EPA U.S. Environmental Protection Agency
Office of Research and Development

Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711

EPA-600/7-78-031a
March 1978

THE EFFECT OF FLUE GAS DESULFURIZATION AVAILABILITY ON ELECTRIC UTILITIES

Volume I. Executive Summary

Interagency
Energy-Environment
Research and Development
Program Report

RESEARCH REPORTING SERIES

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

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

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

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

EPA-600/7-78-031a
March 1978

THE EFFECT OF FLUE GAS DESULFURIZATION AVAILABILITY ON ELECTRIC UTILITIES

Volume I. Executive Summary

by

R.D. Delleney

Radian Corporation
P.O. Box 9948
Austin, Texas 78766

Contract No. 68-02-2608
Task No. 7
Program Element No. EHE624

EPA Project Officers:

John E. Williams
Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, N.C. 27711

and

Kenneth R. Durkee
Emission Standards and Engineering Division
Office of Air Quality Planning and Standards
Research Triangle Park, N.C. 27711

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
and Office of Air and Waste Management
Washington, D.C. 20460

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

This report presents the results of work performed by Radian Corporation of Austin, Texas, for the Office of Air Quality Planning and Standards and the Industrial Environmental Research Laboratory of the United States Environmental Protection Agency. The purpose of this project was to assess the impact of flue gas desulfurization (FGD) system availability on the ability of individual coal-fired generating stations* and of generating systems** to meet consumer demands. Operating information on utilities and FGD systems from all known sources was analyzed with the major emphasis on the Edison Electric Institute (EEI) data base, PEDCo Environmental's Summary Report--Flue Gas Desulfurization Systems, and contacting utilities with operating FGD systems of interest to this study.

This project was originally to consider the subject of reliability and availability. However, during the course of this investigation it became evident that reliability was not a useful measure of the ability of an individual unit or a generating system to respond to consumer demands for electric power. Furthermore, the term "reliability" was not uniformly defined over the data bases used in this study. As a result, this study is concerned almost exclusively with the quantification and assessment of availability, which was defined in a uniform manner.

Almost all commercial applications of flue gas desul furization on coal-fired boilers use either the Lime Process or the Limestone Process. Of the other processes of interest in this study, the Magnesium Oxide and Wellman-Lord Processes are

*Single steam generating plant

**Interconnected pool composed of a mix of numerous generating plants each used at one site while the Double Alkali Process has not been commercially applied to coal-fired boilers. As a result, this study concentrates on the operating experience and data for Lime/Limestone Processes.

At present, many of the measures that lead to a more reliable FGD system include an economic penalty. An assessment of these economic penalties was beyond the scope of this study and is not addressed in this document. As operating experience and technology developments solve some of the problems, these economic penalties may be reduced or eliminated.

1.1 Program Objectives

The objectives of this program were identified in the Work Plan as follows:

- To assess the effect of flue gas desulfurization (FGD) systems on the reliability/availability of electric utility power generation. A comparison of the reliability/availability of existing FGD units with power plant generating equipment was included.

- To define and assess measures which have been or can be used to maintain or improve FGD unit reliability/availability. Emphasis was placed on operating experience at specific installations.

- To report the results of this study in support of EPA's review of the new source performance standards for coal-fired steam generators.

1.2 Definition of Important Terms

- Available - The status of a unit or major piece of equipment which is capable of service, whether or not it is actually in service.

- Availability - The fraction of time that a unit or major piece of equipment is capable of service, whether or not it is actually in service.

- Forced Outage - The occurrence of a component failure or other condition which requires that the unit be removed from service immediately or up to and including the very next weekend.

- Mean Time Between Full Forced Outage - The average time between each occurrence of a component failure or other condition which requires that the unit be removed from service immediately or up to and including the very next weekend. The average time is calculated by dividing the service hours by the number of forced outages.

- Reliability - The probability that a device will not fail or that service is continuous in a specified time period. The term reliability is not defined as a standard in the utility industry. The Mean Time Between Full Forced Outage (MTBFFO) and Loss-of-Load Probability (LOLP) are sometimes used as measures of reliability. The MTBFFO and LOLP can be used to calculate numerical values for reliability.

These terms are commonly used in an examination of the ability of a utility to meet consumer demand. Where possible these terms are in accordance with the Edison Electric Institute (EEI) standard definitions.

1.3 Approach

System reliability has been frequently used as an important measure of the performance of that system. The concept of a system being reliable or dependable is relatively straightforward. However, the quantification and application of this concept is relatively complex and is often poorly understood. A reader usually has a preconceived idea of what reliable or reliability means. These preconceived ideas often inhibit communication of the results of a system reliability analysis.

As an exmple, assume a system has a reliability of 99 percent for a 1000 hour time period. This statement means there is a probability of 99 percent that the system will operate for 1000 hours without a failure. This statement of reliability has three elements: (1) a quality of performance, (2) the performance is expected over a period of time, and (3) reliability is expressed as a probability. No information is provided as to how long the system does not operate when a failure occurs. The statement of 99 percent reliability for 1000 hours does not mean that the system will operate 990 hours out of every 1000 hours. Availability, on the other hand, provides information as to how often a system fails and how long it does not operate as a result of a failure. Availability data thus combine the effects of reliability, maintenance, and repair time and are usually expressed as a percentage.

