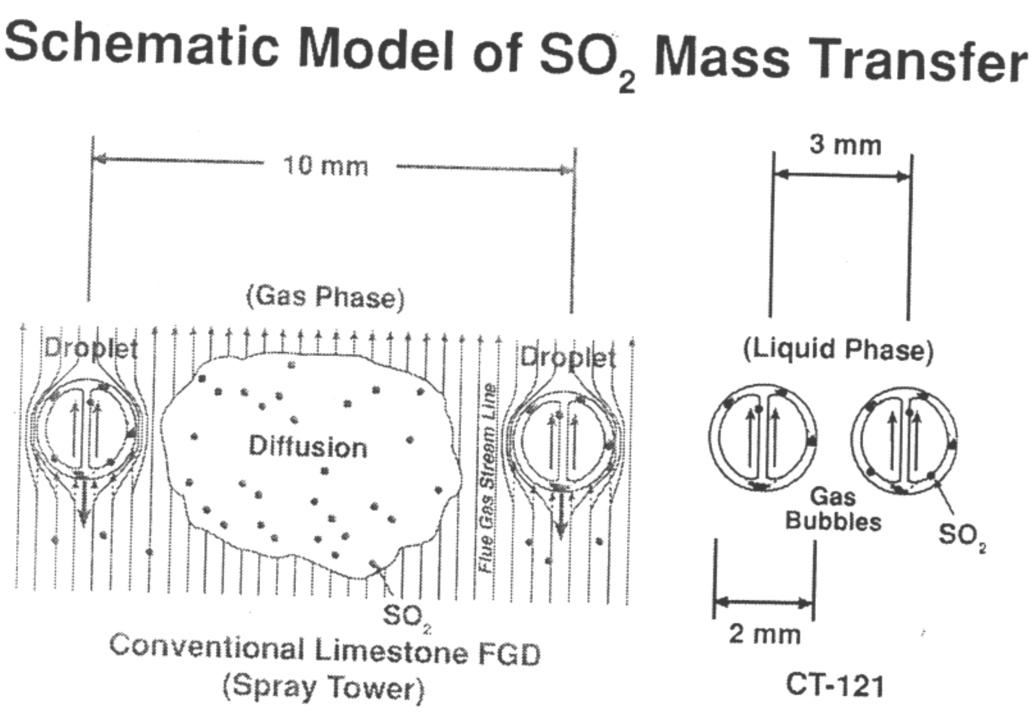


The deeper the gas is injected into the slurry, the greater the interfacial area for mass transfer and the greater the SO_2 removal. In addition, at deeper sparger depths, there is an increase in the gas-phase residence time. SO_2 removal can also be increased by increasing the pH of the slurry in the froth zone, since a higher pH results in higher slurry alkalinity and more rapid neutralization of the absorbed SO_2.

The pH is controlled by the amount of limestone fed to the reaction zone of the JBR. The solids concentration in the JBR is maintained by removing a slurry stream from the bottom of the reaction zone and pumping this stream to a holding tank (i.e., gypsum slurry transfer tank), where it is diluted with pond water before being pumped to the gypsum stack.

The oxygen that reacts with absorbed SO_2 to produce sulfate is provided to some extent by oxygen diffusion from the flue gas, but predominantly by air bubbled into the reaction zone of the JBR. The oxidation air lines enter the very top of the JBR vessel, penetrate the upper and lower deck plates, and introduce the air near the bottom of the JBR. Before the oxidation air enters the JBR, it is saturated with service water to prevent a wet-dry interface at the discharge of the oxidation air lines. Oxygen diffuses from the air into the slurry as the bubbles rise to the froth zone of the JBR. Excess oxidation air mixes with the flue gas and exits the JBR.

Figure 7-6



7.5 Mist Eliminator

From the plenum above the upper deck plate, the clean gas passes horizontally through the mist eliminator. The mist eliminator is a horizontal-gas-flow, two-stage chevron design. The upstream and downstream surfaces of the first stage were washed for 1 minute every 2 and 4 hours, respectively, with gypsum pond return water (this frequency was doubled mid-way through the test block as part of the mist eliminator wash evaluation). The upstream face of the second stage was washed with make-up water for 1 minute every 24 hours. The wash liquor was returned to the reaction zone of the JBR.

7.6 Wet Chimney

After leaving the mist eliminator, the clean gas exits the system through a wet chimney. Since the gas enters the chimney saturated with water, any heat loss results in gas cooling and water condensation in the gas stream. To prevent carryover of the condensed water, a system of gutters attached to the inside of the chimney collect and return the condensate to the JBR. FRP grating sections located in the elbow of the chimney provide a dead zone in the gas path, which allows the collected condensate to drain to the JBR without being re-entrained in the flue gas stream.

7.7 Limestone Preparation Circuit

The limestone preparation circuit is used to grind the limestone to a small enough particle size so that the amount of unreacted limestone needed in the JBR can be kept to a minimum.

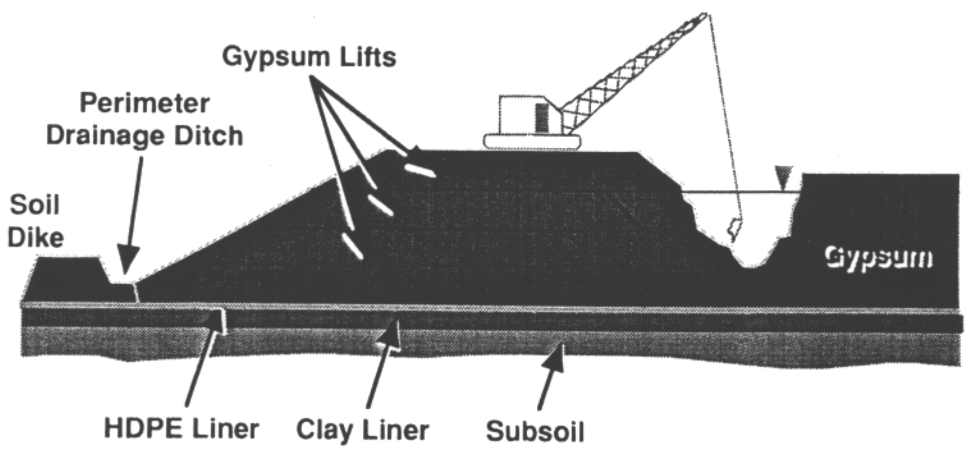
Limestone is received in trucks and pushed into a pile with a front-end loader. From the pile, the limestone is transferred to a silo which feeds the wet ball mill system. Fresh limestone, gypsum pond water, and limestone slurry from the hydroclone underflow are fed to the mill. The effluent from the mill is held in a mill sump. Slurry from the mill sump is pumped to a hydroclone where the coarse and fine limestone particles are separated, with the fine limestone stream sent to the limestone slurry storage tank and the coarser material returned to either the mill inlet or recycled to the mill sump. From the slurry storage tank, the limestone is pumped to the JBR as required the JBR as required to maintain the froth zone pH. The baseline limestone grind for the demonstration project was 90% less than #200 mesh. Tuning of the wet ball mill was necessary to retain this grind size when the limestone source was changed for two Alternate Limestone Test periods.

7.8 Gypsum Stacking

The slurry from the gypsum slurry transfer tank was sent to one of two stacks designed for the purpose of dewatering and storing the gypsum byproduct solids. The gypsum stack, the smaller of the two stacks, was used during the low-particulate test period, and a larger, gypsum/fly ash stack was placed into service for the high-particulate test period. The gypsum/fly ash stack was larger since it had to dewater and store gypsum byproduct with a high ash content compared with the relatively pure gypsum in the gypsum stack. The figure below shows an elevation view of the gypsum stacking area.

Figure 7-7

Upstream Method for
Gypsum Stack Construction Used at Plant Yates



The stacking technique involves filling a high-density polyethylene- (HDPE-) lined diked area with slurry. The filled area is then partially excavated to increase the height of the containment dikes. The process of sedimentation, excavation, and raising perimeter dikes will continue on a recycle water pond, and then returned to the process. A more complete discussion of gypsum byproduct handling, storage, and uses can be found in the Gypsum Evaluation Volume 4 of this report.

7.9 System Control

The three most critical control circuits *in* the process were the JBR level/ΔP control system, the JBR froth zone pH controller, and the JBR solids density controller. Each of these, as well as other key control systems, are described in detail below.

