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INDUSTRIAL HYGIENE STUDY OF TVA WORKERS IN COAL-FIRED POWER PLANTS

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A survey to measure baseline exposure to coal dust, asbestos (1332214), sulfur-dioxide (7446095) (SO_2), nitrogen-dioxide (10102440) (NO_2) fly-ash (68131748), nitric-oxide (10102439) (NO) sulfites (SO_3) sulfates (SO_4) and noise was conducted at the Tennessee Valley Authority (TVA) coal fired power facilities. Personal and area atmospheric samples were taken and historical exposure data examined. The geometric mean concentration (GMC) of atmospheric coal dust ranged from 0.5 to 1.2 milligrams per cubic meter (mg/cu m) in all facilities for the years 1974 through 1979, although GMCS from the individual facilities ranged from 0.4 to 1.6mg/cu m for that time period. The GMCs of atmospheric fly-ash ranged from 0.20 to 0.50 mg/cu m, substantially below the OSHA standard of 5mg/cu m. NO_2 was not found in any appreciable concentrations, NO concentrations ranged from 1.0 to 51.4ppm. GMCs of asbestos decreased from 1.1 fibers per milliliter (f/ml) in 1973 to 0.05f/ml in 1979. Atmospheric mercury concentrations ranged from nondetectable to 0.5/mg/cu m, compared with the OSHA standard of 0.05mg/cu m. Geometric mean noise exposures ranged from 80.1 to 126 decibels on the A-weighted scale as 8 eight hour time weighted exposures. Area sampling for ozone did not detect any ozone generated by facility operations. Atmospheric concentrations of ozone ranged from 0 to 14ppm.

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FOREWORD

The National Institute for Occupational Safety and Health (NIOSH) is responsible for helping to ensure that every person in the Nation has safe and healthful working conditions. To accomplish this end, the Institute engages in research on occupational safety and health problems, including the evaluation of industrial hazards and chemical toxicity determinations.

Since national efforts in the area of energy production are increasing, it is critical that the Institute leads in the assessment and evaluation of the occupational hazards related to energy generation industries. The coal-fired electrical generation industry is likely to grow at an accelerated rate because of our Nation's efforts to decrease the use of foreign oil as fuel, and because nuclear generation is being curtailed in many parts of the country. We are pleased to have sponsored this investigation by the Tennessee Valley Authority to characterize the working conditions in coal-fired power plants.

This report contains the results of TVA's study of the exposure levels of airborne hazardous materials and other hazardous agents found in their coal-fired power plants, and it is one of the most complete documents published to date on the subject.

J. Donald Millar, M.D.
Director, National Institute for
Occupational Safety and Health

PREFACE

This investigation, "Industrial Hygiene Studies of TVA Workers in Coal-Fired Power Plants," was initiated to answer questions that both NIOSH and TVA had about the working conditions of coal-fired power plants in general and TVA's plants specifically. While many of the questions have been answered, many more questions have been identified and await answering. There are ample opportunities for expanding this study to include coal-fired power plants outside the TVA system. Additional non-TVA assessments would collaborate these findings and lead to more confident inferences about the working conditions that can be expected in the industry as a whole.

In order to conduct the large amount of personal sampling that was accomplished during this study, we needed the cooperation of the employees, safety staffs, and management at the two power plants that were studied, Johnsonville and Paradise. The efforts of the safety engineers at the two plants must be recognized and commended. The safety engineers, H. B. Camp at Johnsonville and C. B. Lehman at Paradise, provided insight and many services that were necessary for the successful completion of this study. The efforts of the many TVA employees involved in the different phases of this study are also appreciated.

ABSTRACT

Increasing coal combustion to generate electricity will cause more employees to be exposed to the hazardous agents used or produced by this process, such as fly ash, sulfur dioxide, oxides of nitrogen, coal dust, and asbestos. The impact of this increased exposure would be impossible to measure without having a reliable baseline for comparison. This study attempted to establish baseline industrial hygiene conditions in TVA's coal-fired power plants.

Personal sampling was used to establish mean exposure levels to SO_2, NO_2, and respirable fly ash; and historical exposure data based on several years of personal sampling were used to estimate mean exposure levels for respirable coal dust and asbestos. Characterization and worst-case concentrations of fly ash were taken by means of area sampling. Area sampling for sulfites (SO_3), sulfates (SO_4), and nitric oxide (NO) were also conducted, and historical measurement data on ozone, mercury, and noise were analyzed.

Personal exposure levels to respirable coal dust appeared to be constant over the six-year period included in the study, while the exposure levels to asbestos showed a decline during the seven years when documented sampling took place.

The exposure levels to SO_2 were low. At one of the two power plants studied almost 100 percent of the samples were below the detectable level, and at the other plant about 75 percent were below the detectable level. A similar situation was found regarding NO_2 levels; almost 100 percent of the samples for NO_2 at both plants were nondetectable.

Respirable fly ash concentrations were below the standards for nuisance dust, and the characterization of polynuclear aromatic hydrocarbons and trace elements in fly ash were unremarkable.

Low concentrations of SO_3 and SO_4 were found on in-plant high volume samples, and moderate but inconsistent levels of NO were measured in worst case situations at one of the power plants.

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INTRODUCTION

SUBAGREEMENT I

In 1976 the National Institute for Occupational Safety and Health (NIOSH) and the Tennessee Valley Authority (TVA) established a framework for cooperative efforts in the areas of occupational health, safety, and medicine as they are effected by energy-related activities. The Memorandum of Understanding (MOU) between the agencies provided a mechanism for TVA to conduct investigations that are mutually beneficial for the two agencies, and for NIOSH to provide partial or total funding for the investigations. TVA's health, safety, and medical personnel are in a unique position to study energy related occupational health and safety effects because TVA is the nation's single largest producer of electricity. Coal fired, nuclear, hydroelectric, and oil-fired gas turbine generation are all used in TVA's power system. Also, TVA is taking a lead in energy demonstration programs such as coal gasification and fluidized bed combustion.

Subagreement I to the MOU was signed in 1977 after a year of planning between NIOSH and TVA officials. The subagreement, "Industrial Hygiene Study of TVA Workers in Coal-Fired Power Plants" is part of NIOSH's efforts to assess the occupational well-being of employees in the electrical utility industry. In 1977, the nation was gearing up to increase coal usage and decrease oil usage for electrical generation and NIOSH was unable to predict the occupational health impact caused by greater coal burning. Before this time, the American Medical Association's (AMA) House of Delegates published the results of a comparative mortality study of the various energy sources (1). Occupational health hazards were identified for nuclear, coal, oil, and natural gas electrical generation; and statistics showed that coal-fired power production was associated with higher mortality rates due to accidents and health reasons than the other three energy sources, but there was no dose-effect relationship established. Because of the situation described above, Subagreement I was aimed at starting the process of documenting the occupational health and safety conditions found in coal-fired power plants. At the time the work began on this study, there had not been a comprehensive industrial hygiene study published about coal-fired power plants, and there have been only a few isolated studies that have looked at small fractions of these occupational health problems (2-4).

The design of the Subagreement I study was to select those hazardous health agents and those employees that would be most effected by increased coal combustion, and to document the current exposure levels of those employees to the hazardous agents. The exposure data gathered for this study is applicable only to the time periods in which they were gathered, and therefore retrospectively assigning these exposure data could result in serious errors.

This investigation will not only serve NIOSH needs, but it is the first time that TVA has systematically examined the exposure levels of many of these hazardous agents. The exposure level data base developed by this investigation can be used by TVA management in many decision making processes, such as the institution of engineering controls or personal protective equipment programs.

ELECTRIC UTILITIES AND TVA POWER SYSTEM

There are more than 1000 coal-fired power plants currently operating in the United States for the generation of publicly distributed electricity (5). These plants employ about 394,000 employees engaged in all types of craft, technical and managerial jobs (6). In the near and mid-term future, coal appears to be the preferred type of fuel of electrical generation. The Federal Power Commission estimated in 1977 that by 1986 almost 500 additional coal-fired generation units would have been built (7). In addition to constructing coal-fired units, U.S. utilities are going into the coal mining business also to ensure a continuous supply. This indicates the utilities' long-term commitment to coal combustion.

In 1949, TVA began building large coal-fired power plants to supply power demands in the Tennessee Valley area in excess of its hydroelectric generating capacity. By the end of 1979, TVA's power system included 29 hydroelectric plants, 12 coal-fired power plants, one nuclear power plant, and 48 oil-fired gas turbines for peak load generation. The total generating capacity of these facilities is about 29.9 million kilowatts, and TVA has about 14 million kilowatts of capacity under construction. The total net electrical generation for 1979 was almost 120 billion kilowatt hours. Sixty-four percent of TVA's power was generated from coal combustion in 1979 (8). The 12 coal-fired power plants range in size from 240 thousand kilowatts to 2.6 million kilowatts, and there are a total of 63 generating units among the plants.

The Johnsonville and Paradise power plants were used extensively as representative power plants for this investigation. Their generating capacities are about 1.35 and 2.56 million kilowatts respectively. Johnsonville has 10 balanced draft units averaging 135 thousand kilowatts each. At Paradise there are three positive pressure units, two are 704 thousand kilowatts and one is 1.15 million kilowatts.

Construction of the Johnsonville plant occurred in two phases. The first phase began in 1949 and ended in 1953 when the first six units were synchronized with TVA's power grid. These six units are pulverized coal-fired, balanced draft, single pass, water wall, dry bottom radiant boilers that produce 1,000,000 pounds of steam per hour at 1,670 psig, and they were manufactured by Combustion Engineering, Inc. The second phase of construction began in 1956 and it ended in 1959 when four more units were finished. These boilers were manufactured by Foster Wheeler Corporation. They can produce 1,100,000 pounds of steam per hour at 2,035 psig, and they are radiant, reheat, natural circulation type boilers. Ten electrostatic precipitators (ESP) were added to the Johnsonville plant to control the fly ash emission, and they began operation in 1976.