Many different organizations reporting reliability/ availability type data use slightly different definitions for these terms. PEDCo Environmental's measure of reliability in their FGD status reports is not comparable to the parameters used by EEI to quantify reliability. Therefore, an evaluation based on the quantification of "reliabilities" is not possible in this study. However, the definitions of "availability" used by EEI and PEDCo are essentially the same. As a consequence of the preceding discussion, availability was determined to be the most useful measure of the ability of an individual station or a generating system to respond to consumer demand.

The steps taken in the completion of this project were

- Collect and analyze all available data for utility and flue gas desulfurization systems.
- Determine the effect of FGD units on the availability of individual generating stations and generating systems. It was assumed that the generating station cannot bypass the FGD unit. The FGD unit availabilities are at the full load operation of the generating station unless specified otherwise.
- Survey of existing FGD units to determine how they are meeting or can meet necessary availability levels.
- Document the operating experience at specific FGD installations.
- Define and assess measures that have resulted or can result in high levels of FGD unit availability.

The following items should be taken into account to more completely evaluate the effect of FGD availability on power systems:

- Unit use (base load, intermediate load, etc.)
- Unit interactions
- Coincident outages
- Partial outages (generating unit and scrubber)
- FGD unit configurations
- Network configurations
- Reserve policies

In particular, generating unit use and incidence of coincident full and/or partial outage will strongly influence the effect of FGD on system availability and adequacy. Also, in assessing the effect of FGD on power systems, it is important to recognize the requirement for excess generating capability above the maximum demand. Reserve policies, interconnections, and network state would influence whether or not power was available to offset these potential effects of FGD. Such an assessment was beyond the scope of this study.

2.0 RESULTS AND CONCLUSIONS

The effect of FGD availability on power generation was assessed. The results and conclusions of this study are given in this section.

2.1 Results

The results of this project are:

1) Mature coal-fired generating unit components (i.e. boilers, turbines, etc.) are reported to have an average availability between 80 and 97

percent. Mature coal-fired generating units are reported to have an average availability between 70 and 77 percent.

2) The seven FGD units emphasized in this study have reported average modular availabilities between 44 and 95 percent. Five of these have reported average modular availabilities above 70 percent.

3) An individual base loaded generating station with an FGD unit cannot meet consumer demand without FGD module sparing.

4) Generating systems with FGD on new coal-fired plants can meet a 1985 consumer demand equal to about 89 percent of the capability without FGD based on modeling the new coal capacity in a system as a single generating station with one FGD unit composed of one module. However, the systems cannot maintain the excess generating capability above maximum demand that is required to insure the ability to meet demand. Additional generating units or improvements to the FGD unit availability would have to offset the reduction in generating capability due to FGD units.

5) The availability of existing FGD units is maintained by various combinations of the following: (a) use of trained operating and maintenance crews, (b) bringing modules

off-line each night for maintenance, and (c) inclusion of spare modules.

6) FGD unit components subject to high failure rates include slurry pumps, packing gland water systems, nozzles, valves, fans, mist eliminators, and reheaters.

7) Maintenance methods, operating techniques, and design concepts were identified that can or have been used to produce high FGD availabilities.

8) A preliminary and rudimentary examination of the relationship between the effect of FGD and load duration curves was completed.

2.2 Conclusions

The conclusions for this study are:

1) FGD unit availability is a function of the modular availability, the total number of modules and the number of spare modules. The FGD unit availability is associated with a specific operating load (percent of capacity) for the generating unit. The number of effective spare modules varies with the operating load since all modules are not necessarily required for loads of less than 100 percent of capacity.

2) The availability of FGD units has a significant impact on the ability of an individual generating station and a generating system to meet consumer demand. The reduction in generating capability for a single station varies depending on the FGD unit availability. For a system the effect of FGD largely depends on the fraction of new coal plants in that system. These reductions in capability must be offset by adding generating units or by improving the availability of the FGD units.

3) Use of spare FGD modules dramatically improves total unit availability.

4) Significant progress has been made in the last few years in solving the problems experienced by the existing FGD units. The problems which present the greatest challenge to FGD availability are corrosion, erosion, deposits, unstable chemistry, and instrumentation.

5) A substantial committment on the part of a utility to the operation and maintenance of an FGD unit is required to maintain high levels of FGD unit availability.

3.0 AVAILABILITY ASSESSMENT

An assessment of the effect of flue gas desulfurization units on the availability of individual electric generating stations and generating systems was performed. The effect was quantified by determining the change in the ability of an individual station or generating system to meet consumer demand. This section of the report includes a description of generating unit components and systems (Sections 3.1 and 3.2), a presentation of utility and flue gas desulfurization operating data (Sections 3.3 and 3.4), and a determination of the effect of FGD availability on an individual generating station (Section 3.4) and on generating systems (Section 3.5).

3.1 Generating Unit Component Descriptions

The five major utility equipment component groupings of interest to this study are boilers, turbines, generators, condensers, and others (boiler feed water pumps, etc.). These items are currently used by virtually every utility in the United States.