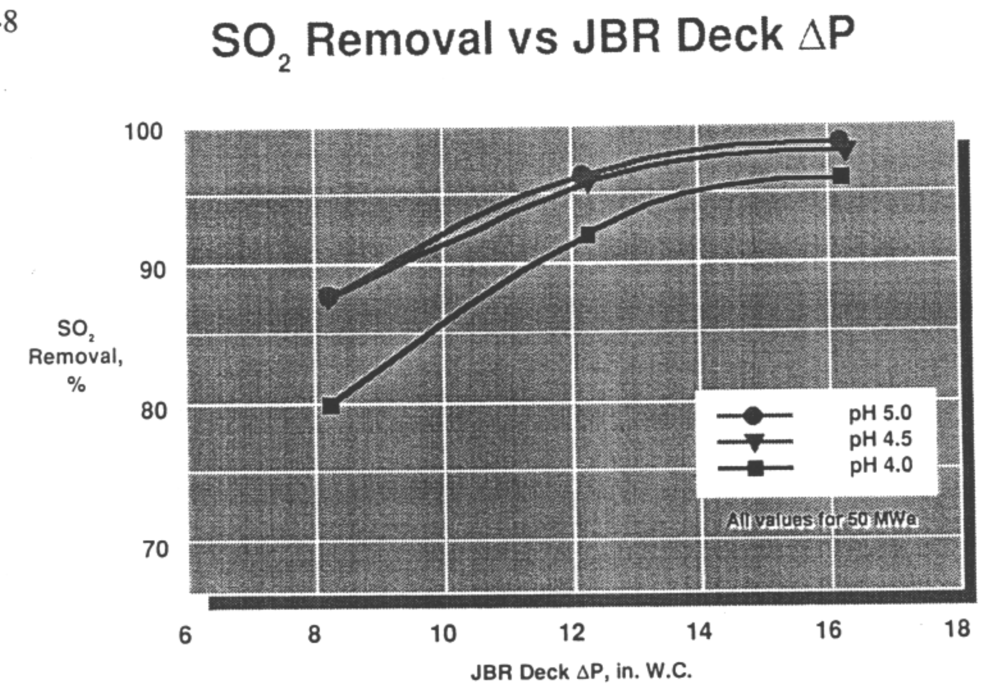
7.10 SO_2 Removal

During normal operation of the FGD system, the amount of SO_2 removed from the flue gas is controlled by varying the JBR ΔP (gas side differential pressure across the JBR). The ΔP is varied by changing the submergence depth of the gas sparger tubes. By increasing the ΔP across the JBR, the amount of gas-liquid surface area in the froth zone is increased. The increased surface area results in increased SO_2 removal. If the ΔP needed to reach the target SO_2 removal efficiency is outside of the established operating range, the froth zone pH set point can be varied as a secondary method of control. Increasing the froth zone pH provides more slurry alkalinity, and therefore, a greater capacity for SO_2 removal in the froth zone of the JBR. In certain cases, the pH can be increased (within a limited range) without lowering limestone utilization significantly, allowing higher SO_2 removal efficiency without the added fan power costs associated with raising the JBR ΔP.

7.11 JBR DP Control

JBR ΔP is the measure of gas side pressure drop between the inlet and outlet plenums of the JBR. The ΔP across the JBR is composed of two components, static head and dynamic head. The dynamic head results from the flow of the flue gas through the sparger tubes and gas risers. The static head is caused by bubbling the gas below the slurry surface; the greater the depth of the sparger tubes in the slurry, the greater the froth zone ΔP. The JBR deck ΔP is controlled by varying the static head (by varying the level of slurry in the JBR).

Figure 7-8



The option to directly control JBR level instead of deck ΔP was included in the design of this system; however, JBR level instrumentation did not perform as well as expected. Since level control could not be used without an accurate level indication, control of JBR deck ΔP was used exclusively for the demonstration project.

7.12 pH/Limestone Feed Rate Control

The pH in the froth zone of the JBR is controlled by varying the amount of limestone fed to the reaction zone. An increased limestone feed rate will increase the pH in both the reaction and froth zones. The two installed pH probes are located just below the sparger openings and provided a good representation of the pH in the froth zone of the JBR.

The limestone feed rate can be controlled in two ways: 1) feed-forward with pH trim; or 2) direct pH feedback control. At different times during testing, both means of control were used. A key factor determining the feasibility of feed-forward control was whether an adequate amount of data had been collected at similar process conditions to allow process modeling. For feed-forward control, the primary signals are the unit load and SO_2 pickup rate (a function of SO_2 removal efficiency and inlet SO_2 concentration). The amount of limestone that needs to be fed is then calculated based on a relationship between unit load, SO_2 pickup rate, and limestone feed rate. The limestone feed rate is trimmed with a feedback signal to maintain the pH set-

The alternate method of control was to only use the pH feedback signal to control limestone feed. Feedback control merely requires a comparison of actual pH with a known pH setpoint.

7.13 Level Control

The levels in the JBR, gypsum slurry transfer tank (GSTT), and wash tank are maintained by adding gypsum surge pond water. The inability to use the JBR level control system was discussed in section 2.5.2, above. Because the gypsum slurry transfer pumps continuously pump approximately 1000 gpm from the GSTT to the gypsum stack to prevent settling in the transfer line, the bleed rate from the slurry transfer tank will always be large enough to require some pond water to maintain level in the GSTT. The wash water tank was only used hourly as the mist eliminator wash, lower deck wash, and upper deck wash systems were automatically actuated. A tank level sensor signaled when the tank was low so that gypsum pond recycle water could be added to the tank.

7.14 JBR Solids Concentration Control

The suspended solids concentration in the JBR is controlled by discharging reaction zone slurry to the slurry transfer tank. The required feed rate to the slurry transfer tank is determined from the density of the JBR blowdown slurry. A dead-band controller is used to set the upper and lower JBR wt.% solids limits. For the majority of the demonstration project, the upper and lower JBR density limits were established at 24 wt.% and 22 wt.%, respectively. These limits were lowered to an average density of 15 wt.% while burning low-sulfur coal to maintain a consistent JBR solid phase residence time (approximately 30 -35 hours) and to ensure that the JBR was operated with a negative water balance.

Water is added to maintain level in the JBR whenever slurry is drawn off for solids concentration control. Water is also added to the JBR for the purposes of deck washing, mist eliminator washing, or routine level control. To maintain a negative water balance, solids must be produced at a rate greater than or equal to the rate at which they are drawn off from the JBR. With the lower SO_2 pickup associated with the low-sulfur coal, fewer gypsum solids are produced per unit time; however, the routine addition of water is not similarly decreased. Because of this lower solids production rate, a lower equilibrium so lids concentration will result and the percent solids setpoint must be lowered to maintain a negative water balance.

Table 7-1 Major Equipment List

Item No	Name	Number In Use	Spare	Unit Capacity	Design Characteristics	Materials of Construction	Vendor
1	Jet Bubbling Reactor	1	0	110MW 42' dia	Wound on a round mandrel onsite, 42' dia, interior by hand layup	Fiberglass reinforced plastic	Ershigs
2	Limestone slurry tank	1	0	28' dia x 35'	Wound on a round mandrel onsite, 28' dia, interior by hand layup	Fiberglass reinforced plastic	Ershigs
3	Dilution tank	1	0	12' dia x 12'	Wound on a round mandrel, 12' dia	Fiberglass reinforced plastic	Ershigs
4	Chimney	1	0	259'	14'x10' sections wound on a round mandrel, joined onsite	Fiberglass reinforced plastic	Ershigs
5	Wet circuit ball mill	1	0		Horizontal axis, fed by weigh-feeder from a day-bin, hydroclone sizing	Rubber lined, 2" steel-ball filled slurry service	KVS
6	Air Compressors	2	0		Axial flow	CS	
7	JBR cooling pumps	3	1		Single entry impeller slurry service	Rubber lined, alloy impeller	Warman
8	Slurry draw-off pumps	2	0		Single entry impeller slurry service	Rubber lined, alloy impeller	Warman
9	Slurry transport pumps	2	0		Single entry impeller slurry service	Rubber lined, alloy impeller	Warman
10	Leachate return pumps	2	0		Single entry impeller liquid service only	Alloy impeller,	Warman

Item No	Name	Number In Use	Spare	Unit Capacity	Design Characteristics	Materials of Construction	Vendor
11	Slurry pipe	~	~	10” ID	Schedule 80	HDPE	various

8.0 TEST PLAN – TECHNICAL APPROACH

The approach to the Yates CT-121 CCT project was to develop a series of test plans that would allow a complete evaluation of both the scrubber technology and the innovative design features incorporated into the Yates application of this technology.

8.1 Objectives

The primary objective of the CT-121 demonstration at Plant Yates Unit 1 was to evaluate the effectiveness of the following innovative design approaches:

- Fiberglass-reinforced plastic (FRP) construction of the
  - jet bubbling reactor (JBR),
  - other key process vessels,
  - and the wet chimney;
- Elimination of the need for a prescrubber;
- Elimination of flue gas reheat;
- Elimination of the need for a spare absorber; and
- Simultaneous SO_2 and particulate collection.

To evaluate the effectiveness of these design advances, the following specific objectives of the two-year demonstration program were established:

- Demonstrate long-term, reliable operation of the CT-121 FGD system;
- Evaluate particulate removal efficiency of the JBR and system operation at normal and elevated particulate loadings;
- Correlate the effects of pH and JBR gas-side pressure drop (ΔP) on system performance
- Correlate the effect of limestone grind on system performance;
- Evaluate the impact of boiler load on system performance;

- Evaluate the effects of alternate fuels and reagents on system performanc e;
- Evaluate equipment and construction material reliability and performance; and
- Monitor solids properties, gypsum stack operation, and possible impacts of the gypsum stack on ground water.