The Paradise plant was also built in two phases. Two 704 thousand kilowatt units were started in 1959 and completed in 1963, and one 1.15 million kilowatt unit went into operation in 1970. All these units were manufactured by Babcock and Wilcox Company. They are radiant, positive pressure, single pass, and cyclone fired, and can produce a total of 18,000,000 pounds of steam per hour at about 3,500 psig. The first two units had ESP's added in the late 1960's and unit three had an ESP installed during construction. Operating at their respective full loads, the Johnsonville and Paradise plants can burn about 11,500 and 21,000 tons of coal per day.

Although the boilers at both Johnsonville and Paradise are radiant boilers, they differ in the draft systems that they use. The balanced draft Johnsonville boilers use fans downstream of each boiler to induce, or pull, gas flow through the unit. Also, there are smaller forced draft fans upstream of each unit that push the combustion air into the boilers; and by balancing the flows of both of the sets of fans, a moderate negative pressure is maintained in the boiler. This negative pressure prevents outward leakage of combustion gases if an opening in the boiler occurs.

The three units at the Paradise power plant have positive pressure draft systems. Sets of upstream fans force the air and combustion gas to flow through the units causing moderate boiler pressures and forcing combustion gas leakage to the atmosphere if openings occur in the boiler (9).

OBJECTIVES

The main objective of conducting the investigations for the Subagreement I between NIOSH and TVA was to determine employee exposure levels for the more common air contaminants found in coal-fired power plants. Also, NIOSH and TVA were interested in examining the effects that boiler design has on the levels of occupational exposure of the craft groups employed in the coal-fired power plants. This exposure data can serve as baseline information against which other exposure data can be compared. Comparisons could be made to the exposure levels caused by alternate coal combustion, such as fluidized bed combustion or coal gasification and liquefaction.

Documenting accurate employee exposure levels is one of the first steps necessary in eventually establishing dose-effect relationships for the contaminants found in coal-fired power plants. The results of this industrial hygiene investigation begin to build a reliable employee exposure record.

METHODS

GENERAL

Early in the planning stages of the Subagreement I investigation it was decided that the design of the power plant facilities probably has a significant effect on the occupational exposure to agents related to coal combustion, and the one design difference that would have the greatest influence on exposure levels was thought to be the boiler draft system, either balanced draft or positive pressure as previously described. The Johnsonville and Paradise power plants were chosen as typical examples of TVA plants using balanced draft and positive pressure boiler draft systems respectively. Their overall maintenance conditions were also typical of the rest of TVA's coal-fired plants. Appendix A presents a breakdown of all TVA's coal-fired power plants and their respective units.

The coal-fired power plant craft groups selected for study in the Subagreement I investigation were discussed by TVA and NIOSH representatives prior to the signing of the subagreement. The ten craft groups finally chosen were asbestos workers, conveyor-dumper car operators (coal handlers), boilermakers, steamfitters, machinists, electricians (powerhouse), laborers (powerhouse), assistant unit operators, auxiliary operators, and instrument mechanics. The chosen craft groups were selected based on their exposure to coal, asbestos, and combustion products. A detailed listing of all of the jobs included in these craft groups is given in Appendix B.

After a short period of time into the study, a small modification was made in the craft group listing. The assistant unit operators and the auxiliary operators were combined into a single surrogate group called "operators." This consolidation was done to provide a craft group large enough for significant sampling because neither original group was individually large enough, and since the work locations and type of activities of two craft groups are essentially similar, the results can be applied to either group.

The agents that were chosen for study were also identified early in the planning stages of the subagreement. Four of the five agents (coal dust, sulfur dioxide [SO_2], nitrogen dioxide [NO_2], and fly ash) were chosen because it was thought that employee exposure to them would be directly proportional to coal usage. The fifth agent, asbestos, was selected because of its universal interest and because it has had historically high usage in coal-fired power plants. The selection of these agents was not meant to be all inclusive of the hazardous agents found in coal-fired power plants, but it was meant to represent the expected hazardous agents associated with coal combustion. Fly ash, SO_2, and NO_2 exposure levels were measured during this study, and the exposure levels for respirable coal dust and asbestos were taken from TVA industrial hygiene records.

There are many uncontrollable aspects of operating a coal-fired power plant that can effect the occupational exposure to airborne contaminants. Some of these aspects include atmospheric or meteorological conditions, coal quality, load factor, and maintenance activities. Also, there are aspects of each craft group's activities that are uncontrollable and could possibly effect exposure levels, such as the location of daily jobs. And there are individual differences between employees in how they accomplish similar tasks which can effect personal exposures. In order to account for these variables, a random sampling plan was adopted.

A maximum random sampling strategy would have required that the plant, day, shift, employee, and agent all be individually selected in a random manner for each personal sample taken, but this strategy was not practical because of limited resources. As previously discussed, the plant selection was narrowed to two representative plants. The day selected for sampling of the various craft groups was randomly selected during 12, week-long sampling trips that were evenly spaced over a 12-month period for each plant. The selections of the employees and their target air contaminants were also randomized as much as possible for each trip. Twelve trips in 12 months were chosen to balance out the uncontrollable plant operating parameters previously mentioned. All seasons and most meteorological conditions were anticipated for the sampling trips.

During each trip, four personal samples per each craft group were taken for each air contaminant. This yielded a total of about 48, 8-hour, time-weighted-average (TWA) exposure levels for each contaminant, craft, and plant from which future exposure estimates can be drawn.

As the study progressed, several changes were made in the sampling strategy. After three trips to each plant, the NO_2 sampling stopped because of nondetectable levels found at both plants; and after six trips to the Johnsonville plant SO_2 sampling was suspended because of nondetectable levels. The only other significant change in the sampling strategy was extending the 12-month period to 18 months because of personnel shortages early in the study. By extending the sampling period to 18 months, possible seasonal variations in exposure levels were not randomized as much as desired. A greater number of the sampling trips were conducted in the winter or cold weather months than in the summer. The possible results of this methods change were not evaluated.

Because of the decreased work load from the cancelled NO_2 and partially cancelled SO_2 personal sampling protocol, the NIOSH project officer suggested that the study be expanded to include some hazardous agents that are not directly related to coal combustion, but are of concern in coal-fired power plants. Agreements were reached and the additional agents investigated were heat stress, mercury (Hg), noise, ozone, and carbon monoxide (CO). Also, additional fly ash characterizations were decided upon, and area fly ash samples were analyzed for sulfates, sulfites, polynuclear aromatic hydrocarbons (PAH's), elements and size distribution. Industrial hygiene files were searched for exposure data on all five agents, and some limited area sampling was conducted to measure worst-case concentrations of CO.

EXPERIMENTAL

Coal Dust

Measurement of employee exposure to respirable coal dust at TVA coal-fired power plants has taken place since the mid-1950's, but consistent and documented sampling methods have been used only since 1974. The method used in TVA since that time has been the 10-mm cyclone and membrane filter combination with a personal sampling pump running at 2.0 or 1.7 lpm. Three different coal mine dust personal sampling units have been used to collect respirable coal dust exposure data--the MSA Model G and the Bendix Models 30 and 41. The samplers have been used based on availability and the preference of the industrial hygienist. When the 2.0-lpm sampling rate was used, the calculated coal dust concentration was multiplied 1.38 (10) and at the rate of 1.7 lpm there was not a correction factor used. The membrane filter used was the 0.8 μm mixed cellulose ester, and the gravimetric analysis was completed either at TVA's analytical laboratory or the Pittsburgh Field Health Group Laboratory of the Bureau of Mines in Pittsburgh. The coal dust samples taken at the two different flow rates were not separated because it was not always known which flow rate was used when the data was taken from the files.

Exposure to respirable coal dust in TVA is not a function of the boiler pressure since similar equipment is used for coal receiving, preparation, and handling on both balanced draft and positive pressure boiler systems. Although the coal pulverizers are different at different plants, all respirable coal dust sampling was conducted in areas away from the pulverizers, such as the bunker rooms, beltlines, and crusher buildings. As part of TVA's standard industrial hygiene program, periodic monitoring is conducted of employees'respirable coal dust exposure at all of the 12 TVA coal-fired power plants. Because of the above reasons, additional personal respirable coal dust sampling was not conducted for this investigation; instead, industrial hygiene files were searched and all of the respirable coal dust exposure data were extracted for the years 1974-1979 inclusive, and the reduced data is presented in the Results section of this report.

Periodically, the crystalline silica contents of the respirable coal dust samples were determined, and these data are summarized for this report. Usually, several personal samples were combined after their gravimetric analyses to give enough mass for the silica analysis. All combined samples were taken on the same day and at the same location in the coal system of one plant. The analyses for the crystalline silica have been done for the entire six-year period following a method equivalent to NIOSH P&CAM 110 (11), "Quartz in Coal by Infrared Spectroscopy," and the instrument that has been used is a Perkin Elmer Model 467, Grating Infrared Spectrophotometer.

The total sulfur contents of the coal burned at both Johnsonville and Paradise were collected from plant engineering records. Sulfur levels in the coal are measured and used as operating parameters for the boilers. It was hypothesized that the trend in SO_2 exposure levels found in each plant could possibly follow the trend in the sulfur content of the coal burned in each plant.

Fly Ash

Fly ash has never been thoroughly investigated by TVA industrial hygiene personnel so there were not any records from which historical exposure levels could be determined. All the craft groups, except the asbestos workers and the conveyor and dumper car operators, were sampled for respirable fly ash exposure at both

Johnsonville and Paradise power plants. The asbestos workers' exposure level to fly ash was not measured because of the obvious interference caused by insulation dust; and the conveyor and dumper car operators were not sampled because of coal dust interference and because the majority of their work locations are physically separated from the powerhouse. Although these results will be reported as fly ash, it should be noted that the sampler really collected the general respirable particulates found in the power plants, and there could be some interferences included in the analysis, such as low levels of welding fumes.