There are two basic reasons for selecting these equipment items for study. First, each is generally accepted by the electric power utility industry as being commercially demonstrated technology. Second, data has been recorded and in many cases is available concerning the reliability, availability, and failure rates of each of these equipment items.

3.2 Description of Generating Systems

Systems of varying mixes of power plant generating types were examined. The 1985 projections by the National

Electric Reliability Council (NA-35) were the basis for the mix of generating types specified in these systems. The National Electric Reliability Council (NERC) consists of nine Regional Reliability Councils and encompasses essentially all of the power systems of the United States. The ten systems shown in Table 3-1 represent the projected mixes for the nine regional councils and the total projected mix for the NERC for 1985.

The column titled New Coal under Fossil-Fired Steam Turbines is of particular interest. The New Coal in Table 3-1 represents the percentage of total capacity resulting from coal-fired steam turbines completed between 1976 and 1985. This New Coal capacity is assumed to come under EPA's New Source Performance Standards. Therefore, control of SO_2 emissions for this generating capacity may be required. For this study, all of this New Coal generating capacity is assumed to use flue gas desulfurization as the method of SO_2 control. As a result, the effect of FGD on each system follows directly from its effect on the New Coal steam generators in that system.

3.3 Utility and Flue Gas Desulfurization Operating Data

A significant disparity exists between the quality and quantity of data available for utility systems as compared to flue gas desulfurization systems. Detailed performance data for equipment used in the electric utility industry have been collected on a continuing basis since 1965. There are at least four data banks for utility systems in the United States. Performance data for operating FGD systems, however, is sparse. At present the PEDCo Summary Report--Flue Gas Desulfurization Systems (PE-259) is the primary source.

TABLE 3-1. PERCENTAGE BREAKDOWN OF SYSTEM GENERATING CAPABILITY BY PRIMARY FUEL AND EQUIPMENT--1985

	Fossil-Fired - By Type of Primary Fuel								
	Steam Turbines								Pump Storage
System Number	New Coal	Total Coal	Oil	Gas	Combust. Turb.	Comb. Cycle	Nuclear	Hydro	and Other
1	18.4	72.5	5.0	0.5	3.4	0.3	14.7	0.8	2.8
2	33.6	37.8	10.6	38.1	1.8	1.3	8.5	0.5	1.4
3	3.5	26.4	22.3	0	14.0	0.4	31.5	1.5	3.9
4	14.5	52.7	6.7	0.2	8.1	0	30.5	0.9	0.9
5	29.2	58.7	2.0	0.5	8.9	0.2	21.1	8.6	0
6	4.4	9.9	37.7	0	8.4	0.9	30.0	7.8	5.3
7	11.7	42.0	11.7	0	6.5	0.6	30.4	5.8	3.0
8	30.0	36.1	11.4	28.4	5.5	1.6	13.5	3.2	0.3
9	13.5	24.5	16.6	1.2	5.1	2.1	14.9	30.6	5.0
10	16.0	40.1	13.8	5.7	6.4	0.9	21.8	8.4	2.9

Source: NA-325

3.3.1 Utility Operating Data

There are four primary systems in operation in the United States which collect and report power system performance data. These systems are the Edison Electric Institute (EEI) Prime Movers Committee; the Nuclear Plant Reliability Data Systems (NPRDS) under the direction of the American National Standards Institute (ANSI) subcommittee N18-20; the Gray Book I, issued by the Nuclear Regulatory Commission (NRC Gray Book); and the Federal Power Commission (FPC).

The EEI reports were found to be the best sources of data that are relevant to this study. Particularly useful was a special report issued in October 1976 on mature* fossil units categorized by fuel (ED-059). Data from this report are presented in Table 3-2.

3.3.2 Flue Gas Desulfurization Operating Data

An initial screening of PEDCo's Summary Report--Flue Gas Desulfurization Systems (PE-259) for the January to March, 1977. period identified 16 operational lime/limestone wet scrubbing systems and 1 operational system using magnesium oxide. No sites using double alkali or Wellman-Lord were listed. The criteria for selecting units for inclusion in this study were: (1) the system treats flue gas from a utility generating station greater than 50 Mw in size, (2) the system has been operating approximately one year or more, and (3) the system is not a test or demonstration unit. After application of these criteria to the operating systems, only 12 lime/limestone units remained. Table 3-3 illustrates average values for the seven units for which these performance indicators were available. The average modular availability is the average of the availabilities of the modules in an FGD system.

*A mature unit has completed the breakin period and has operated long enough to have a known incidence of outage.