8.2 Overall System Reliability

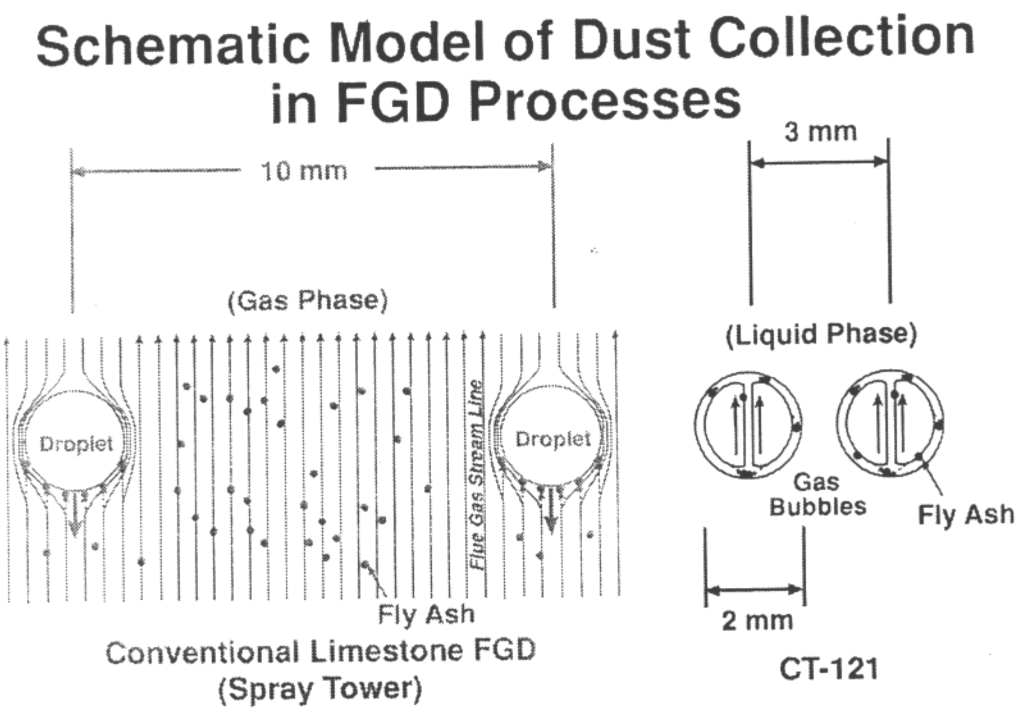
One of the specific objectives of the demonstration program was to evaluate the operability and reliability of the Yates CT -121 process, as constructed. The reliability of an FGD system is a function of the amount of outage time caused by equipment failures in the system. The performance indicators used to characterize and evaluate system reliability consist of Availability Index, Reliability Index, FGD Utilization Index, and Operability Index. These terms are defined as:

Availability Index	=	Hours the FGD system was available for operation divided by the hours in the period.
Reliability Index	=	Hours the FGD system was operated divided by the number of hours it was called on to operate.
FGD Utilization Index	=	Hours the FGD system was operated divided by the total hours in the period.
Operability Index	=	Hours the FGD system was operated divided by the hours of boiler operation in the period. (Due to the fact that the FGD system must always be operated then the boiler is in service, this value will always be unity).

8.3 Particulate Removal Evaluation

The ability to simultaneously remove SO_2 and particulate is a key advantage of the CT-121 process. To evaluate this capability, three different series of particulate measurements were performed. These measurements occurred at low-, high-, and moderate-particulate loading, and were completed concurrently with parametric testing used to characterize SO_2 removal efficiency under varied process conditions.

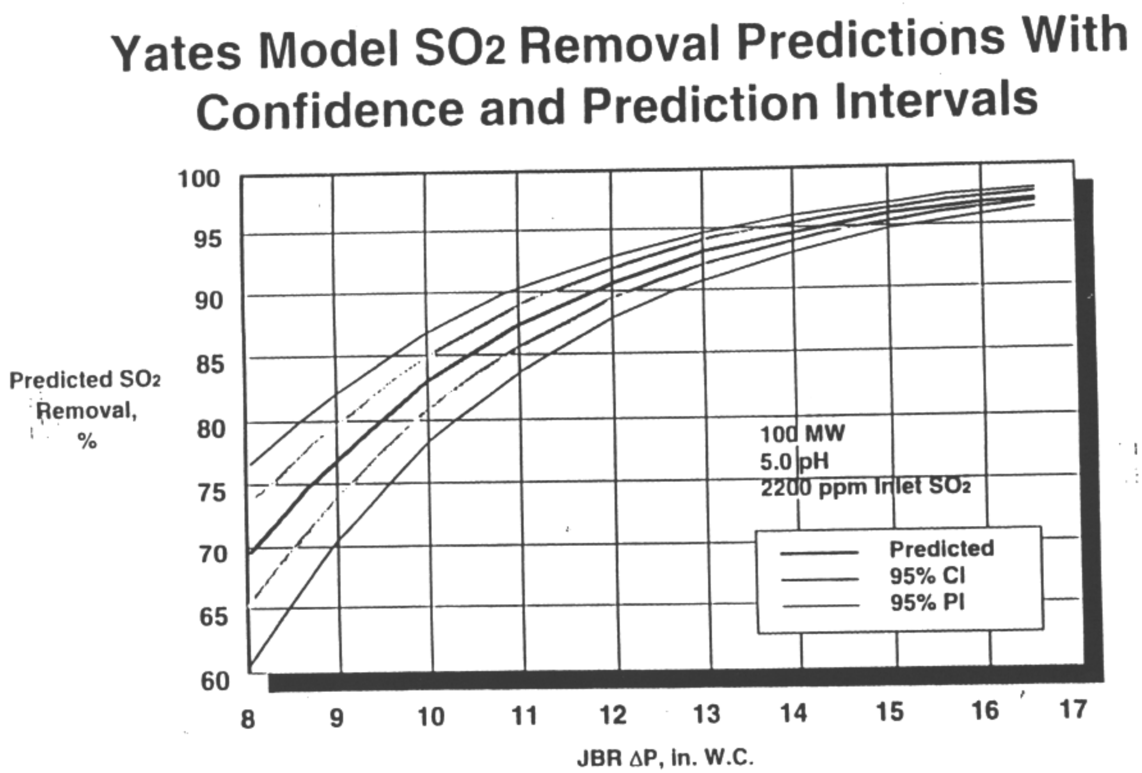
Figure 8-1



8.4 JBR ΔP, pH, and Boiler Load Effects on System Performance

JBR ΔP and pH are the principal operator-controlled variables used to control SO_2 removal efficiency in the CT-121 process. The SO_2 removal efficiency increases with increasing pH and with increasing ΔP (i.e., increasing sparger tube submergence depth). The selection of the operating setpoints for these variables in a commercial CT-121 application will depend on an economic evaluation of the trade-offs between SO_2 removal efficiency and the costs of increasing JBR ΔP and pH, while complying with the SO_2 removal efficiency determined by regulatory requirements. One of the specific objectives of the demonstration was to evaluate the response of the process to changes in JBR ΔP, pH and boiler load while varying the source of limestone and coal. The CT-121 process' response to these variables was measured under normal and elevated particulate loading conditions.

Figure 8-2



8.5 Limestone Grind Effects

Limestone is ground from 1" x 3/4" limestone to a size range of 90% <#200 mesh in a wet ball mill grinding circuit. Grinding the limestone is necessary to provide adequate surface area for dissolution and to maintain good limestone utilization. A trade-off exists between the cost of the energy used to grind the limestone and the raw materials cost savings resulting from the higher utilization.

Tests using an alternate limestone grind were performed to determine the impact of increased particle size on limestone utilization. These results were used in the optimization analysis to determine the most economical limestone grind for long-term operation. Determining the effect limestone particle size has on scrubber performance is an important step in optimizing scrubber operation. Grind size can impact limestone dissolution (which will affect limestone utilization), SO_2 removal efficiency, and the cost of operation. The larger the grind size at which the scrubber can operate successfully, the lower the ball mill power consumption. In cases of new installations, this information can be useful in ball mill sizing, thus potentially reducing capital costs.

8.6 Effects of Alternate Fuels and Reagents

For the CT-121 process to be commercially viable, it must demonstrate flexible operation under a wide range of conditions. These conditions include varying limestone reagent sources, fuel sources, and fuel sulfur content. Coal from four different sources (with significantly different sulfur contents) and limestone from three different suppliers were used during the demonstration program to provide a wide spectrum of test conditions. Limestones from several different regions (i.e., geologically different) were evaluated to determine whether the CT-121 process had the flexibility to operate successfully in widely differing geographic regions. Likewise, scrubber performance was evaluated with the boiler burning coals with sulfur contents ranging from 1.2% to 4.3% to ascertain the flexibility of the scrubber with regard to boiler fuel selection.