The personal sampling was done using either Bendix Models 41 or 30 or MSA Model G pumps operated 1.7 lpm with 10-mm nylon cyclones and Gelman 5.0 μm pore size polyvinyl chloride membrane filters. The gravimetric analysis was done at TVA laboratories.

The size distribution of airborne fly ash was measured at both Johnsonville and Paradise using an Andersen Cascade Impactor. Filter media, Gelman DM-800, were used as the impaction surfaces and the manufacturer operating instructions were used (12). Analysis of the impaction media was gravimetric, and the size distributions were calculated per the instruction manual. Ten size distributions were measured at Paradise over five trips, and eight were taken at Johnsonville in four trips.

High-volume fly ash sampling was conducted at both power plants to collect sufficient mass in order to analyze it for three types of trace constituents: PAH's; metals; and radioactive species. The high-volume samplers were General Metals Works, Inc., and they were operated at 40 cubic feet per minute for various time periods at several locations in the plant.

The analysis for PAH's looked for benzo(a)anthracene, benzo(a)pyrene, chrysene, fluoranthene, and pyrene. The analytical technique basically followed the methods published by Karasek in 1978 (13) and of the Environmental Protection Agency in 1979 (14). A Micrometrics high-pressure liquid chromatograph (HPLC) with a fluorescence detector was used for the analysis. Soxhlet extraction using nanograde methanol was used on the entire 8- by 10-inch, Gelman spectrographic grade glass fiber filter (without binder). The extract was concentrated and then analyzed by HPLC.

Analyses for 21 metallic elements were conducted using a variety of instruments. A Jarrell-Ash inductively coupled argon plasma atomic emissions spectrometer was used for aluminum, beryllium, cadmium, iron, calcium, magnesium, potassium, titanium, sodium, barium, vanadium, copper, manganese, boron, chromium, zinc, nickel, and lead. While flame atomic absorption spectroscopy (AAS) was used for tin and cobalt, and hydride generation AAS was used for arsenic. The filters used for elemental analysis sampling were spectrograde (15-17).

There were seven radioactivity analyses performed on high-volume fly ash samples. They were total uranium, thorium-230, radon-226, lead-210, polonium-210, gross α, and gross β. Each of these analyses was standard procedure from TVA's Radioanalytical Laboratory Procedure Manual of the Laboratory Services Branch.

Sulfur Dioxide

The method chosen for measuring personal, time-weighted-average exposure to SO_2. was using long-term SO_2 indicator tubes from National Draeger, Inc., and a DuPont Model P-30 low flow sampling pump running at 15 milliliters per minute (ml/min). The Draeger tube was tested along with the Abcor passive SO_2 dosimeter, the Kitigawa and MSA long-term indicator tubes, and the impregnated filter system developed by Eller (18). This testing was conducted prior to this study in order to select a standard SO_2 sampling method for use throughout TVA that did not depend on liquid medium impinger sampling. Each 8-hour TWA required two Draeger tubes to cover the entire shift, and, if during the shift the concentration indicated by the tube was approaching its capacity, a third or even a fourth tube was used. The Draeger SO_2 tube has the equivalent capacity of about 15 ppm continuous concentration when used at 15 ml/min for four hours.

Worst-case area sampling for SO_2 was conducted at the Paradise plant using Draeger SO_2 long-term indicator tubes at 15 ml/min. Locations for the worst-case sampling were surveyed using a direct reading instrument, and the area of highest concentration was sampled. There was no worst-case sampling for SO_2 conducted at the Johnsonville plant because there was not any significant concentrations of SO_2 located.

Area sampling for three sulfur species was conducted at both plants. The impregnated filter method of Eller (18) was used, and the analysis was done at TVA laboratories using a Dionex ion chromatograph system 10. The sulfur species sampled for were SO_2, sulfites, and sulfates. The flow rate used for the sampling was 1.5 lpm.

Oxides of Nitrogen

Personal sampling for nitrogen dioxide (NO_2) took place at both the Johnsonville and Paradise power plants during three trips to each plant. The sampling method used was the Palmes (19) passive sampler for NO_2. At the beginning of this study, these samplers were not commercially available so they were fabricated in TVA's support shop out of the same materials originally described by Palmes and also used in a NIOSH study (20). The sampler preparation and analysis were done in TVA laboratories using a Beckman spectrophotometer model 26.

Area, worst-case sampling for oxides of nitrogen was done at selected locations at both power plants. Three methods of comparative area sampling were used at Paradise--the Palmes passive sampler, impinger method (21), and the NIOSH developed triethanolamine (TEA) tube (22). The Palmes and impinger methods only detected NO_2 while the TEA method detected NO and NO_2. Flowrates for the impinger and TEA methods were 1.0 lpm and 50 ml/min respectively. Analyses for these samples were done at TVA laboratories following the referenced methods. The area sampling at Johnsonville for NO and NO_2 was limited to the impinger and TEA tube methods using the same flowrates and analytical methods.

The area sampling at Paradise revealed significant levels of NO. It was mutually decided between NIOSH and TVA to include some personal sampling for NO among the Paradise craft groups. The three crafts selected for sampling, based on their SO_2 exposure levels, were steamfitters, laborers, and instrument mechanics. The selection of these three craft groups was pegged to SO_2 exposure because both SO_2 and NO are direct combustion products and should occur together. Three of four members of these three craft groups were sampled using the TEA tubes (22) and DuPont low-flow sampling pumps on two trips to Paradise. The flowrate for this personal sampling was 50 ml/min., and the analysis was done for both NO and NO_2.

Asbestos

Since 1973, TVA has regularly monitored its asbestos workers for personal exposure to asbestos. The sampling method used during this period of time is equivalent to the NIOSH SDS 2.02 (23). It was published in 1968 (24), and it uses the 37-mm mixed cellulose ester membrane filter with a pore size of 0.8 µm. Sampling is done with an open-faced filter at a flowrate of 1.5 lpm ± 5 percent. Analysis of the personal samples for asbestos was done by an equivalent method to NIOSH P&CAM 239 which was also published in 1977 (25).

Because asbestos exposure is periodically measured, additional sampling was not conducted for this study. As with respirable coal dust, industrial hygiene records were searched and all eight-hour TWA's for asbestos were extracted. The exposure levels for all 12 TVA coal-fired power plants are given in the Results section of this report.

Heat Stress

The heat stress data collected for this report were not exposure data, they were occupational disease (OD) data from all 12 coal-fired power plants. The OD data were generated whenever an employee reported to the plant medical or nursing station because of feeling ill. If the diagnosis indicated possible heat related symptoms then heat was listed as a causative agent on form TVA 1890, Report of Injury or Illness. The record of 1890's is computerized in TVA, and the record was searched for all 1890's having a heat related disease as the diagnosis or heat as a causative agent. Heat related diseases included heat exhaustion, heat stroke, sun stroke, and heat cramps.

Mercury

Long-term exposure to mercury has not been measured in TVA historically. Short-term breathing zone samples have been taken while employees were engaged in mercury cleanup operations after a spill has occurred. These breathing zone samples were usually taken using a direct reading instrument such as the Johnson and Williams Model MV-2, and the General Electric Hg Vapor Detector. Area sampling for mercury was done using these two instruments also.

Some routine area sampling for mercury vapor was conducted in the instrument mechanics' shop where mercury containing equipment is repaired, and in mercury storage rooms.

When major mercury spills have occurred, urinary mercury levels have been occasionally measured and compared to expected values. The analysis for urinary mercury has been done by TVA laboratories using the equivalent to NIOSH P&CAM 145 (26). The results of the area sampling and urinalysis for mercury are summarized later.

Noise

Noise exposure data for coal-fired power plant employees were taken from historical industrial hygiene reports from 1975 to 1979. Most of the exposure data have the job titles or craft group listed with them, but 66 of the 428 eight-hour TWA exposures are for employees with unknown job titles. The personal exposures were measured using a slow response noise dosimeter as specified by the Occupational Safety and Health Administration's General Industry Regulations (27). The noise dosimeter predominantly used during the five years of monitoring was the General Radio Model 1944. If the exposure measurement period was reasonably long as compared to the exposure period (5 to 7 hours for an 8-hour shift), then the exposure was extrapolated to include the full exposure period.

The method of selecting employees for noise exposure monitoring was based on their likelihood of overexposure. That is, those employees expected to have the highest exposure levels were sampled, and those employees who were thought to have low exposure levels were not sampled. This also meant that certain craft groups were sampled much more frequently than others, and some craft groups were not sampled at all.

Ozone

There have been three general surveys conducted to measure ozone concentrations around the generation equipment in TVA's coal-fired power plants. Area sampling at points of predetermined grid was done using MSA detector tubes and hand pumps. All three surveys were conducted in 1978 at three different power plants.

Other ozone sampling has been conducted in TVA. It has been done to measure the ozone concentrations generated by arc welding processes. All of this sampling was conducted in the welders breathing zone level using MSA detector tubes and hand pumps.

Carbon Monoxide

General area surveys around units 2 and 3 of the Paradise power plant were conducted to assess the level of carbon monoxide given off by the units. Indicator tubes and hand pumps by MSA were used to survey all sides of the units on all of the enclosed elevations. The survey of unit 2 took place when it was in a steady state operating mode, and the survey of unit 3 took place while it was being fired up using #2 fuel oil.