TABLE 3-2. OPERATING DATA FOR MATURE COAL-FIRED UNITS (390-599 Mw)

	Year	Units in Service	Operating Availability (%)
Unit			
Coal Only	1972	32	75.1
	1973	19	74.3
	1974	20	69.9
Coal Primary	1972	36	74.2
	1973	30	77.3
	1974	35	71.5
Boilers			
Coal Only	1972	32	79.6
	1973	19	83.0
	1974	20	76.7
Coal Primary	1972	36	79.0
	1973	30	84.0
	1974	35	77.6
Turbines			
Coal Only	1972	32	86.3
	1973	19	88.4
	1974	20	89.7
Coal Primary	1972	36	86.4
	1973	30	90.6
	1974	35	89.5
Condensers			
Coal Only	1972	32	96.7
	1973	19	97.4
	1974	20	97.3
Coal Primary	1972	36	96.0
	1973	30	97.6
	1974	35	97.7
Generators			
Coal Only	1972	32	91.0
	1973	19	96.3
	1974	20	94.0
Coal Primary	1972	36	90.2
	1973	30	96.1
	1974	35	94.4
Other			
Coal Only	1972	32	95.0
	1973	19	98.3
	1974	20	96.2
Coal Primary	1972	36	94.3
	1973	30	98.0
	1974	35	97.0

Source: ED-059

TABLE 3-3. FGD MODULE PERFORMANCE DATA - AVERAGE VALUES

System	MW	No. of Modules	Average Modular Availability (%)	Utilization[a] (%)
Will County No. 1	167	2	44.2	33.6
La Cygne No. 1	874	7	88.6	N.A.
Phillips	413	4	60.6	49.7
Cholla No. 1	126	2	91.5	N.A.
Green River	64	1	72.6[b]	62.1
Sherburne County No. 1	720	11(+1 spare)	90.9	70.9
Bruce Mansfield No. 1	825	6	77.8[c]	76.8

[a]Utilization is the hours the FGD unit operated divided by the hours in the period expressed as a percentage.

[b]Includes two-month outage in March-April, 1977, to reline stack.

[c]Including reduction to half-load from March-July, 1977, due to repairs to stack lining. Bruce Mansfield reports that the repairs were necessary due to the improper installation of the original lining.

Sources: AN-184, BE-478, HE-258, KR-115, MU-155, PE-259, PE-267, PE-287, PE-288

The average modular availabilities vary from one unit to the next. However, five of the seven units have average modular availabilities greater than 70 percent. Furthermore, three are greater than 88 percent. Consequently, an average modular availability in the range of 70 to 90 percent was assumed for a mature FGD unit. This 70 to 90 percent modular availability range will receive primary emphasis in evaluating the effect of the availability of FGD systems on individual generating stations and on generating systems.

Analysis of the FGD availability data leads to several conclusions. No correlation between FGD availability and the size of the generating unit, the type of FGD process, or the size of the FGD modules was observed. The three systems examined in this study which have a large number of modules and/or a spare module (La Cygne No. 1, Sherburne County No. 1, and Bruce Mansfield No. 1), all have reasonably high modular availabilities. Application on a peaking or intermediate unit rather than base load allows maintenance to be performed on a more routine basis and, therefore, enhances reliable operation. Since FGD units have operated successfully on low sulfur coal (e.g. Sherburne County No. 1) and high sulfur coal (e.g. La Cygne), the proper design and operation of the system were determined to be more important than the sulfur content of the coal. Historically, inclusion of spare modules and an open water balance without recycle are additional factors that have contributed to more reliable operation. The establishment of a separate operating and maintenance crew that is specifically trained to work with the FGD unit is a final important factor in reliable operation. While all of these factors do not apply to every FGD system, they are all important considerations in any analysis of system availability.

One comparison of interest is that of the availability for the initial operating period for older units with the availability for the initial operating period for newer units. This comparison is particularly interesting for units by the same vendor. Table 3-4 presents the first year average modular availabilities for the seven FGD units emphasized in this study. This table points out the substantial improvements in the initial operating experience of units installed by the same vendor. The newer B&W and Chemico units show significant improvements relative to the older units by the same vendor. Furthermore, the newer units in general show improved average modular availabilities during the initial operating period. These improvements might be expected as a result of general advances in the state-of-the-art and particularly due to increased design and operating experience in the FGD industry. Radian has previously examined this "learning curve" effect in a study for EPA (DI-R-116).

3.4 Effect of Flue Gas Desulfurization Availability on an Individual Generating Station

A parametric study was performed to provide an overview of the effect of FGD unit availability on an individual generating station. Availability of the generating plant was assumed to be 75 percent while the FGD unit availability was varied from 0 to 100 percent. The results of this parametric study are shown in Figure 3-1. As can be seen, the FGD unit availability has a dramatic effect on generating station availability and, therefore, on the ability of the generating station to respond to demands for power.

As previously stated, an FGD modular availability in the 70 to 90 percent range was assumed for a mature FGD system. The FGD unit availability at full capacity can be calculated using the modular availability. the number of modules in the

TABLE 3-4. THE INITIAL AVAILABILITY OF SEVEN FGD SYSTEMS

System	Start-up	Vendor	First Year Modular Availability (%)
Will County No. 1	2/72	B & W[a]	~49
La Cygne No. 1	2/73	B & W	~87*
Phillips	7/73	Chemico	~36
Bruce Mansfield No. 1	4/76	Chemico	~80
Cholla No. 1	10/73	R - C[b]	N.A.
Green River	9/75	AAF[c]	~85
Sherburne County No. 1	3/76	CE[d]	~90

N.A. - Not Available

* - Second year availability is reported because data for the first year were not available.