8.7 Equipment and Materials Evaluation

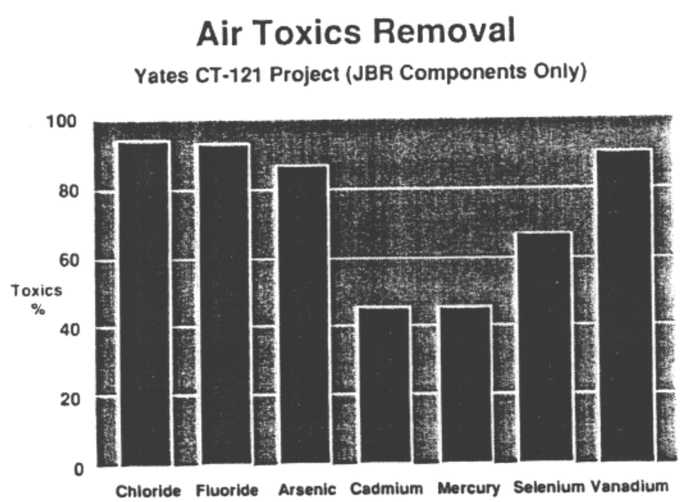
The evaluation of the equipment and materials of construction is critical to the evaluation of system reliability. The scrubber system cannot operate in a reliable manner if any critical equipment fails or if there is a systemic problem with any of the materials of construction.

Equipment failures, as well as all maintenance actions, were documented during this demonstration project. Periodic inspections of the system, special material samples, and erosion resistant coatings were used in the evaluation of installed and optional materials of construction. This was especially critical during periods of elevated particulate loading, as was the case during the high-ash test period. Additionally, the susceptibility of the sparger tubes to plugging was monitored during the moderate-ash tests. During testing with the ESP completely de-energized, the fly ash exhibited a tendency to agglomerate on the inside surfaces of the sparger tubes.

8.8 Air Toxics Removal Efficiency

An additional test objective was added after the test program began. This objective involved DOE-sponsored air toxics testing conducted at the Yates CT-121 scrubber. The testing was designed to evaluate the ability of the CT-121 process to remove both organic and inorganic toxic air pollutants. Additional, limited air toxics testing was added in conjunction with the last round of particulate testing to develop data on inorganic toxics removal under moderate-ash loading conditions. These tests were designed to provide a more detailed analysis of inorganic toxic species removal as a function of particle size.

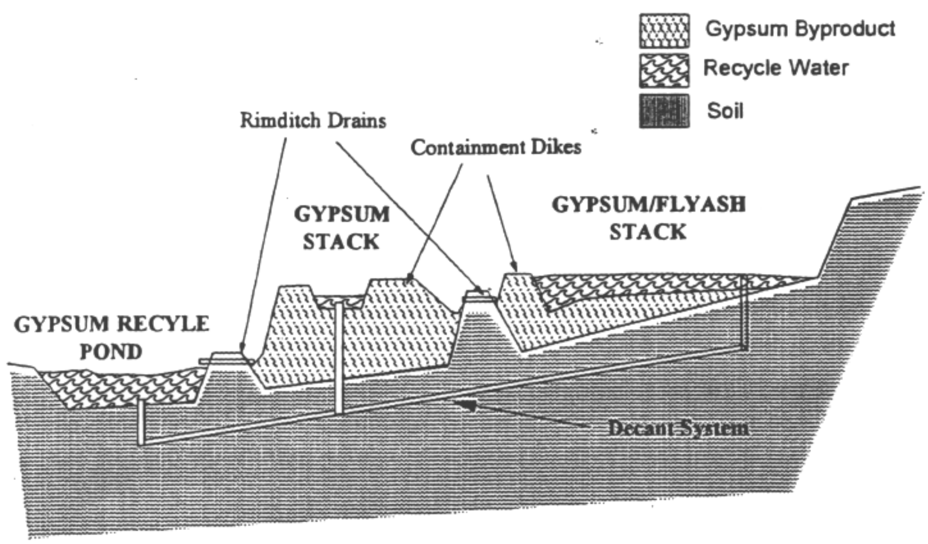
Figure 8-3



8.9 Solids Dewatering Properties and Gypsum/Ash Stack Operation

The FGD byproduct gypsum solids are disposed of by stacking. Stacking combines the advantages of ponding and landfills -- low operating costs and equipment requirements, and smaller space requirements and reduced environmental impact, respectively. For the high-ash test period, the previously unused "gypsum-fly ash" stack was placed into service. The gypsum-fly ash stack used for the high-ash period of testing was approximately twice the size of the stack used during the low-ash test period to accommodate the larger amount of solids produced due to ash removal in the scrubber. During both test phases, handling, stackabilty, and trafficability of the stacks were carefully monitored.

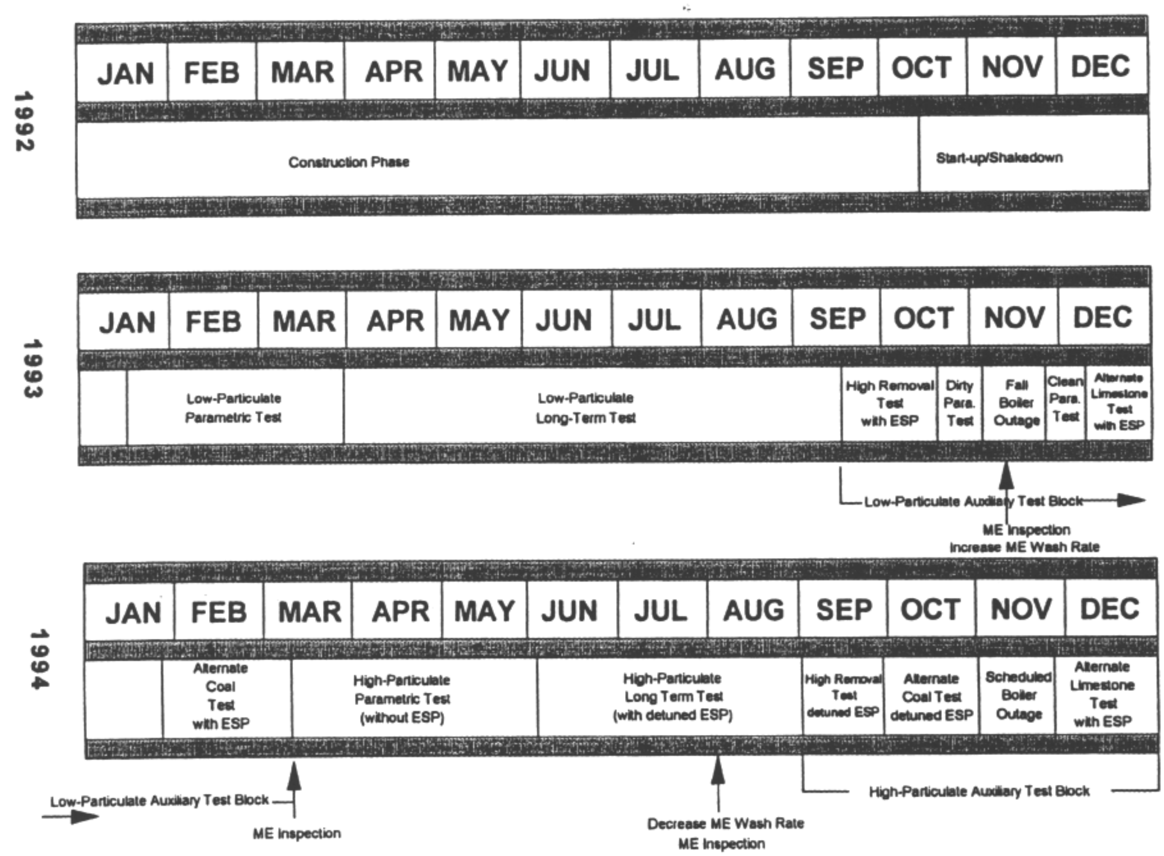
Figure 8-4 **Elevation view of the Internal Features of the Gypsum Stack at Plant Yates** *(looking North)*