STATISTICAL

The methods used for statistical presentation of the exposure data generated for this study were chosen for two main reasons: First, consensus acceptance of the methods as being appropriate and correct; and second, wide understanding of the statistics and their meanings. Mostly, data have been reduced to a measure of central tendency and a measure of the data dispersion. The recent trend in describing industrial hygiene data has been to assume it fits a log-normal frequency distribution, and to use the geometric mean (GM) and the geometric standard deviation (GSD) as the descriptors for the data population (28-31). Goodness-of-fit testing to the log-normal frequency distribution was tried for most data sets generated in this study when the data populations appeared to be homogeneous. Other frequency distributions such as the exponential, normal, and Weibull were tested, but in all cases when a single distribution could be used to describe a data set it was the log-normal distribution.

Most of the data analyses were done using the statistical package provided with the Tektronix Model 4051 Graphics System computer (32). The method (33) used in the Tektronix statistical package for testing and plotting log-normal frequency distributions is the same method recommended by Leidel (28) in NIOSH's Occupational Exposure Sampling Strategy Manual. Log-probability graphs presenting the cumulative frequency distribution for each data set were generated by the 4051 Graphics System along with the GM and GSD and the Kolmogorov-Smirnov goodness-of-fit test. Confidence limits (95 percent) were calculated for the mean exposure levels where appropriate.

There were some data sets that were gathered from nonhomogeneous populations. Analysis and presentation of these data were limited to simple tables or histograms.

The exposure data for respirable fly ash, SO_2, and NO_2 taken from the Johnsonville and Paradise power plants were analyzed to determine if there was a significant difference in exposure levels at each plant. This was done to test if the boiler draft design differences previously discussed had any effect on exposure. A two-sample t-test was used to determine if the geometric mean exposure levels of the corresponding craft groups were different ($\alpha = .05$) between Johnsonville and Paradise power plants. This test was part of the Tektronix statistical package also.

Over the past several years the results of analyses reported by TVA laboratories have been inconsistent when less-than-detectable levels of the analyte were found. Sometimes zero (0) values were reported, and other times less-than values were reported. In this report, all zero values were converted to less-than values, and then the statistical analysis was done using the nominal less-than value. An example of this would be respirable coal dust exposures reported as 0.0 mg/m^3. The zero value was changed to <0.1 mg/m^3 which TVA uses as the minimum quantifiable level for coal dust analysis, and when the statistical analysis was done the <0.1 mg/m^3 value was used as 0.1 mg/m^3 for calculation purposes. The obvious impacts of this manipulation are twofold: First, the inferred mean respirable coal dust exposure level is biased upward; and second, the frequency distribution of the data is skewed because the distribution of exposure levels below 0.1 mg/m^3 is censored. In some cases, the censored data have been the cause of rejecting goodness-of-fit tests on some of the frequency distribution analyses.

There are a few things that have to be kept in mind when reading the results from these statistical methods. First, even though attempts were made to eliminate bias from the data gathering phase of this study, it is not claimed that all bias was eliminated. As stated before, personal sampling for exposure levels was not done in a completely random manner due to practical restrictions, and even the statistical methods employed may not be the best possible ones to use. But even with these limitations, the results of this study reasonably estimate the exposure levels that can be expected in coal-fired power plants even though the level of significance is not known in all cases.

RESULTS

GENERAL

The presentation of the data in this section is meant to be as straightforward as possible, and attempts are made to give the logical comparisons and interpretations that would be beneficial to knowledgeable readers of this report. In many cases the reduced data are given as the arithmetic or geometric means and their associated standard deviations as well as the 95 percent confidence limits in order to allow the readers to make their own comparisons.

There is a large amount of information given in the tables and figures of this section, but the limitations and reservations concerning this information must be remembered. Those data of particular interest should be used only within the context of the conditions described in the narrative parts of this report.

EXPERIMENTAL

Coal Dust

In the six-year period during which well documented respirable coal dust exposures were taken at TVA coal-fired power plants, more than 700 eight-hour TWA's were measured for conveyor and dumper car operators. At some of the plants, employees having job titles such as tripper car operator and beltline attendant were included in this craft group. The exposure data were not equally distributed between the years and plants during the period, but because the coal processing equipment at all of the plants is essentially similar, it was decided that the exposure data population was homogeneous and it could be analyzed as such. The data have been broken down annually in Table 1 to determine if there was a trend in exposure over the six years. The GM's ranged from about 0.5 mg/m^3 in 1974 to about 1.2 mg/m^3 in 1976, and there does not appear to be any trend in the geometric mean exposure levels.

Table 1. Annual Respirable Coal Dust Exposure Levels at TVA Coal-Fired Power Plants

	No. of	Exposure		95% Conf. Limits (mg/m^3)	
Year	TWA's	GM(mg/m^3)	GSD	Lower	Upper
1974	81	0.5	3.9	0.37	0.67
1975	55	1.1	2.7	0.85	1.43
1976	415	1.2	2.4	1.01	1.31
1977	74	0.8	2.8	0.63	1.01
1978	23	0.8	2.6	0.54	1.18
1979	54	0.6	1.9	0.51	0.71
Combined	702	0.9	2.8	0.83	0.97

Figures 1-6 present log-probability plots for the annual respirable coal dust exposure data, and Figure 7 presents the log-probability plot for all of data combined. Table 2 gives the GM of the data separated by the power plant at which it was taken along with the corresponding GSD, sample size, and confidence limits. The minimum quantifiable used for respirable coal dust is 0.1 mg/m^3, and this is the value used for all exposure data that were reported as 0.0 mg/m^3 or <0.1 mg/m^3.

Table 2. Combined Respirable Coal Dust Exposure Data for 1974-1979 at TVA Coal-Fired Power Plants

Plant	No. of TWA's	Exposure GM (mg/m^3)	Exposure GSD	95% Conf. Limits Lower	95% Conf. Limits Upper
Allen	38	1.4	2.2	1.1	1.8
Bull Run	25	0.6	2.8	0.4	0.9
Colbert	40	0.4	2.7	0.3	0.5
Cumberland	49	0.9	3.1	0.7	1.2
Gallatin	43	0.4	3.7	0.3	0.6
Johnsonville	76	0.8	2.2	0.7	1.0
John Sevier	46	0.7	3.0	0.5	1.0
Kingston	66	1.1	2.8	0.9	1.4
Paradise	122	1.3	2.6	1.1	1.5
Shawnee	95	1.2	2.5	1.0	1.4
Watts Bar	58	1.0	2.2	0.8	1.2
Widows Creek	44	1.6	2.6	1.2	2.1
	702				

Another craft that has the potential for respirable coal dust exposures is the heavy equipment operator group that works on the coal storage pile. These employees are also referred to as pan scraper operators and dozer operators. The exposures of this group potentially have wide variability because of several reasons: First, the condition of the equipment cab where the operator sits; second, the season; and third, the meteorological conditions. If the equipment cab is air conditioned and has intact windows the level of coal dust exposure is decreased. Wintertime exposures should be lower than summer exposures because the cab of the equipment is closed to keep the operator warm. Meteorological conditions, such as precipitation and wind, also could limit or exaggerate the coal dust generated on the storage pile. Because of all these uncontrollable parameters, the respirable coal dust exposure data for heavy equipment operators were not combined into a true single population for analysis. If a sufficiently large number of samples were taken in a random manner and it was assumed that the variations in the equipment and meteorological conditions were random, then an exposure mean could be calculated.

Forty-one eight-hour TWA's were found for coal pile heavy equipment operators. The range of exposure was from less than 0.1 mg/m^3 to 6.8 mg/m^3. The concentrations for the heavy equipment operators compares reasonably well to those for all of the conveyor and dumper car operators. Even though the 41 personal samples of respirable coal dust are probably not representative of the heavy equipment operators coal dust exposure for all of TVA, a geometric mean and geometric standard deviation has been calculated for discussion reasons, GM = 0.5 mg/m^3 and GSD = 2.6.

Other TVA craft groups could have respirable coal dust exposure if their jobs require that they work within the coal processing system. But the exposure for these additional crafts would not be regular in nature. Powerhouse laborers have the potential for the greatest nonregular exposure because of the clean-up activities that they perform in the coal system. Insufficient exposure data were found for the powerhouse laborers to provide an estimate of their respirable coal dust exposure.

The crystalline silica content of the coal that TVA purchases is highly variable because of the large number of sources for the coal. The range of crystalline silica percentage found was relatively large from less than 1 percent to 9 percent. The OSHA standard for respirable coal dust containing less than 5 percent crystalline silica is 2.4 mg/m^3 while the standard for coal having 9 percent silica is calculated as 0.9 mg/m^3 (27). Ranges of crystalline silica contents found in air samples for coal dust at TVA's power plants are given in Table 3. Other reports of free silica in coal have overall ranges of less than 1 percent to almost 10 percent (34).

As with crystalline silica, the sulfur content of the coal that TVA uses varies with each source, although not as greatly as does the silica. Historically, TVA has tried to negotiate long-term coal delivery contracts for the power plants. These contracts had the effect of stabilizing the sulfur content of the coal received; but recently, TVA has tried to purchase low sulfur coal in order to help meet SO_2 emission standards. Short-term contracts are more frequent now (8) and the sulfur content of the coals will probably have more variability. The Johnsonville plant receives most of its coal by barge and railroad from multiple sources, while Paradise receives almost all of its coal from a nearby mine by beltline directly to the coal storage area. The sulfur content of the bulk coal is regularly measured at each plant, and the lifetime histories of sulfur content for Paradise and Johnsonville power plants are given in Figures 8 and 9. Although the average sulfur content of Paradise (4.6%) coal is a little higher than that for Johnsonville (3.9%), the variation at Paradise is less, reflecting the predominant single source.

Table 3. Crystalline Silica Content of Airborne Coal Dust at TVA Coal-Fired Power Plants

Plant	Crystalline Silica* (%)
Allen	1.5 - 6.5
Bull Run	1 - 2
Colbert	1 - 4.5
Cumberland	1 - 4
Gallatin	ND**
Johnsonville	1 - 5
John Sevier	ND
Kingston	<1 - 9
Paradise	1 - 5
Shawnee	1 - 5
Watts Bar	<1 - 8
Widows Creek	<1 - 8

*Crystalline silica analyses were performed on air samples taken by industrial hygiene personnel.