[a]Babcock and Wilcox

[b]Research Cottrell

[c]American Air Filter

[d]Combustion Engineering

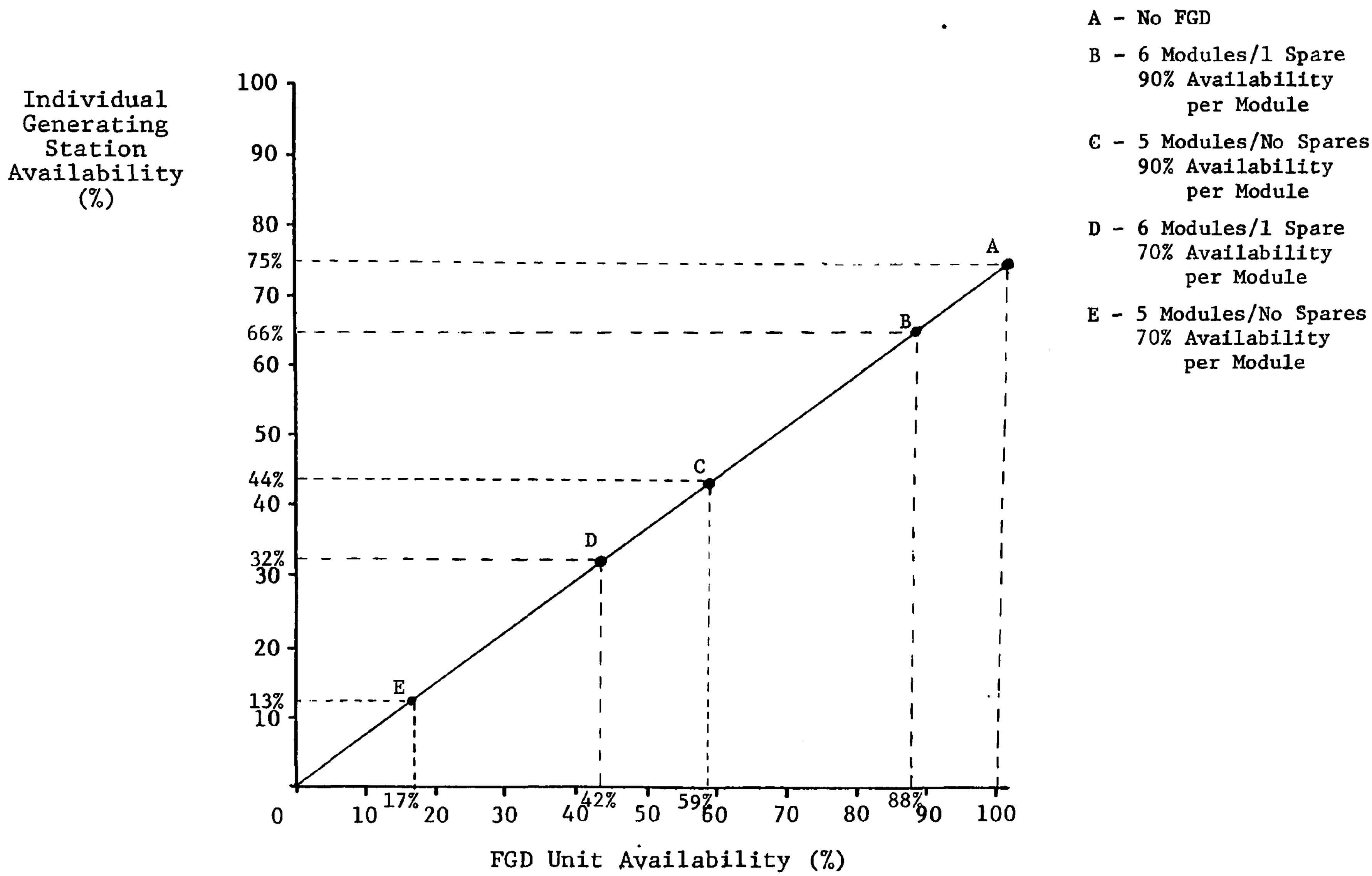

Figure 3-1. Effect of flue gas desulfurization unit availability on individual generating station availability at maximum load.

FGD unit, and the number of modules required for operation at full capacity. Assume a five module FGD unit with identical modules and no spares. With a 70 percent modular availability, the FGD unit availability at full capacity would be 17 percent. With a 90 percent modular availability, the FGD unit availability at full capacity would be 59 percent. The resultant plant availability for an individual station with an FGD system would then range from about 13 to 44 percent. For the 13 percent plant availability (70 percent FGD availability), a reduction of about 62 percent results. With a plant availability of 44 percent (90 percent FGD availability), the reduction is about 31 percent. The methodology used in these calculations is given in Appendix A.

Next, assume a spare module is added to the FGD unit such that five of the six modules can treat the flue gas generated at full capacity operation of the boiler. The spare module results in a full capacity availability of 42 percent for the unit with a modular availability of 70 percent. The unit with a 90 percent modular availability has a full capacity availability of 88 percent with a spare module. The resultant plant availability for an individual station with an FGD unit would then range from about 32 to 66 percent. The use of a spare module, therefore, improves the availability of the unit dramatically. Unit availability improves still more with each spare module added but the economics become less favorable with each spare added.