8.10 Overall Test Schedule

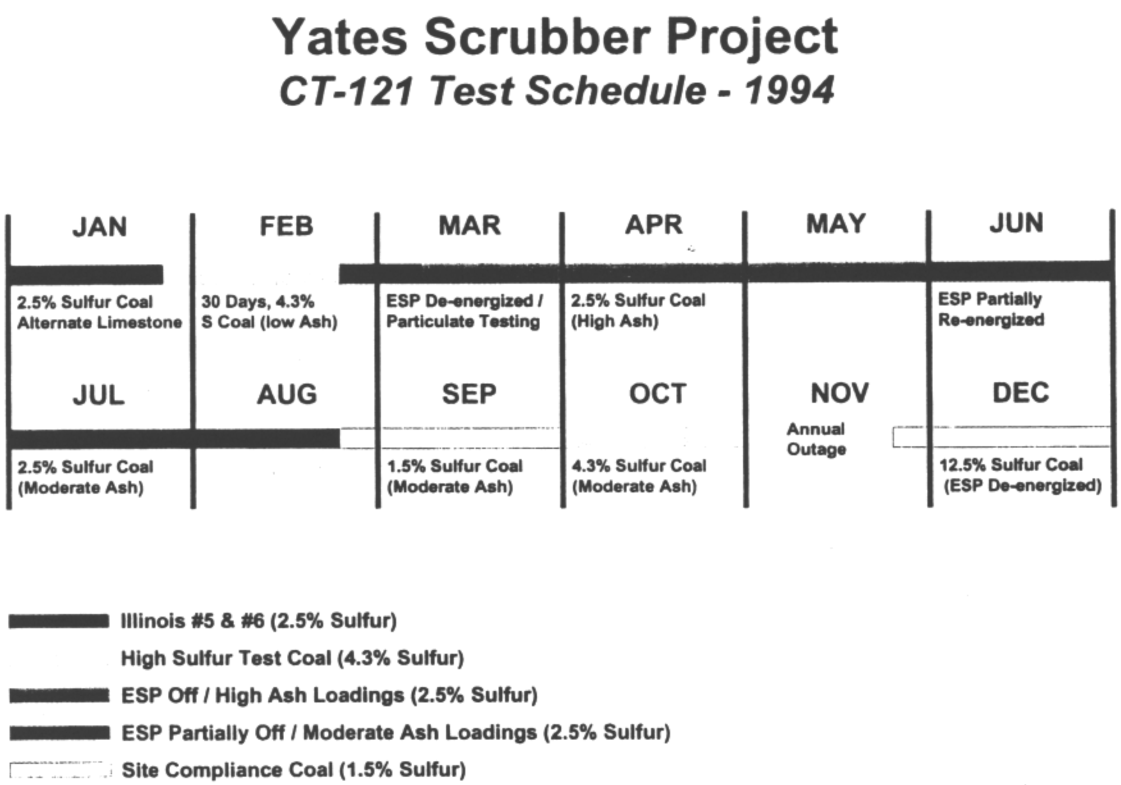
The overall demonstration test consisted of two periods: a low-particulate test period with the ESP energized, and a high-particulate period with the ESP de-energized in a step-wise fashion. Figure 3-1 shows the final test schedule for the entire demonstration program. This plan incorporates revisions to the original test plan that were developed based on intermediate test results and plant scheduling requirements. As more was learned about the CT-121 process during testing, it was discovered that some tests were no longer necessary and others needed to be added or expanded. An example of this was the additional particulate removal testing that was conducted simultaneously with the first part of the High-Particulate Alternate Limestone Test period. This testing was added to develop more data on particulate removal under moderate-ash loadings, which was considered the most likely scenario for a future CT-121 retrofit. Also, because mist eliminator performance changed very slowly, the mist eliminator wash test plan was expanded to allow a more lengthy evaluation period.

Figure 8-5 **Project Test Schedule**



Another change involved altering the high-particulate test period in 1994 to include testing at moderately elevated particulate loadings at the scrubber inlet. This change was in direct response to problems encountered during the High-Particulate Parametric Test block, specifically sparger tube plugging. The more moderate-ash loading was continued for the remainder of the test period, which included the Long-Term and Auxiliary Test blocks, to more realistically approximate the type of conditions expected in a retrofit to a boiler with a marginally performing particulate collection device.

Figure 8-6



Summaries of Volumes 2 through 6b of the Yates Final Report

Volume 2 of 6

Performance - Operations

VOLUME 2 SUMMARY

"As part of the second round (Round II) of the Clean Coal Technology (CCT) program, the Department of Energy (DOE), the Southern electric system, and the Electric Power Research Institute (EPRI) sponsored a 100 MWe demonstration of the Chiyoda Thoroughbred CT-121 wet-limestone flue gas desulfurization (FGD) system. The CCT program is a major initiative of the DOE, designed to allow coal to reach its full potential as a source of energy for the national and international marketplace. The demonstration was conducted at Georgia Power Company's Plant Yates Unit 1, located near Newnan, Georgia.

This volume of the final report discusses the results of the two-year process evaluation portion of the demonstration project. The evaluation of the CT-121 flue gas desulfiirization process at Georgia Power's Plant Yates provided insight into operation of this technology under a wide variety of process conditions. Areas of evaluation included:

- Reliability and availability of the process under a variety of ash loading and process conditions;
- SO_2 and particulate removal efficiency;
- Air toxics removal efficiency;
- Process flexibility using alternate coal and limestone sources;
- Performance of equipment and materials of construction;
- Process control systems; and
- Gypsum byproduct quality and stacking as a dewatering and disposal technique.

To accomplish the goals of the demonstration project, the process evaluation was divided into two distinct periods: a low-particulate and a high-particulate test period. Each of these test periods was further divided into a series of three test blocks: Parametric, Long-Term, and Auxiliary Test blocks.

Operating Statistics

The process performed exceptionally well during the evaluation. Avai lability and reliability indices were both 97% for the entire process evaluation, including test periods in which the ESP was completely deenergized and full fly ash loading was introduced to the scrubber. Much of the scrubber unavailability was related t o failures in auxiliary systems that were not directly associated with the CT-121 process (e.g., ball mill failures). Reliability and availability were somewhat lower during the high -ash testing than during low -ash testing due to the effects of full ash l oading on the scrubber. However, operation without a particulate collection device upstream of a CT-121 scrubber is not a likely scenario. Operating statistics showed improvement during periods of moderate-ash loading, which is a more likely CT -121 retrofit scenario.

The excellent availability of the CT -121 process is due to several factors, including the inherent reliability of the process design, the existence of installed spares for all key process instruments and critical pumps, and the forgiving nat ure of the process despite difficulties such as sparger tube plugging or clogged gas cooling nozzles.

SO_2 Removal Efficiency

SO_2 removal efficiency was evaluated throughout the demonstration project. SO_2 removal efficiency was generally excellent, and g reater than 90% efficiency was achieved during all test periods. It was demonstrated that 95% removal efficiency can easily be maintained under all expected combinations of boiler load and coal sulfur content by selecting the appropriate process setpoints. Removal efficiency as high as 99% was reached on several occasions while operating within the normal range of the independent process variables (JBR froth zone pH, and JBR ΔP). Some decrease in SO_2 removal efficiency was observed as a result of fouling of the sparger tubes, which occurred during high -ash testing. However, target performance levels were maintained by simply adjusting the pH or JBR ΔP setpoints.

The CT-121 process was operated under a wide variety of process operating conditions and the data gathered were used to develop performance models that could be used to characterize SO_2 removal efficiency as a function of several independent process variables. Multivariable regression analyses were performed on these data and resulted in the development of several predictive performance models. A single comprehensive model (which had a goodness of fit (R^2) of 0.935) was developed for the entire range of operating conditions. Several models were also developed that covered a more limited range of operating conditions, but had R^2 values superior to that of the more comprehensive model. These types of predictive performance models serve two valuable purposes. They permit comparison of the actual SO_2 removal efficiency to that predicted by the model, which can be used to identify process problems, such as sparger tube plugging. The models can also be used to determine the operating setpoints necessary to ensure that target SO_2 removal efficiency is achieved.

Particulate Removal Efficiency

Particulate removal efficiency was evaluated at three distinct ash loading levels during the demonstration: low-particulate loading (ESP 100% energized), high-particulate loading (ESP completely deenergized), and moderate-ash loading (approximately 90% ESP efficiency). During all three particulate removal tests, particulate removal efficiency was measured above 97%, and usually in excess of 99%. Removal efficiency of particulate greater than 10 micrometers in size was typically greater than 99.9%. Typical outlet particulate loading values were around 0.01 lb/MMBtu during the low- and moderate-ash loading tests and around 0.045 lb/MMBtu during the high-ash loading tests. Quantitative analyses of the outlet catch during the moderate-ash tests indicated that approximately 20% of the outlet particulate is sulfuric acid mist and carryover from the scrubber.

Air Toxics

Two test programs measured toxic air pollutant removal efficiency during the demonstration. One program was a DOE-sponsored test and the other, which focused on inorganic toxics, was done in conjunction with the moderate-ash particulate removal measurements. The data collected indicate that the CT-121 process was successful in removing a large fraction (generally >75%) of most inorganic toxics, however there is a high degree of uncertainty associated with many of these data, particularly in the measurement of cobalt, mercury, manganese, and nickel.

Process Flexibility

Throughout the performance evaluation, parameters such as coal source, coal sulfur content, and limestone source were varied. The purpose of investigating these variations was to determine if the CT-121 process was a viable SO_2 and particulate removal technology at Plant Yates as well as other potential sites. By evaluating coal and from several limestone sources, it was successfully demonstrated that the CT-121 process is adaptable to many new construction or retrofit scenarios, and that excellent performance could be achieved with limestone and coal from alternate sources.