**No data.

Fly Ash

The results of the personal sampling for respirable fly ash conducted during the twelve trips to both Johnsonville and Paradise power plants are given in Figures 10-23. These log-probability plots present the distributions of the 8-hour TWA's for each craft group at each plant. Some of the craft group frequency distributions for personal exposure to respirable fly ash failed the goodness-of-fit tests for the log-normal distribution. Seven of the fourteen frequency distributions did not satisfy the Kolmogorov-Smirnov goodness-of-fit criteria at $\alpha = 0.05$, and five of the fourteen did not pass at $\alpha = 0.01$ (35). The meaning of the significance level for this goodness-of-fit test is that at $\alpha = 0.05$ there is a 5 percent chance of falsely rejecting the distribution as being a log-normal distribution and at $\alpha = 0.01$ there is a 1 percent chance of falsely rejecting it. Even though five of the distributions could be rejected, the goodness-of-fit of these distributions to the log-normal was better than any of the other distributions that were investigated. Table 4 lists the fourteen craft groups and whether or not they passed the goodness-of-fit criteria for the log-normal distribution.

The geometric mean exposure levels of the craft groups were all in the same order of magnitude; the GM's ranged from 0.20 mg/m^3 for the Johnsonville machinists to 0.50 mg/m^3 for the Johnsonville boilermakers. The GSD's of these respirable fly ash exposure distributions range from 2.3 to 3.5. As part of the analysis of the fly ash exposure data, the data for the same craft group at the two power plants were tested against each other to determine if there was a significant difference in exposure level at the two plants. A 2-sample T-test for equality of means was used to estimate the significance of the difference of the GM's for each set of craft groups. Table 5 presents the GM, GSD, sample size, and the two-tail significance level for the difference of the GM's.

It can be seen on Table 5 that the respirable fly ash exposure levels are significantly higher at the Paradise power plant for four of the seven craft groups, and there is no significant difference in exposure levels for the other three craft groups. There do not appear to be any reasons why some of the craft groups at Paradise have greater exposures than their Johnsonville counterparts and other craft groups do not. It was hypothesized at the beginning of this study that the positive pressure design of the units at Paradise could cause greater exposure to combustion products than at Johnsonville, but with just four of the seven craft group exposure levels significantly higher at Paradise this hypothesis is only vaguely supported. Figure 24 graphically presents the comparisons of craft group fly ash exposure levels.

Since this study was the first large scale investigation of respirable fly ash exposure in TVA, it is of interest to note that the levels of exposure are substantially below the 5 mg/m^3 standard required by OSHA and recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) for respirable nuisance dust. It should be noted that there is no basis for assuming that fly ash should be classified as a nuisance dust; it could be regulated based on its hazardous constituents, singly or together. The exposure levels are also well below the ACGIH proposed standard of 3 mg/m^3 for amorphous silica (36). Of the 675 8-hour TWA's for respirable fly ash, only nine of the TWA's were greater than 5 mg/m^3. At this time, no other fly ash sampling results have been found to compare against these findings to determine if they are representative of average exposure levels for the industry.

Size distribution data on fly ash were gathered using an Andersen Cascade Impactor. Eight samples were taken at the Johnsonville power plant and ten samples were taken at Paradise. The size distributions established by this sampling are given in Figures 25-33. Each of these figures present two size distributions, one for about six hours and the other for about twenty-four hours, and both sampling periods were during the same sampling trip.

All of the size distributions appear reasonable except the 5.1 hour sample taken November 5, 1979, at the Paradise steam plant. Even though this particular size distribution is presented in Figure 29, it is probably a nonvalid sample because no particulate loading was found on the last four stages of the impactor or on the final filter. This nonloading condition is highly unlikely, if it could happen at all. No specific reason was found to discard this size distribution, so it is presented with the rest of them, but its usefulness is doubtful.

Table 4. Results of Goodness-of-Fit Testing of Respirable Fly Ash Exposure Data to the Log-Normal Frequency Distribution

Craft Group	Power Plant	Log-Normal Distribution $\alpha = 0.05$	$\alpha = 0.01$
Laborers	Johnsonville	Yes	Yes
	Paradise	Yes	Yes
Instrument Mechanics	Johnsonville	No	No
	Paradise	No	Yes
Boilermakers	Johnsonville	Yes	Yes
	Paradise	Yes	Yes
Operators	Johnsonville	No	No
	Paradise	Yes	Yes
Steamfitters	Johnsonville	No	No
	Paradise	Yes	Yes
Machinists	Johnsonville	No	No
	Paradise	No	Yes
Electricians	Johnsonville	No	No
	Paradise	Yes	Yes

Table 5. Results of Respirable Fly Ash Exposure Monitoring for Seven Craft Groups at Johnsonville and Paradise Power Plants

Craft Group	Plant	GM (mg/m^3)	GSD	N	Level	Significant Difference
Operators	J*	0.21	2.3	48	0.011	Yes
	P**	0.37	3.2	55		
Electricians	J	0.23	2.5	49	0.011	Yes
	P	0.40	2.8	44		
Machinists	J	0.20	2.4	49	0.006	Yes
	P	0.40	3.5	48		
Instrument Mechanics	J	0.21	2.4	47	0.057	Marginally
	P	0.33	3.0	47		
Steamfitters	J	0.24	2.4	49	0.179	No
	P	0.32	2.7	46		
Boilermakers	J	0.50	3.2	48	0.326	No
	P	0.40	2.8	48		
Laborers	J	0.37	3.1	49	0.727	No
	P	0.40	2.7	48		

*Johnsonville
**Paradise

The mass median aerodynamic diameters (MMAD) of these fly ash size distributors are given in Table 6.

The fly ash size distributions at Johnsonville have a relatively narrow range of MMAD's from 2.6 to 8.6 μm, but the range of MMAD's at Paradise is much wider, 0.35 to 14.4 μm. Most of the previous size distribution analyses reported in the literature have not been based on airborne sampling in the workplace environment; but they have collected bulk fly ash samples from plant mechanical collectors, electrostatic precipitators, and by stack sampling (37-40). The bulk fly ashes were then sized by aerodynamic or optical methods. This method would yield biased size distributions if it was used to estimated the size distributions of fly ash in the workplace environment.

Table 6. Fly Ash Size Distributions at Johnsonville and Paradise Power Plants

Plant	Date	Sampling Period (Hrs)	Mass Median Aerodynamic Diameter (μm)
Johnsonville	12/3/79	6.3	5.1
	12/4/79	24	5.1
	1/7/80	6.1	4.2
	1/8/80	24	8.6
	1/28/80	6.9	3.1
	1/29/80	24	3.2
	2/25/80	5.8	2.6
	2/26/80	24	4.3
Paradise	11/5/79	5.1	*
	11/6/79	**	1.6
	12/10/79	4.0	7.2
	12/11/79	24	6.7
	1/14/80	6.7	3.8
	1/15/80	24	2.0
	2/4/80	6.8	0.35
	2/5/80	24	0.48
	3/3/80	5.8	12.3
	3/4/80	24	14.4

*Questionable sample, previously discussed.
**Unknown sampling period, sample pumped turned off by power plant employee.

Although MMAD's are given for each impactor sample taken, the GSD's of the size distributions have not been calculated. The GSD's were not calculated because on many of the log-probability graphs the 84.1% and the 15.9% probability point are on an extrapolated portion of the curve. The curves were drawn by sight through the points and the extreme ends of the scale were weighted very lightly, if at all. Also, several times the MMAD's were read from an extrapolated portion of the curve making the GSD calculation even more questionable.

The analyses of the fly ash samples for polynuclear aeromatic hydrocarbons (PAH's) did not produce any measurable quantities of the five PAH's that were investigated. Due to a technical problem with the fluorescence detector of the high pressure liquid chromatograph (HPLC), a preliminary set of analyses was conducted using an ultraviolet (UV) detector at 254 nanometers wavelength. These preliminary analyses showed a definite peak where benzo (a) pyrene (BaP) was expected to be located for all eight fly ash samples. But none of the other four PAH's were identified using the UV detector.

After the fluorescence detector was repaired, duplicate analyses were run to confirm the preliminary results, but there were no PAH peaks identified, not even the BaP peak. These contradictory results caused the samples to be run again using the fluorescence detector, because fluorescence is the specified method. Again, there were no recognizable PAH peaks found for any of the samples. The chemist that performed all of the analyses could not explain the presence of the peak located where BaP was expected to be eluded from the chromatographic column when UV detection was used.

Polynuclear aromatic hydrocarbons, in particular BaP, have been identified in some of the ash of coal-fired industrial boilers as reported in an EPA study (41). The concentrations of BaP and other PAH's were low, and these species were found only in bottom ash or collector ash and not in the fly ash taken by stack sampling. In a 1967 study by the Public Health Service (PHS) that investigated the general sources of PAH's (42), the PHS concluded that the low BaP emissions found from coal-fired power plants burning pulverized coal are due to the high combustion efficiency; and that the combustion efficiency is the primary controlling factor for BaP emissions. The EPA study supports this conclusion.

There have been many investigations into the elemental composition of coal ash, and, as previously mentioned, these studies have concentrated on ash sample taken from the furnace bottom, fly ash collectors, and stack sampling. The elemental composition analysis for this study was done on total airborne fly ash, found in the powerhouse, and collected by high volume sampling.

Eight high volume samples were taken, four each at Johnsonville and Paradise. Table 7 gives the details of each of the samples, and Table 8 gives the elemental composition of the eight samples and two blanks.

The results from the four samples from each plant should not be over-interpreted, that is, since there is substantial variation in the relative compositions, the results should be used only as indicators of the order of magnitude concentrations of the elements and not as representative mean values.