Previously, the discussion has been limited to operation of the generating unit at full capacity. During periods of reduced load on the generating station an FGD module might be down but the FGD unit could still treat all of the flue gas. For this reason, the availability of the unit for a range of boiler loads and the load duration curve for the generating station are both important considerations. The effect of a load duration curve was considered in a rudimentary manner in the appendix of the Task Report.

3.5 Effect of Flue Gas Desulfurization Availability on Generating Systems

This study considers the effect of FGD on the nine NERC regions and on the nation as a whole. The approach to this examination is the same as that used for an individual utility generating station in the preceding section. For the generating systems, however, the FGD units will only affect the new coal-fired capacity that comes under EPA's New Source Performance Standards. As previously stated, all of this new coal-fired capacity is assumed to use flue gas desulfurization as the method of SO_2 control. Therefore, the effect of FGD on each system is proportional to the new coal-fired steam turbine generating capacity in that system.

A parametric study of the effect of FGD availability on 10 utility systems was performed for the year 1985. FGD unit availability was varied from 0 to 100 percent. The effect of this availability on the new coal-fired capacity then determined the overall effect on the system. The new coal-fired capacity was represented as a single generating plant with one FGD unit composed of one module. FGD unit availabilities of 70, 80, and 90 percent are emphasized in estimating the impact of FGD availability on electric generation.

The effect of flue gas desulfurization on a utility system was estimated as shown below:

$$\text{\% Capacity With FGD} = (\text{100\% Capacity Without FGD}) - (\text{\% New Coal}) \times (\text{1-FGD Availability})$$

The system is assumed to be at 100 percent capacity prior to application of FGD. The reduction in capacity due to the use of FGD was approximated as the product of the fraction of new coal capacity in a system and the reduction in availability of this new coal capacity due to FGD. The fraction of new coal represents coal-fired plants coming on line between 1976 and 1985.

For example, in 1985 System 4 has 14.5 percent new coal capacity (Table 3-1). If an FGD availability of 80 percent is assumed, the effect of FGD is estimated by

$$100\% - (14.5\%)(1-.8) =$$
$$100\% - (14.5\%)(.2) =$$
$$100\% - 2.9\% = 97.1\%$$

Therefore, the estimated effect of the use of FGD is a reduction of generating capacity to 97.1 percent of the capacity without FGD. The impact of FGD on each system examined using the method above is shown in Table 3-5 for 1985. Projections were not carried beyond 1985 because data for the systems examined was not readily available beyond 1985. Additional follow-on work will be done to carry the projections through 1998 and to also consider other factors such as load demand curves.

The effect of FGD varies from system to system depending on the amount of new coal capacity and the FGD availability that is assumed. System 2 shows the greatest impact while System 3 is the least affected. The percent new coal for each system is shown in Table 3-6.

The effect of FGD availability on a generating system is observed to be less dramatic than for an individual station. This would be expected due to the diluting effect of power generation with fuels other than coal or with coal units that do not have FGD systems for SO_2 control. For a single new coal station the

TABLE 3-5. ESTIMATED EFFECT OF FLUE GAS DESULFURIZATION UNIT AVAILABILITY ON 1985 SYSTEMS[a]

System	FGD Unit Availability (%)[b]		
	70	80	90
1	94	96	98
2	90	93	96
3	99	99+	99+
4	95	97	99
5	91	94	97
6	99	99+	99+
7	97	98	99
8	91	94	97
9	96	97	98
10	95	97	98+

[a]Effect is determined by the ratio of system generating capability with FGD units over system generating capability without FGD units expressed as a percentage.

[b]One FGD unit composed of one module on a single generating station representing all new coal capacity.

TABLE 3-6. NEW COAL GENERATING CAPACITY IN EACH SYSTEM - 1985[a]

System	% of 1985 Total Capacity
1	18.4
2	33.6
3	3.5
4	14.5
5	29.2
6	4.4
7	11.7
8	30.0
9	13.5
10	16.0

[a]Fraction of 1985 total capacity represented by coal-fired units coming on-line between 1976 and 1985.

entire station was affected by FGD availability. Conversely, only the new coal capacity of a generating system is affected by FGD.

The significance of the 1985 impacts shown in Table 3-5 is difficult to put into perspective until a comparison is made with consumer demand. The National Electric Reliability Council (NERC) has projected the 1985 summer total resources and peak loads in megawatts for the systems examined in this study (NA-325). The summer peak demand as a fraction of the total summer resources for each system is presented in Table 3-7.

TABLE 3-7. SUMMER PEAK LOADS - 1985 PROJECTIONS BY NERC

System	Summer Peak Load (%)[a]
1	89
2	82
3	78
4	85
5	80
6	71
7	85
8	88
9	76
10 (Nation)	81

[a]Expressed as a percentage of the total summer resources (MW) projected for 1985 by NERC.