The Yates CT-121 process maintained high limestone utilization (typically greater than 97%) while achieving high SO_2 removal efficiency. Because of the unique JBR design, the CT-121 process can operate at a lower pH than conventional spray tower wet limestone FGD processes while still attaining excellent SO_2 removal efficiency. Under low-particulate conditions, it was determined that pH could be raised as high as 5.3 before any significant decrease in limestone utilization was observed. However, due to the design of the CT-121 process, little improvement in SO_2 removal efficiency is realized by raising pH above 4.5. During high-ash testing, elevated aluminum and fluoride concentrations in the scrubbing liquor resulted in inhibited limestone dissolution. To ensure greater than 97% limestone utilization was maintained when operating under elevated aluminum and fluoride concentrations, the pH range was restricted to 4.0 or lower.

Materials of Construction

The materials of construction, particularly the fiberglass reinforced plastics (FRP) used in many of the systems, were frequently inspected throughout the process evaluation period. With the exception of erosion damage in the JBR inlet, the JBR, as well as all other process equipment, piping, and vessels constructed of FRP, exhibited no signs of corrosion or erosion damage during the demonstration project. In general, the wide use of FRP for this highly abrasive, high chloride, closed-loop environment was successful. With some design modifications, such as moving the gas cooling section further upstream of the JBR, the observed inlet plenum erosion could be prevented.

Process Control

The two key process control systems, pH and JBR level control, were not initially as successful as anticipated. Of the two pH measurement devices, only the Van London probe/Rosemount transmitter arrangement worked well. The pH control circuit's transient response was improved through the use of feedforward - feedback control, and reliable redundant readings were obtained only after the pH probes were located adjacent to one another. JBR level control using three differential pressure instruments was unreliable because these instruments were prone to plugging, which resulted in erroneous readings. To resolve this problem, the existing JBR gas-side differential pressure instrument was used as a surrogate for JBR level. This system worked well, and although no redundant instrumentation was available, no problems were experienced. However, gas side differential pressure is not always proportional to JBR level, and may require adjustment to maintain a constant SO_2 removal efficiency under changing boiler load conditions

Gypsum Byproduct

One of the most unexpected findings of the demonstration project was the impact of limestone selection on gypsum dewatering characteristics. Because the first limestone evaluated resulted in smaller-than-expected gypsum particle size and poor dewatering characteristics, a bench-scale evaluation of limestone source effects on gypsum size and dewatering was begun. While most of the limestones were very high in purity (typically > 95% $CaCO_3$), inert content and iron concentration in the limestone appeared to correlate with gypsum quality, with higher inert and iron levels resulting in poorer gypsum quality.

In general, above average gypsum byproduct quality was observed. During low-ash testing, the Dravo limestone produced gypsum that filtered and settled well, and had a mean particle size of 43 micrometers. The gypsum stack, a gravity sedimentation process chosen for dewatering and storage of the byproduct solids, worked well during the low-ash test period. The gypsum/ash disposal stack worked equally well during the high-ash test period, even with up to 40% ash in the byproduct solids.

Conclusions

The demonstration of the CT-121 scrubber technology at Plant Yates was highly successful. High SO_2, particulate, and air toxics removal efficiencies were measured under conditions of varying coal sulfur content, limestone sources, and ash loading, all while achieving 97% availability and reliability. In general, the materials of construction performed admirably, although some deficiencies were noted. For each shortcoming, suitable solutions were identified and implemented when practicable, although some suggested solutions are more geared for future designs.

Volume 3 of 6

Performance – Equipment

3a Equipment, Materials and Maintenance
3b Instrumentation and Controls / Data Acquisition System
3c Materials Test and Evaluation Program

VOLUME 3a SUMMARY **Equipment, Materials and Mainteanace**

"The Yates material demonstration program was an innovative approach to analyzing the performance of construction materials in a full -scale, forced-oxidized limestone scrubber retrofitted to a boiler burning high -sulfur coal. During the design process, a variety of materials were selected for use, including some that were expected to fail in a relatively short time and others that were proven to be survivable in this type of environment. Information on field performance of construction materials was collected primarily by subjective examinations conducted during scheduled, mechanical, routine, and planned shutdowns.

A variety of materials were tested at Yates for use in piping, pumps, and valves, am ong others. These materials including stainless steels, aluminum, high density polyethylene, fiberglass reinforced plastics, rubber-lined carbon steel, basalt, and plastic lined pipe. One of the most important lessons learned during the demonstration was the criticality of proper material selection during the design phase. The scrubber equipment fabricated of materials with superior characteristics for the environments in which they were placed required very little maintenance, while some of the marginal material (purposely selected for evaluation) resulted in chronic maintenance requirements. Thus, it can be concluded that the reliability and availability of the scrubber are as dependent on material specification as they are on the fundamental design elements.

One of the biggest project successes was in the widespread use of FRP for major process vessels and piping. This material withstood a harsh environment of high solids content, high chloride concentration, and low pH slurries throughout the two year demonstration period and beyond. The only area of concern was in the inlet duct and plenum of the JBR, where FRP surfaces were subject to high velocity slurry sprays and suffered severe erosion damage. To mitigate erosion, several coating materials were evaluated in this duct. The most promising of these materials was a silicon carbide and resin material that displayed excellent resistance to the erosive forces. FRP pipe was also used with much success; however, it is important to have a QA program in place to assure that the FRP has been fabricated, prepared, and installed correctly.
Rubber lined pumps seemed to provide adequate protection in the low pH, high chloride environment; however, the A-49 seemed to be a more suitable material for the seal plate adapters than the A-04 material, which quickly corroded. Some pumps were outfitted with A-49 (27% chromium) impellers, which also performed well in this harsh environment

Valve selection was another focus because of the large amount of knife gate slurry valves require in the process. All valves used were lined to avoid the use of expensive alloy body materials. The materials used included 316 stainless steel for the gates in water service and 317LM for those in slurry service. One of the most important lessons learned was to avoid penetrating the valve liner when bolting up the valve body. This can lead to invasive penetration of the slurry material, which can quickly corrode the valve body.

Generally, high-alloy stainless steels, such as Hastelloy C-22 and C-276 and 317LM, as well as rubber lined carbon steel, FRP, and HDPE, are all well suited to the harsh environments present within a closed-loop flue gas desulfurization process. Each has superior corrosion resistance and excellent erosion resistance, with very few exceptions. Care should be exercised to ensure the most appropriate material is selected for each application to minimize corrective maintenance and maximize process availability.

== =================

VOLUME 3b SUMMARY Instrumentaton and Controls / Data Acquistion System

"The instrumentation and controls and data acquisition system used for the CT -121 scrubber demonstration were designed for ease of use, adaptability, and ease of data analysis. Several key aspects of these systems are discussed in this volume, including:

- Design approaches;
- Equipment descriptions;
- Preoperational testing;
- Discussions of operating experiences; and
- Lessons learned.

One of the key design objectives, operating the scrubber without increasing power plant personnel, was achieved through the use of innovative control techniques and a high degree of automation. Significant preoperational testing proved to be invaluable, allowing a very smooth startup and developing a base of operational and maintenance experience for operators and technicians.

An automated data collection and reduction system was designed by integrating several software packages with the scrubber's distributed control system. This system was used successfully throughout the demonstration for producing reduced data in the form of plots and reports. These data were instrumental in helping the process engineers monitor the scrubber's performance and make operating decisions during a wide variety of test programs.

Several systems were evaluated for control of the most important process variables. The most suitable methods for monitoring and controlling pH, JBR level, slurry density, flue gas components, tank levels, and flue gas flow are discussed in this volume. JBR pH and level control, the most critical of the process variables, proved to be the most difficult to develop appropriate control schemes for; however, adequate methods were developed and tested during the demonstration. This volume contains detailed discussions of the systems evaluated, as well as recommendations for control methods for each process variable.

==

VOLUME 3c SUMMARY — Materials Test and Evaluation Program

"One of the unique features of the Plant Yates Chiyoda Thoroughbred 121 (CT -121) flue gas desulfurization system is the broad use of fiberglass -reinforced plastics (FRP) in construction of all major process vessels including the jet bubbling reactor, the limestone slurry storage tank, the gypsum slurry storage tank, the inlet duct, the mist -eliminator, a good percentage of the piping, and the wet chimney. The choice of material was based on the excellent corrosion resistance properties of FRP, low life-cycle costs in comparison with other conventional choices, and favorable FRP experience in chemical and pharmaceutical industries. The Yates scrubber facilities were constructed and operated as a demonstration of the extensive use of FRP for future CT-121 FGD designs. A comprehensive FRP test and evaluation program was performed as a part of this program to address the following material objectives:

- Verify that the state-of-the-art in FRP design and construction could support cost-effective construction and reliable operation of the CT -121 process equipment;
- Evaluate the structural reliability of FRP structures as well as the diagnostic tools for evaluating structural integrity;
- Determine the type and extent of routine FRP maintenance and the degree of unscheduled maintenance that could be incurred as a result of FRP construction; and
- Evaluate the design methods and the construction technology for manufacturing larger, more durable FRP scrubber equipment.

The structural design of the FRP process equipment and materials of construction was performed by Ershigs, Inc. using standard design guidelines and formulas. In addition to conventional design approach, finite element analysis was performed to:

- Determine the state of stress and strain in different components of the JBR and the LSST, and
- Better understand areas of design uncertainty and verify design assumptions.