Another aspect of elemental composition that has been addressed by other investigators is the particle size dependency of elements in fly ash particulate (37-39). It has been shown with great certainty that due to the vaporization and condensation processes occurring in the furnaces and exhaust gas systems, specific elements are preferentially concentrated in particles of certain sizes. The elemental analysis for elemental composition in the study did not take into account the fly ash particle size when the analyses were conducted.

Table 7. Information on High Volume Samples Analyzed for Elemental Composition

Filter Number	Plant	Net Wt.(mg)	Fly Ash Concentration (mg/m^3)
01529 (blank)	Johnsonville	-	-
01521	Johnsonville	167	0.23
01523	Johnsonville	360	0.45
01525	Johnsonville	170	0.56
01527	Johnsonville	1,413	0.95
01495(blank)	Paradise	-	-
01485	Paradise	2,078	1.9
01487	Paradise	400	0.59
01488	Paradise	459	0.27
01491	Paradise	1,319	0.77

In order to compare the magnitudes of the elemental compositions presented in Table 8, portions of the results of another investigation (43) are given in Table 9. These compositional results came from the analyses of bottom ash produced by burning a medium volatile bituminous coal.

Table 8. Elemental Composition of Fly Ash Taken by High Volume Sampling in the Powerhouse

Elemental Concentration (net ppm wt*)

Sample	Al	As	B	Ba	Be	Ca	Cd	Co	Cr	Cu	Fe	K	Mg	Mn	Na	Ni	Pb	Sn	Ti	V	Zn
01529 (blank)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
01521	12,900	140	**	48	14	6,100	8	140	84	2,950	32,800	1,020	**	930	**	290	570	2,870	550	78	2,480
01523	14,900	150	**	140	7	7,000	7	67	39	300	28,400	2,300	**	500	**	130	270	1,300	940	110	760
01525	6,350	31	**	120	14	3,600	8	140	82	220	15,200	700	**	260	**	280	560	2,820	490	45	620
01527	17,500	130	14	210	3	10,800	9	17	39	340	28,400	3,140	990	310	**	68	45	340	1,040	140	500
01495 (blank)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
01485	19,600	200	**	45	5	5,920	12	12	160	410	47,900	5,490	790	99	**	23	51	230	1,280	180	420
01487	54,900	430	1,730	540	60	1,000	24	60	190	180	36,200	4,750	**	96	**	120	130	**	3,010	250	560
01488	9,850	150	**	**	52	**	8	52	55	1,860	36,300	2,420	**	200	**	100	120	1,050	770	81	120
01491	16,600	130	520	160	18	14,000	10	18	140	860	59,700	4,790	1,900	230	1,740	36	190	360	910	100	1,200

*Blank values for each element have been subtracted before ppm wt was calculated
**Less than or equal to blank values.

Table 9. Range of Trace Elements Present in Coal Ash from Medium Volatile Bituminous Coal (43)

Element	Max.	Min.	Concentration (ppm wt) Average, (7 samples)
B	780	74	218
Ba	1,800	230	896
Be	31	4	13
Co	290	10	105 (6 samples)
Cr	230	36	169
Cu	560	130	313
Mn	4,400	125	1,432
Ni	440	20	263 (6 samples)
Pb	210	52	96
Sn	160	29	75
V	860	170	390
Zn	460	50	195 (6 samples)

Even though Table 9 presents the composition of bottom ash, the results of the fly ash composition are within reasonable agreement of them.

Analyses for radioactivity were conducted on four high volume samples taken at both Johnsonville and Paradise power plants. There were seven analyses conducted; and of these seven, the analyses for ^{210}Po, ^{226}Ra, and Th did not detect any significant levels of these radionuclides. The other four analyses for total U, ^{210}Pb, gross α, and gross β did produce levels of activity significantly above background levels. But it should be kept in mind that these activity levels are still insignificant when compared to maximum permissible concentrations (MPC) for nonoccupational exposures (44). Results of the radionuclide determinations are given in Table 10, all concentrations are given as picocuries per cubic meter (pCi/m^3) except for U which is given as micrograms per cubic meter ($\mu g/m^3$).

One of the samples taken at Paradise (sample #006549-0) has significantly higher levels of α, β, and U than any of the other samples taken at either Johnsonville or Paradise. The details of sample #006549-0 were examined to determine if there was a reason for the activity levels of this sample to be two to fifteen times greater than the other ones and no reason was found.

The levels of airborne uranium found in the power plant are about 0.001% of the ACGIH recommended standard for total uranium, and about 0.04% of the OSHA standard for soluble uranium.

Table 10. Radionuclide Concentrations Measured from High Volume Fly Ash Samples Taken in Johnsonville and Paradise Power Plants

Sample	Plant	Radionuclide Airborne Concentrations α(pCi/m^3)	β(pCi/m^3)	U(μg/m^3)	^{210}Pb(pCi/m^3)
Blank	-	0.0001	0.0046	0.0001	0.001
006542-5	Johnsonville	0.0018	0.0158	0.0027	0.018
006543-3	Johnsonville	0.0050	0.0200	0.0039	0.033
006544-1	Johnsonville	0.0062	0.0322	0.0022	0.029
006545-8	Johnsonville	0.0048	0.0213	0.0021	0.030
006546-6	Paradise	0.0035	0.0178	0.0034	0.017
006547-4	Paradise	0.0057	0.0216	0.0084	0.014
006548-2	Paradise	0.0018	0.0173	0.0022	0.024
006549-0	Paradise	0.0140	0.0580	0.0352	0.046

Reports of other investigations have identified potassium-40 as a radionuclide being present in all types of coal and fly ash (45,46). The range of ^{40}K activity that was reported is 0.73 to 7.4 pCi/g. This compares to the combined ^{238}U and ^{236}U activities of 0.36 to 12.5 pCi/g from the same ash samples. The activity of ^{40}K was not measured in these fly ash samples.

When compared to the nonoccupational MPC for ^{210}Pb listed in 10 CFR 20, the average annual exposure to ^{210}Pb at Johnsonville and Paradise would be about 1%.

Sulfur Dioxide

Comparative results of personal sampling for SO_2 at Johnsonville and Paradise are given in Figures 34-40. Each of these histograms shows the exposure frequencies of the same craft group at each power plant. At Johnsonville there were 161 of 168 samples that were nondetectable and at Paradise there were 259 of 341, 96 percent and 76 percent respectively. The minimum detectable level of the Draeger four-hour indicator tube is 0.2 ppm integrated over the four-hour period; and this means the minimum detectable level for an eight-hour TWA is 0.1 ppm.

Even though there were a large number of nondetectable SO_2 measurements at Paradise, cumulative frequency distributions were generated using the truncated or trimmed data technique. This technique is based on the assumption that the frequency distribution is continuous both above and below the point of truncation, which in this case is the minimum detectable level of the Draeger SO_2 tube. Using the detectable samples for each craft group, frequency distributions were calculated and extrapolated below the minimum detectable level to include all nondetectable data points. The GM and GSD for these frequency distributions are given in Table 11.

It can be seen from Table 11 that the geometric mean exposure level for each craft is very low ranging from 0.06 ppm to 0.16 ppm. These facts are significant but not very interesting. The effect of the very large GSD's for instrument mechanics, electricians, and operators is that it allows for the prediction of some level of overexposure to SO_2 for these crafts. Based on these frequency distributions, approximately two percent of the instrument mechanics', two percent of the laborers', seven percent of the electricians', and eight percent of the operators' personal samples can be expected to show concentrations greater than the 5 ppm OSHA standard. Figures 41-47 present the log-probability graphs for the frequency distributions for the seven Paradise craft groups' SO_2 exposure generated by the trimmed data analysis technique. The hypothesis that the SO_2 exposures at each plant would be related to the sulfur content of the coal was not supported.

Table 11 presents a breakdown of the detectable SO_2 exposures of craft groups at the Paradise power plant.

The exposure results indicate that the Paradise power plant, being positive pressure, has a much greater potential for creating high SO_2 exposure areas than the balanced draft Johnsonville power plant. These data also show that when exposure occurs at Paradise it tends to be substantial, and this is supported by the results of the worst-case area sampling conducted there.

Table 11. Detectable SO_2 Exposures for Craft Groups at Paradise Power Plant

Craft	Total Samples	Detectable Samples			
		Number	Percent	GM(ppm)*	GSD*
Boilermakers	48	11	23	0.11	4.6
Steamfitters	49	11	22	0.06	5.1
Machinists	46	8	17	0.13	5.0
Electricians	48	11	23	0.07	12.5
Laborers	48	18	38	0.16	5.0
Instrument Mechanics	48	13	27	0.09	7.3
Operators	54	18	33	0.07	14.7

*Extrapolated from trimmed data analysis.

Table 12 shows the high area concentrations found close to a large leak in the flue gas duct system leading to the electrostatic precipitator for the unit. Although these concentrations were found in areas that are normally accessible to employees, there were no employees in the area at the time of sampling. Respiratory protection was worn by industrial hygiene personnel while this area sampling was done.