Source: NA-325

Each of the cases presented for 1985 in Table 3-5 can potentially meet the highest summer peak load projected by the NERC for 1985 (Table 3-7). However, it is critical to understand that the primary reason consumer demand can be met in these 1985 example systems is the excess capability above peak loads that is built into the utility systems. The maximum summer peak load projected for 1985 is not greater than 89 percent of total resources due to the presence of excess capacity. Table 3-7 indicates that the excess capability above the peak load varies from 11 to 24 percent. The utility industry is required to maintain these types of excess capabilities to insure their ability to meet consumer demand, to allow for growth of demand, and to provide emergency power if a generating unit or units, a transmission line, or an interconnection should fail.

To maintain this generating capability above maximum demand, a general reduction in generating capability that occurs for any reason including the application of FGD must be offset. The effect of the reduction in generating capability due to FGD unit availability was estimated assuming that reductions would be offset by the addition of more generating capacity.

It is important to note that the data in Table 3-5 are for 1985. Because lead times for construction of new coal generating units range from 7 to 10 years, 1985 is probably the first year that the effects of the NSPS would be seen. Because of the projected rapid growth in requirements for new coal units brought on by the energy crisis, it is important to estimate the effects of a revised NSPS in years beyond 1985. The amount of new coal generating capability beyond 1985 that would be subject to any revised new source performance standards has been estimated as 133,800 Mw in 1988 and 386,800 Mw in 1998 (WO-139). The 1988 estimate includes the 1980-1988 projects while the 1998 estimate includes 1980-1998. The additional generating capacity required to offset the reduction in generating capability caused by FGD is thus expected to increase significantly between 1985 and 2000 due to this threefold increase in new coal capacity. Consequently, the effects of FGD on reliability will probably increase in magnitude in the future. Rough estimates of this effect, obtained by analyzing all new coal as a single unit with a single scrubber unit composed of one module, are given in Table 3-8. Average FGD availabilities of 70, 80, and 90 percent were assumed. These additional generating requirements are estimates for the entire United States. They cannot be apportioned or extrapolated to any specific generating system.

TABLE 3-8. ESTIMATE OF MEGAWATTS OF ADDITIONAL GENERATING CAPACITY REQUIRED TO OFFSET THE EFFECT OF FGD IN 1988 AND 1998

Year	FGD Availability[a]		
	70%	80%	90%
1988	40,100 Mw	26,800 Mw	13,400 Mw
1998	116,000 Mw	77,400 Mw	38,700 Mw

[a]One FGD unit composed of one module on a single generating unit representing all new coal capacity.

4.0 IMPROVEMENTS TO FLUE GAS DESULFURIZATION AVAILABILITY

This report has emphasized experience at lime/limestone FGD units. Solutions to some of the problems encountered by lime/limestone FGD systems have been found. The system components which are subject to high failure rates have also been identified. Methods to overcome these high failure rates such as sparing or maintenance have subsequently been examined. Certain measures that have resulted or can result in high levels of system availability have also been defined by the FGD industry.

4.1 Operating Experience for Existing Systems

A similarity in the problems from system to system is observed. These problems can be generally grouped as follows: (1) erosion of pumps, seals, and control valves; (2) deposits, plugging, or scaling on scrubber internals, nozzles, strainers, mist eliminators, and in-line reheaters; (3) corrosion of fans, reheaters, ducts, and stacks; and (4) vibration and poor thermal mixing with direct-fired reheaters. Solutions are also often similar and, therefore, often applicable from one system to the other. However, any application must be examined on a case-by-case basis. Resistant materials or coatings have generally been used in attempts to overcome erosion and corrosion problems. Careful control of the scrubber operation and the prevention of solids entrainment in the gas have been partially successful in preventing deposits buildup, plugging, or scale. The use of large operating and maintenance crews in addition to control of the chemistry appears to be the most dependable solution to plugging and scaling at this time, however. This approach also applies to erosion and corrosion problems in some instances. Workable solutions for the direct-fired reheater problems have not been reported.

4.2 Measures to Improve Flue Gas Desulfurization Availability

Various measures have been or can be used to maintain high levels of FGD availability. These measures which are discussed below can be grouped into maintenance methods, operating techniques, and design concepts.

Maintenance Methods

The maintenance methods applied by La Cygne and Sherburne County have successfully maintained a high system availability. The important factors in these maintenance programs are: (1) taking one or more modules off-line each night for inspection and cleaning, (2) use of a separate maintenance crew trained to work on the FGD system, and (3) a general dedication to gaining a better understanding of the system and how to maintain it better.

Operating Techniques

There are several operating techniques that have been or can be used to contribute to maintaining a high FGD system availability. Over and underspray of mist eliminators (demisters) removes deposits from the mist eliminators. Operating with an open loop water balance has historically benefited the FGD system. Automatic pH and process control result in more stable operation and tend to prevent major failures such as massive scaling. Finally, a staff of operators and technicians to work with the FGD system on a daily basis is very important.

Design Concepts

Each of the FGD systems examined in this study differs somewhat in design concept. Some of the concepts that have been or potentially can be successful in enhancing availability are: (1) dry particulate removal before the FGD system with an electrostatic precipitator (ESP), (2) dry flue gas booster fan between the ESP and scrubber rather than a wet fan after the scrubber, (3) adequate sparing of pumps, valves, lime/limestone feed systems, packing gland water systems, etc., (4) spray tower scrubber configuration, (5) adequate instrumentation for pH, SO_2, additive use, etc. with automatic controls, (6) indirect reheat of flue gas, and (7) adequate particle dropout area to reduce solids carryover to the mist eliminators.