The results showed that the FRP structures vessels, as designed by conventional design techniques, would safely operate under the specified operating conditions. However, the resulting deck deflections at full load would be higher than the tolerances required for the sparger tube alignment. This problem was quickly resolved by minor adjustments in the thickness of laminates and arrangements of the supports.

Following a two-year design and construction phase, the CT -121 FGD system at Plant Yates was placed in operation in October, 1992. Prior to the scrubber start -up, the structural reliability and operability of the JBR and the LSST were tested under hydrostatic loading conditions. Following the startup, routine general inspections were performed to monitor the structural condition, abrasion, and corrosion in various parts. During the first phase of the demonstration program, the pre-existing electrostatic precipitators (ESP) were utilized at full capacity to remove the ash from flue gas entering the process. Shortly after the startup, the color-based abrasion-indicator/coating began to show signs of severe abrasion in the inlet duct. Between March, 1992 and September, 1993, the damaged areas were repaired several times. A technical solution was finally formulated based on high resilience of rubbery materials. To this end, several compliant polyurethane coating systems were evaluated in the inlet duct for their endurance and longevity in this highly abrasive environment. These proved to be successful in controlling the abrasion problem. The only remaining issue in this area is to maintain the bond between the coating system and FRP. The inspections continued during the high-ash phase, when the ESP fields were de-energized to determine the impact of high ash concentration in the slurry on scrubber performance. The CT-121 FRP process equipment has been in operation for nearly four years. With the exception of the inlet duct abrasion, the FRP performance can be classified as very satisfactory. The following specific conclusions have therefore been reached:

- FRP is a suitable material for application to the CT-121 process.
- FRP is prone to abrasion in the areas of high velocity gradient and particulate concentration. In these areas, the FRP surface should be coated with an appropriate coating system, consistent with the nature of flow. The test results show that abrasion due to normal flow can be controlled by compliant coatings. On the other hand, coatings that had a large concentration of fillers worked better in areas of high shear.
- Strain gaging and acoustic emission testing can be effective and valuable tools for verifying the structural integrity of FRP vessels. Acoustic emission was proven successful in locating the structural faults associated with FRP construction.
- Preliminary creep of the material during initial loading can lead to higher than anticipated strains. However, with time, the strain measurements should reach equilibrium and comply with theoretical expectations.
- The design standards for large FRP vessels need to be improved in order to increase product reliability. This can be accomplished by incorporating finite element analysis into the design process. Further, the existing acoustic emission standards appear to be too sensitive for application to large FRP vessels not used in highly corrosive environments. The "knee analysis" combined with "cluster analysis" were found to be a more practical approach for performing diagnostics and quality control experiments.
- Novel FRP construction may be available that could significantly reduce the cost of construction for large cylindrical FRP structures. These construction methods need to be proven under a controlled research environment if they are to be recommended for future CT-121 installations.

==

Gypsum Stacking and Byproduct Evaluation

VOLUME 4 SUMMARY **Gypsum Stacking and Byprodcut Evaluation**

"The Chiyoda Thoroughbred-121 (CT-121) flue gas desulfurization (FGD) process was selected for demonstration at Georgia Power Company's Plant Yates near Newnan, Georgia by the Department of Energy under its Clean Coal Technology Program. During the approximately two-year operating period for the demonstration project, the FGD equipment installed on Unit 1 produced gypsum and a gypsum/ash mix as byproduct materials.

The scope of work included tasks designed to investigate storage/disposal and utilization options for the byproducts. Project objectives in this area included demonstration of the "stacking" technology to construct separate stacks for FGD gypsum and ash/gypsum which are larger than previously attempted; use of FGD gypsum as an agricultural soil amendment; and use of processed gypsum as a replacement for mined gypsum in wallboard and cement manufacturing processes.

The wet stacking disposal facility was designed to provide adequate storage for the projected byproduct volumes and, where possible, allow use of full-scale procedures and field evaluation of stackability. Although the ash/gypsum facility is still in operation, results clearly indicate that FGD gypsum and gypsum/ash can be successfully stored by wet stacking using upstream construction methods. Field evaluations have provided a number of recommendations to improve stackability and operational efficiency for future projects, and for modifying and implementing design elements of the demonstration facility to future large-scale projects.

Extensive greenhouse and field agronomic evaluations have concluded that the Yates gypsum is a high-quality material, similar to or better than most gypsum materials currently marketed. It should be suitable as a soil amendment on peanuts and other crops, and poses minimal, if any, environmental concerns. In fact, a plant food license has been obtained from the Georgia Department of Agriculture for food crop soil amendments. Benefits include amendments of acidic soils which limit root growth and crop yields, plus improvement of water infiltration and other properties of weathered soils. Other field work has determined that some grasses, particularly weeping lovegrass, can be established, for revegetation purposes, directly on the gypsum stack slopes.

Due to funding limitations, other manufacturing demonstrations for wallboard and cement industries were not undertaken. These tasks were actually proposed additions to the original scope of work. However, it appears that these potential end-users of CT-121 FGD gypsum are still clearly interested in this application.

==

Environmental Monitoring Plan

VOLUME 5 SUMMARY

"The purpose of the Innovative Clean Coal Technology demonstration project entitled "Demonstration of Innovative Applications of Technology for the CT -121 EGD Process," conducted at Plant Yates, was to demonstrate the use of the Chiyoda Thoroughbred-21 flue gas desulfurization process as a means of reducing SO_2 and particulate emissions from pulverized -coal utility boilers that use high -sulfur coal. The project was also designed to demonstrate the lower cost and higher reliability of the CT -121 process compared to conventional wet limestone FGD processes.

As the project sponsor, Southern Company Services, Inc., (SCS) was required to develop and implement an approved Environmental Monitoring Plan (EMP). The EMP for this project was prepared by Radian Corporation for SCS and submitted to the U.S. Department of Energy (DOE) on December 18, 1990. The EMP was subsequently revised and resubmitted on January 16, 1995.

The EMP was developed to fulfill the following specific objectives:

- To provide monitoring data to fulfill environmental compliance requirements of local, state, and federal regulatory agencies;
- To define and describe supplemental monitoring activities;
- To ensure that emissions and environmental impacts were consistent with projections provided in documents prepared for this project as required by the National Environmental Policy Act of 1970 (NEPA); and
- To develop an environmental record that can be used for fu ture replication of the subject technology.

This report presents and discusses the data obtained during the CT -121 demonstration project in fulfillment of the EMP objectives.

===

Volume 6a and 6b of 6

Data and Supplemental Testing Appendices

VOLUME 6a SUMMARY **Data and Supplemental Testing Appendices**

Appedix sections, in the order in which they are found in Volume 6a:

- **Design and Development of the Liquid Collector s – DynaFlow**

  "Under a DOE Clean Coal II Project, Southern Company Services is installing a 100 Chiyoda Thoroughbred 121 Flue Gas Desulfurization Demonstration Unit at the Yates Plant of Georgia Power Company, Unit 1. The Chiyoda Jet Bubbling Reactor will be connected to a horizontal gas flow two stage mist eliminator and a fiberglass stack supported by an open steel girder support tower. The outlet ducts and stack liner will be operated wet without reheat of the flue gas. The purpose of the program at DynaFlow Systems, described in this report, is to develop a liquid collector and drainage system for the wet duct and stack to minimize the potential for stack liquid droplet discharge when the scrubber is operating.

  The objectives of the program were the following:

  (1) Develop a velocity profile into the mist eliminator with a RMS flow uniformit of no larger than 0.25.

  (2) Develop liquid collectors for the duct and stack downstream of the mist eliminator that will collect and drain liquid from the walls to prevent reentrainment and stack liquid droplet discharge large enough in diameter to reach ground level.

  (3)Measure the duct and stack system pressure loss with and without required liquid collectors.

  The results of the experimental and ana lytical work to satisfy these objectives are presented in the sections that follow, including the recommendation of geometry for internal vanes, liquid collectors and drains that must be installed in the field unit to satisfy the objectives of the study.

The gas flow patterns and liquid flow patterns without and with liquid collectors in the model were recorded and edited with voice comments on a VHS video tape. The Appendix gives a list of titles for the video recording.

Five copies of the video tapes were sent with the design drawings of the liquid collectors for construction.

The original duct and stack designs were reviewed to assure that the geometry is suitable for wet operation.

- **Particulate Sampling across the CT -121 - Southern Research Institute**

  - **Electrostatic Precipitator (ESP) Operatng Phase (Low mass loadings) – 1993**

"As part of the Innovative Clean Coal Technology (ICCT) program, funded primarily by Southern Company Services and the U. S. Department of Energy, a Chiyoda CT-121 Jet Bubbling Reactor (JBR) was installed at Georgia Power Company's Plant Yates Unit 1. As part of the two year demonstration of this innovative process for Flue Gas Desulfurization (FGD), Southern Research Institute was contracted to determine the particulate mass removal efficiency, particle fractional collection efficiency an d SO3/H2SO4 mist removal efficiency of the JBR. The test program, which this report covers, was conducted with an energized electrostatic precipitator installed ahead of the JBR.