Table 12. Results of Worst-Case Area Sampling for SO_2 at Paradise Power Plant Using Draeger Long-Term Indicator Tubes

Sequential Sampling: 3/14/79, Elevation 461.5, So Unit 3

Sample	Time		Δ Time (min.)	Flowrate (ml/min.)	Conc. (ppm)
1	Start:	7:48	28	15	83
	Stop:	8:16			
2	Start:	8:16	18	15	100
	Stop:	8:34			
3	Start:	8:34	27	15	84
	Stop:	9:01			
4	Start:	9:01	24	15	86
	Stop:	9:25			
5	Start:	9:25	27	15	77
	Stop:	9:52			
Replicate Sampling: 3/15/79, Elevation 497, SW Unit 3					
1	Start:	7:54	52	15	44
	Stop:	8:46			
2	Start:	7:54	52	15	41
	Stop:	8:46			
3	Start:	7:54	52	15	40
	Stop:	8:46			
4	Start:	7:54	52	15	42
	Stop:	8:46			
5	Start:	7:54	52	15	37
	Stop:	8:46			Average 41 ppm
6	Start:	8:49	57	15	41
	Stop:	9:46			
7	Start:	8:49	57	15	40
	Stop:	9:46			
8	Start:	8:49	57	15	40
	Stop:	9:46			
9	Start:	8:49	57	15	37
	Stop:	9:46			
10	Start:	8:49	57	15	42
	Stop:	9:46			Average 40 ppm

During a later trip to Paradise, a grid area sampling protocol was conducted around unit 3 to determine the maximum concentration found at that time. Short-term MSA detector tubes were used, and the range of concentrations found was 0 to 15 ppm. The difference in the concentrations was due to maintenance of the boiler and patching of flue gas leaks.

Worst-case sampling at Johnsonville yielded a maximum area concentration of 0.2 ppm with more than 95 percent of the samples being nondetectable.

It was suspected that sulfur species other than SO_2 could be present in the power plants. The impregnated filter method developed by Eller at NIOSH was used to sample for SO_2 and the sulfite and sulfate particulates. Area sampling was done at both Johnsonville and Paradise to determine the concentration of these species. One technical problem developed that totally interferred with the sulfite analysis, polyvinyl chloride (PVC) filters were used as the first stage particulate filter of the samplers. The PVC caused a nitrate interference with the ion chromotography analysis for sulfites. Results for the SO_2 and sulfate are given in Table 13.

Table 13. Area Sampling Results for Sulfur Dioxide, Sulfites and Sulfates Using Impregnated Filter Samples

Sample	Temp. (^{o}C)	Location	SO_2 (ppm)	SO_3 (mg/m^3)	SO_4 (mg/m^3)
Johnsonville Power Plant, March 17 - March 19, 1980					
1	32	Unit 5, Level 5	<0.04	-	<0.10
2	32	Unit 5, Level 5	<0.04	-	<0.10
3	31	Unit 4, Level 5	<0.04	-	<0.10
4	31	Unit 4, Level 5	<0.04	-	<0.10
5	31.5	Unit 4, Level 5	<0.04	-	<0.10
6	31.5	Unit 4, Level 5	<0.04	-	<0.10
Paradise Power Plant, March 24 - March 26, 1980					
1	31	Unit 3, Level 4	2.9	-	0.27
2	31	Unit 3, Level 4	2.2	-	0.28
3	31	Unit 3, Level 4	5.6	-	0.42
4	31	Unit 3, Level 4	5.3	-	0.50
5	29	Unit 1, Level 4	1.1	-	0.14
6	29	Unit 1, Level 4	0.9	-	0.11
7	26	Unit 2, Level 4	<0.04	-	0.11
8	26	Unit 2, Level 4	<0.04	-	<0.10

There was a substantial amount of unreported SO_2 personal sampling conducted at three of TVA's coal-fired power plants in 1976 and 1977. The Abcor Gasbadge passive SO_2 samplers were used to measure 178 eight-hour TWA's at the Allen plant, 1951 TWA's at Cumberland, and 1365 TWA's at Paradise. Only powerhouse workers were sampled during these investigations. The SO_2 Gasbadge has a minimum detectable level of 0.5 ppm integrated over an eight-hour period, and the analysis was done at the Abcor laboratories for all samples. More than 65 percent of the personal exposures at Allen were below the 0.5 ppm minimum detectable level while at Cumberland almost 88 percent were below it and at Paradise more than 87 percent were below it. This compares to 76 percent below the 0.1 ppm minimum detectable level at Paradise for this study. The percentage of undetectable personal exposures for each of the two studies qualitatively appears comparable when the difference in the minimum detectable levels is taken into account.

Oxides of Nitrogen

Nitrogen dioxide (NO_2) was not found in any appreciable levels by either personal or area sampling. The concentrations reported from the analytical laboratory were only slightly different than the blank levels reported, and there were two instances when the blanks were actually higher than any of the exposed samplers. Because of not finding any NO_2 exposure, personal sampling for NO_2 was ended after the third trip to each power plant.

Since nitric oxide (NO) is a direct combustion product, it was decided to conduct some worst-case area sampling for NO using the triethanolamine (TEA) tubes developed by Willey et. al. at NIOSH (47). The tubes were commercially manufactured by SKC, Inc. As a reference to detect any NO_2, the Saltzman (21) liquid impinger method was used along with the TEA tubes. The results of the area sampling at Johnsonville and Paradise power plants are given in Table 14.

Based on the significant amount of NO found at the Paradise power plant, a limited personal sampling survey was conducted to determine the employee exposure levels to NO. The craft groups selected for NO sampling were chosen because of their relatively high sulfur dioxide exposure levels. It was anticipated that these groups would have the highest NO exposure because both gases are direct combustion products. The steamfitters, laborers, and instrument mechanics were sampled during two trips. Three or four employees of each group were monitored during each trip using the TEA tubes produced by SKC, Inc. Both sections of the tubes were analyzed giving NO_2 as well as NO exposure levels. The results of this sampling is given in Table 15. It shows that the NO exposure was greater than NO_2 exposure, but they were not close to the area concentrations previously found.

Table 14. Area Sampling Results for NO and NO_2 Using TEA Tubes and Saltzman Liquid Impinger Methods

Sample	NO (ppm) TEA Tube	NO_2 (ppm) TEA Tube	NO_2 (ppm) Impinger
Johnsonville Power Plant, July 17 - July 18, 1979			
1	1.0	<0.2	0.03
2	1.3	<0.2	0.04
3	1.3	<0.2	0.16
4	1.3	<0.2	0.02
Average	1.2	<0.2	0.06
5	1.3	<0.2	0.02
6	1.3	<0.2	0.11
7	1.0	<0.2	0.03
8	1.0	<0.2	0.02
Average	1.2	<0.2	0.05
Paradise Power Plant, March 12 - March 15, 1979			
1	7.8	<0.2	0.03
2	5.5	<0.2	0.08
3	8.7	<0.2	0.12
4	7.4	<0.2	0.05
Average	7.4	<0.2	0.07
5	46.3	<0.2	0.28
6	32.3	<0.2	0.11
7	36.3	<0.2	0.24
8	51.4	<0.2	0.91
Average	41.6	<0.2	0.39
9	30.4	<0.2	0.28
10	30.4	<0.2	0.35
11	5.2	<0.2	0.25
12	35.4	<0.2	void
Average	25.4	<0.2	0.29
13	11.1	<0.5	0.12
14	16.5	<0.5	0.07
15	16.5	<0.5	0.11
16	16.5	<0.5	0.11
Average	15.2	<0.5	0.10

Table 15. Personal Sampling to Determine Exposure Levels of Nitric Oxide and Nitrogen Dioxide Using TEA Sorbent Tubes

Date	Craft	8-Hour TWA's NO (ppm)	8-Hour TWA's NO_2 (ppm)
2/4/80	Steamfitters	0.85	<0.2
		0.48	<0.2
		5.0	0.34
		<0.2	<0.2
2/5/80	Laborers	1.1	<0.2
		2.2	<0.2
		1.2	<0.2
		3.6	<0.2
2/6/80	Instrument Mechanics	1.0	0.88
		1.2	<0.2
		1.2	<0.2
		3.6	<0.2
3/3/80	Steamfitters	<0.2	<0.2
		<0.2	<0.2
		<0.2	<0.2
		<0.2	<0.2
3/4/80	Laborers	0.76	<0.2
		<0.2	<0.2
		<0.2	<0.2
3/5/80	Instrument Mechanics	<0.2	<0.2
		0.65	<0.2
		<0.2	<0.2

Asbestos

Unlike the respirable coal dust data extracted from industrial hygiene records which were determined to be homogeneous, the asbestos exposure data pulled from the files are known to have a bias. Over the past decade, TVA has tried to eliminate as much asbestos as possible from its operations, and there has been great success in finding and using substitute materials for the vast amount of thermal insulation material used in coal-fired power plants (48). This concentrated effort has been very effective in decreasing the asbestos exposure levels for insulation workers and all personnel working nearby. It should be noted that during all asbestos operations in TVA's coal-fired power plants, respiratory protection and protective clothing are required so the data presented in this report are exposure data and not necessarily dose related.

Almost 700 eight-hour TWA exposure levels were found for asbestos workers and possibly for some powerhouse laborers that help in clean-up operations. The laborers could be included because some of the asbestos exposure data did not have the job or craft title of the employees sampled. Figures 48-54 give log-probability plots of the exposure data by year from 1973 to 1979. For the most part, the annual asbestos data fit the log-normal frequency distribution very well. The geometric means of the annual data show a substantial decrease in exposure levels from about 1.1 fibers per milliliter (f/ml) in 1973 to about 0.05 f/ml in 1979. The geometric standard deviations for the seven years are reasonably similar and quite large averaging about 4.1. This means that there is a wide variation in exposure levels, and there is still small probability that an overexposure to asbestos can be found in TVA. For comparison purposes, all of the GM's, GSD's, and sample sizes are presented in Table 16.

The asbestos exposure levels in Table 16 are the GM's of worst-case sampling, and they are not the continuous exposure levels found in TVA. Personal samples were taken only when known asbestos work was being conducted. The majority of the time, TVA asbestos workers handle non-asbestos bearing material so that typical daily asbestos exposure levels are essentially zero.

The minimum quantifiable level for an eight-hour TWA asbestos exposure used in TVA is 0.01 f/ml even though the minimum quantifiable level per filter listed in NIOSH P&CAM 239 is 0.1 f/ml. The TVA sampling procedure for asbestos requires that multiple filters must be used in sequence over the sampling period. The sampling time per filter usually runs 15-30 minutes, and in most cases 5-12 filters are used to determine a single eight-hour TWA. Consequently, if only one filter gives a concentration of 0.1 f/ml and all of the rest are below 0.1 f/ml then the TWA would be calculated below 0.1 f/ml for that employee.