The areas of improvement discussed in this section represent a composite of experience at several specific FGD units. Future FGD units might be expected to include many of these improvements.

APPENDIX A

Availability Calculations

The calculations of the availability of the station with FGD assuming a five module FGD unit without a spare are shown below. For a FGD modular availability of 70 percent, the availability of the station with FGD is given by the product of the FGD unit availability and the station availability.

$$\begin{aligned} \text{Availability} &= (.70)^5\ (.75) \\ &= (.17)\ (.75) \\ &= .13 \end{aligned}$$

For a FGD modular availability of 90 percent, the availability of the station with FGD is given by the same calculation.

$$\begin{aligned} \text{Availability} &= (.9)^5\ (.75) \\ &= (.59)\ (.75) \\ &= .44 \end{aligned}$$

If a spare module is added to the FGD unit, the availability of the station with FGD is improved as shown below.

$$\begin{aligned} \text{Availability} &= [(.9)^6 + 6(.9)^5\ (.1)]\ (.75) \\ &= (.53 + .35)\ (.75) \\ &= (.88)\ (.75) \\ &= .66 \end{aligned}$$

BIBLIOGRAPHY

BIBLIOGRAPHY

AN-184 Anderson, Andy, Private communications. Kentucky Utilities, 12 May 1977.

BE-478 Beard, J.B., Private communications, Kentucky Utilities Co., Lexington, KY, 12 July 1977.

DI-R-161 Dickerman, James C., et al., Comparison of the availability and reliability of equipment utilized in the electric utility industry, draft report. EPA Contract No. 68-02-1319, Task 12, Radian Project No. 200-045-62. Austin, TX, Radian Corporation, December 1976.

ED-059 Edison Electric Institute, Prime Movers Committee, Equipment Availability Task Force, EEI equipment availability summary report on trends of large mature fossil units categorized by fuel and in commercial operation prior to January 1, 1971. N.Y., Oct. 1976.

HE-258 Heacock, Frank A., Jr. and Robert J. Gleason, "Scrubber surpasses 90% availability", Elect. World 1975 (May 15), 42.

KR-115 Kruger, R.J. and M.F. Dinville, "Northern States Power Company Sherburne County Generating Plant limestone scrubber experience". Presented at the Utility Representative Conference on Wet Scrubbing, Las Vegas, NV, Feb. 1977.

MU-155 Mundth, Lyman K., Private communication, Arizona Public Service Co., Phoenix, AZ, 20 July 1977.

BIBLIOGRAPHY (Continued)

NA-325 National Electric Reliability Council, 6th Annual Review of Overall Reliability and Adequacy of the North American Bulk Power Systems. July 1976.

PE-259 PEDCo Environmental, Inc., Flue Gas Desulfurization Systems, Jan., Feb., March 1977, summary report. EPA Contract No. 68-02-1321, Task No. 28, Cincinnati, OH, 1977.

PE-267 Pernick, S.L., Jr., Private communication, Manager, Environmental Affairs, Duquesne Light, Pittsburgh, PA, 9 December 1976.

PE-287 Pernick. S.L., Private communication, Duquesne Light, Pittsburgh, PA, 11 August 1977.

PE-288 PEDCo Environmental Inc., Summary report, Flue gas desulfurization systems, June - July 1977. EPA Contract No. 68-01-4147, Task No. 3. Cincinnati, OH, 1977.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-78-031a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE The Effect of Flue Gas Desulfurization Availability on Electric Utilities Volume I. Executive Summary		5. REPORT DATE March 1978 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.D. Delleney		8. PERFORMING ORGANIZATION REPORT NO. 78-200-187-07-13
9. PERFORMING ORGANIZATION NAME AND ADDRESS Radian Corporation P.O. Box 9948 Austin, Texas 78766		10. PROGRAM ELEMENT NO. EHE624 11. CONTRACT/GRANT NO. 68-02-2608, Task 7
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 4-12/77 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES EPA project officers are J.E. Williams (IERL-RTP, 919/541-2483) and K.R. Durkee (OAQPS/ESED, 919/541-5301).

16. ABSTRACT The report gives results of an analysis of the effect of the availability of a flue gas desulfurization system on the ability of an individual power plant to generate electricity at its rated capacity. (The availability of anything is the fraction of time it is capable of service, whether or not it is actually in service.) Also analyzed are its effects on a power generating system (a group of several coal-, oil-, and gas-fired power plants plus nuclear and hydroelectric plants).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Calcium Oxides	Air Pollution Control	13B	07B
Flue Gases	Limestone	Stationary Sources	21B	08G
Desulfurization	Sulfur Dioxide	Alkali Scrubbing	07A,07D	
Electric Utilities	Dust	Particulate		11G
Alkalies		Venturi/Spray Towers		
Scrubbers		Mist Eliminators		

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 35
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)