The test program was designed to evaluate the scrubber under nine test condi tions. Table 1 presents the conditions for each test. During each test day, three measurements were obtained at the inlet and outlet sampling locations for total mass loading, particle size distribution and SO2/SO3.

  - **Increased Mass Loading Phase – 1994**

"As part of the Innovative Clean Coal Technology (ICCT) program, funded primarily by Southern Company Services and the U. S. Department of Energy, a Chiyoda CT-121 Jet Bubbling Reactor (JBR) was installed at Georgia Power Company's Plant Yates Unit 1. As part of the two-year demonstration of this innovative process for Flue Gas Desulfurization (FGD), Southern Research Institute was contracted to determine the particulate mass removal efficiency, SO3/H2SO4 mist removal efficiency, and particle fractional collec tion efficiency of the JBR. The test program, which this report covers, was conducted with the electrostatic precipitator installed ahead of the JBR in reduced collection efficiency modes and de-energized.

This test program was designed to evaluate the op eration s of the JBR under increased inlet mass loadings. Table 1 presents the nine different test conditions which were evaluated. The second, third, and fourth fields of the ESP were de-energized for all test conditions in Table 1. During each day of tes ting, three EPA Method 5B measurements were obtained at the inlet and outlet sampling locations, as well as, SO2/SO3 and particle size distribution measurements.

- **Particulate Testing Across the CT -121 – Radian Corporation**

  - **Marginally Performing Electrostatic Precipitator (High mass loadings) – 1994**

This document presents the results of a test measurement program performed by Radian Corporation for Southern Company Services at the CT-121 Scrubber Project at Plant Yates. Particulate removal efficiency by the JBR has been previously measured under low- and high-ash loading conditions. For this test program ash loading was set to simulate a marginally performing ESP. Although the ESP was completely energized, the particulate removal efficiency of the ESP was approximately 90% (vs. 99% normally) due to the low sulfur content of the coal. Burning low sulfur coal can result in reduced ash resistivity and decreased collection efficiency in the ESP. As a result; the ESP efficiency was roughly equivalent to that achieved with higher sulfur coals and partially energized ESPs.

Characterization of the dust emissions at Plant Yates was complicated due to the conditions of the wet stack. Sorting out what mass was attributable to dust, sulfuric acid mist, and scrubber carryover was not feasible using a typical sampling approach, so Radian characterized the particulate effluent by source apportionment. This involved chemically characterizing the emitted fly ash, the inlet fly ash, and the scrubber liquor. Radian used a computerized data analysis and reduction routine to apportion the mass of material in the stack effluent to each of it's respective sources. In addition, Radian collected samples for air toxics analysis (metals) from the stack during the 100 megawatt test conditions. Samples were also collected from the JBR inlet and stack for the determination of particle-size distribution (PSD).

The Radian field crew arrived on November 30, 1994, for equipment setup; sample collection began at noon on December 1. Testing was performed during four process operating conditions which are listed in Table 1.

==

Appedix sections, in the order in which they are found in Volume 6b:

- **Design Calculations for a CT -121 Jet Bubbling Reactor – Ershigs**

- **FRP Acoustic Emissions Report - Physical Acoustics Corporation**

  - **Jet Bubbling Reactor – 1994**

    An Acoustic Emission (AE) test was performed on a scrubber tank known as the JBR (Jet Bubbling Reactor) tank for Southern Company Services, Yates Plant. This test used the Recommended Practice for Acoustic Emission Testing of Fiberglass Reinforced Plastic Resin (RP) Tanks/Vessels, published by the Committee on Acoustic Emission from Reinforced Plastics (CARP) of the Society of the Plastics Industry.

    A total of 50 AE sensors, configured as shown in Figure 1, were used to monitor the tank. Analysis of the data, after taking account of known noise incidents, showed that the tank exhibited acoustic emission data well in excess of the CARP acceptance criteria.

  - **Limestone Slurry Storage Tank – 1994**

    An Acoustic Emission (AE) test was performed on a limestone slurry tank for Southern Company Services, Yates Plant. This test used the Recommended Practice for Acoustic Emission Testing of Fiberglass Reinforced Plastic Resin (RP) Tanks/Vessels, published by the Committee on Acoustic Emission from Reinforced Plastics (CARP) of the Society of the Plastics Industry.

    A total of 33 AE sensors, configured as shown in Figure 1, were used to monitor the tank. Analysis of the data after taking account of known noise incidents showed that the tank exhibited Acoustic Emission data well in excess of the CARP acceptance criteria.

(continued)

- **Jet Bubbling Reactor – 1991**

Southern Company has recently construc ted large fiber reinforced plastic (FRP) vessels at Plant Yates (Georgia Power Company). These FRP vessels are used as the primary parts of the CT-121 flue gas desulfurization (FGD) process. FRP was primarily selected because it provided an economic advant age over other more conventional choice of materials. To verify the integrity of the FRP construction, QC/QA testing was sought. According to the previous experience of FRP equipment users, Acoustic Emission (AE) monitoring of FRP vessels provides the most promising diagnostic tool for FRP vessels. Accordingly, Physical Acoustics Corporation (PAC) was contracted to perform the required testing and verify the integrity of the FRP vessels and their construction. To reach this goal, hydro-testing was scheduled during the pre-operation phase of the Flue gas desulfurization (FGD) process on both the Limestone Slurry (LS) and the Jet Bubble Reactor (JBR) vessels. The primary goal of the hydro-tests were:

a) Detect, locate and Classify emission sources;

b) Evaluate the effectiveness of AE, if active sources are detected, distinguish emi

c) Provide an AE baseline for both the Jet Bubble Reactor (JBR) and Limestone Slurry (LS) vessels for future AE testing.

- **Limestone Slurry Storage Tank – 1991**

Two on-site fabricated Fiber Reinforced Plastic (FRP) vessels were tested using Acoustic Emission (AE) Non-Destructive Testing (NDT). Physical Acoustics Corporation was contracted by the Southern Company Services to perform the tests during an initial hydro test. The vessels are located at Plant Yates of the Georgia Power Company and are components in the CT-121 Flue Gas Desulfurization (FGD) process.

Both vessels were extensively tested using acoustic emission which proved its feasibility for providing "real time" monitoring of the structural integrity during proof loading. Acoustic emission also detected areas of delamination around the internal structure-to-vessel wall interface. The data obtained shows continuous emission during the testing which is indicative of a structure seeking equilibrium. An extensive data baseline has been saved for future testin g of the vessels. This baseline will be compared with data obtained at a later date.

- **Strain Monitoring - SCS**

Georgia Power's Plant Yates Unit I was selected as a joint project with the DOE to construct a full-scale demonstration project utilizing the Chiyoda reduction process to remove the S02 gases. The Chiyoda process involves the "wet scrubbing" of the waste gas, and to facilitate this process, the primary vessels are required to be corrosive resistant. Therefore, the primary process vessels, the Jet-Bubbling Reactor Vessel (JBR) and the Limestone Slurry Tank were both constructed of a filament-wound fiber reinforced plastic (FRP) composite material which is basically inert to the corrosive environment of the Chiyoda chemical process.

As part of the demonstration of this technology, the structural integrity of the FRP vessels was requested to determine the suitability of the material for the designated design duty. Strain testing was adopted as one of the methods to quantify the behavior of the primary vessels for the loadings to be applied during the operating life of the vessels.

This testing proved to be beneficial in calibrating the design practice and q uality assurance of the field constructed vessel and structures. Various hydrostatic tests were conducted both prior to and at the completion of the demonstration period. to qualify the integrity of the vessel structure initially, and after the required operating demonstration period.

Results of the testing include the comparison of the design hydrostatic stresses to the experimentally determined stresses. a means of quantification of the safety factors used in design, and discussions on the behavior of th e FRP material . These discussions provided insight on life cycle creep which may occur in FRP vessels.

The results and research which occurred in reduction of the data and review of material performance. also demonstrated the importance of unique informa tion applicable for each FRP material. Industry experience has suggested that engineering data and properties of FRP constructed material require a much more comprehensive requirement on the part of the owner to specify carefully many aspects of the design process, quality assurance requirements. and construction requirements. In addition, performance testing of the completed structure is very important to comprehensively test the total system.

The strain testing was successful is providing comprehensive d ata during the hydro tests and providing insight into the time and duty affects on the FRP vessels. This experimental test data correlated very well with theoretical stresses utilizing the design material properties.

The strain testing provided a full scale verification of the structural integrity of the vessel. In addition, the strain testing provides a tool for the trending of the performance of the structural composite material.

The test data from the hydrostatic tests on the Plant Yates Jet-Bubbling Reactor and Limestone Slurry Tank compared well with the predicted stress levels and material properties provided in the manufacturers design calculations. In ad dition. the test data provided some valuable insight into the long term behavior of the material properties. This strain testing provides a rational means to evaluate the life cycle behavior of a FRP vessel both at initial loading and a trending tool over time.

- **Abrasion and Corrosion Coupons - SCS**

==