It was not possible to compare the annual exposure levels at the different power plants because of too small data sets at several of the plants, but it was felt that combining the data into a single population was possible because the asbestos work at each plant is very similar. Currently, the majority of the asbestos exposures occurring in TVA comes from removing old thermal insulation during repair work.

Table 16. Annual Asbestos Exposure Levels for Asbestos Workers in TVA Coal-Fired Power Plants

Year	Number of TWA's	Exposure GM (f/ml)	Exposure GSD	Confidence Limits Low	Confidence Limits High
1973	115	1.1	4.2	0.85	1.4
1974	67	0.73	4.3	0.54	1.0
1975	30	0.29	4.9	0.16	0.51
1976	176	0.22	4.8	0.17	0.28
1977	84	0.03	2.7	0.02	0.04
1978	60	0.06	4.0	0.04	0.09
1979	153	0.05	4.1	0.04	0.06

Very little asbestos exposure data are available for the years before 1973. The OSHA asbestos standard issued in June 1972 (47) was the reason that TVA's asbestos monitoring program began in early 1973. During the years 1958-1970, area concentrations of asbestos were occasionally measured using one of three methods: (1) Bausch and Lomb Dust Counter; (2) Southern Research Institute's Aerosol Photometer; and (3) the impinger collection and microscopic count.

During this time period the standard units used to describe airborne particulate loading were millions of particles per cubic foot (mppcf), and all three of the above methods reported concentrations in mppcf. Also, these three methods were not fiber specific, all particles were counted when the samples were analyzed.

The types of exposures that were usually included were power saw cutting of 30 percent asbestos Transite board, Limpet spraying of asbestos materials, and mixing and working with asbestos cements. Various engineering control methods were investigated to suppress the dust generation from Transite cutting during the early 1960's.

Table 17 gives some descriptive information as well as the measured dust concentrations for the asbestos monitoring that took place before 1973. Because of the different sampling and analytical methods there is not a satisfactory method of converting these old data into equivalent concentrations based on the current sampling and analysis techniques. As presented in Table 17, the concentrations are for area samples except for two personal samples taken on Limpet spray operators. It is the opinion of the TVA industrial hygienists who have observed the Limpet spray operation that the spray operators probably had the highest potential peak asbestos exposure of any TVA employees working with asbestos, but there are no substantial exposure data to document this type of exposure.

The exposure described from Transite cutting and Limpet spraying cannot be assigned to the asbestos workers at TVA's coal-fired power plants. The majority of both the Transite cutting and Limpet spraying were conducted during the construction of the power plants, and the construction and operations workforces were not necessarily the same, although some construction employees did continue into the operations workforce and their previous asbestos exposures were significant.

The general impressions of the industrial hygienists who worked for TVA during the 1960's and early 1970's are that some of the modes of routine asbestos exposure, such as thermal insulation removal, during this early time period were probably similar to those modes of exposures that were found during the 1973 personal monitoring program, but the other routine modes of early asbestos exposure were completely different from operation observed in 1973. Specifically, asbestos bearing insulation was no longer required by TVA's engineering design group. Since the frequency and modes of handling asbestos prior to 1973 were greater and less controlled, it is the consensus opinion of TVA's long standing industrial hygienists that the asbestos exposure levels before 1973 were probably higher than found in 1973, or later, and that there were more and higher peak exposure levels than during the 1973, or later, monitoring. Because of the inadequacy of early sampling methods and records, there is no way of documenting these impressions and opinions.

Table 17. Results of Asbestos Monitoring that was Conducted Before 1973 in TVA

Location/Date	Activity	Sampling Method/ Number of Samples	Concentration (mppcf)
Paradise Steam Plant/ January 17-18, 1962	Cutting Transite using radial arm saw and water jet control during plant construction	B&L Dust Counter/14	2.8 to 8.1
Paradise Steam Plant/ May 5-6, 1962	Cutting Transite using hand held circular saw with water jet control	B&L Dust Counter/8	0.8 to 18.2
Gallatin Steam Plant/ July 15, 1964	Mixing and applying asbestos cement	SRI Aerosol Photometer/5	3 to 15
Colbert Steam Plant/ Unknown Date	Cutting Transite using down draft table per Occupational Health Branch Drawing #408	B&L Dust Counter/13	1.3 to 26.1
Unknown Location and Date	Letter from Derryberry to Clifton, March 27, 1968:		
	1. Installing turbine insulation	SRI Aerosol Photometer/unknown number	3.8 to 7.0
	2. Limpet spraying during 1964-1965	SRI Aerosol Photometer/unknown number	20 to 100
		B&L Dust Counter/ unknown number	21.4 to 24
	3. Personal samples of Limpet spray operations	Midget impinger/2	12.6 and 27.1

Heat Stress

In the 14-year period from 1966 to 1979 there were 63 cases of heat related occupational disease (OD) reported in TVA coal-fired power plants. There were 55 cases diagnosed as heat exhaustion and the remaining eight were heat cramps and heat overexposure as reported on TVA 1890's, Report of Injury or Illness. The reported cases were evenly distributed through the whole 14-year period.

Three of the plants, Allen, Colbert, and Shawnee, had 42 of the cases, leaving the other 21 distributed over eight plants, and two plants reporting no heat related OD's. There were no environmental data reported for any of the OD's so there could not be any correlation determined between the adverse health effects and working conditions.

Mercury

Breathing zone concentrations of mercury for employees cleaning up mercury spills are not given in this report. It is felt that reporting these concentrations could seriously mislead readers by suggesting that the concentrations were the same as personal exposures. When mercury clean-up operations are conducted at TVA plants, the employees are required to wear respiratory protection until the area sample concentrations are below 0.05 mg/m^3 which is the standard for mercury vapor (27). Also, major mercury spills occur infrequently at TVA coal-fired power plants, so one-time breathing zone concentrations do not indicate usual conditions.

The instrument mechanic (IM) craft has the potential for regular mercury exposure. They repair the gauges and other equipment that use mercury so that in the IM shop or in the plant where they work there could be exposures to mercury vapor. Some of the power plants have a separate mercury storage room for storing and handling mercury in well ventilated conditions to avoid shop contamination.

Area monitoring for mercury vapor has been conducted at all 12 coal-fired power plants, and Table 18 gives the locations and concentration ranges for each of the plants. The greatest area concentration found at any of the plants was almost 0.5 mg/m^3 at the Kingston plant in 1970. This concentration was found near the surface of a contaminated area of the instrument shop and the area was cleaned afterwards. Whenever area concentrations are found to be higher than 0.05 mg/m^3 decontamination procedures must be followed until the airborne concentration is acceptable.

The concentrations presented in Table 18 should not be over-represented. There are only a few measurements given for each plant, and the background conditions were not written into the reports from which these data were taken.

Urinary mercury levels were determined for employees working in clean-up crews for various mercury spills, and these levels are reported in Table 19. The highest urinary mercury level recorded was 41 micrograms per liter (µg/l) with most of them substantially lower. These compare to levels found in unexposed people of 0 to 25 µg/l (49).

Table 18. Area Mercury Concentrations Found in TVA Coal-Fired Power Plants

Plant	Location	Concentration Range (mg/m^3)	Number of Samples
Allen	Instrument Shop	ND* - 0.08	5
	Hg Storage	ND	3
Bull Run	Instrument Shop	ND	1
	Hg Storage	ND	1
Colbert	Instrument Shop	0.4	2
Cumberland	Instrument Shop	ND - 0.2	6
Gallatin	Instrument Shop	ND - 0.07	6
	Hg Storage	ND - 0.05	2
John Sevier	Instrument Shop	0.02	1
	Hg Storage	ND	1
Johnsonville	Instrument Shop	ND - 0.04	8
	Hg Storage	0.01 - 0.15	8
Kingston	Instrument Shop	ND - 0.4	11
Paradise	Instrument Shop	<0.1	1
Shawnee	Instrument Shop	ND - 2.0	Unk.**
	Hg Storage	ND	3
Watts Bar	Instrument Shop	0.02	1
Widows Creek	Instrument Shop	ND - 0.5	Unk.
	Hg Storage	0.03 - 0.5	Unk.

* ND - Nondetectable.
** Unk. - Unknown.

Table 19. Urinary Mercury Levels of Employees* Engaged in Mercury Spill Clean-up Operations at TVA Coal-Fired Power Plants

Plant	Date of Sample	Concentration (μg/l)
Paradise	4/14-15/69	20, 13, 16, 18
	8/22/69	17, 40
Shawnee	10/8-9/68	20, 40
	6/23-25/71	17, 27, 13, 17, 11, 17
Colbert	8/13-14/70	11, 15
	8/26-31/70	2, 14, 24, 2, 9, 15 13, 15, 13, 34, 34 15, 15
	9/1-2/70	6, 5
	10/21-22/70	15, 37, 3, 14
	11/13/70	4, ND**
	12/23/70	40, 20, 16, 40
	4/12/72	16, 41
	2/9-10/73	12, 23, 15

*All employees involved in mercury clean-up must wear personal protective equipment, including respiratory protection.

**Nondetectable.

Noise

Over 400 eight-hour TWA noise exposure measurements were taken from industrial hygiene files for TVA employees in coal-fired power plants. This represents the personal noise monitoring that was conducted from 1975 to 1979 inclusive. There were not enough exposure levels found for separate craft groups at each of the plants for frequency analysis; but, looking at the combined exposures of a single craft at all of the plants, there were four groups that had 252 of the 428 measured exposures. These groups include the assistant unit operators (AUO), auxiliary operators (AO), heavy equipment operators (HEO), and laborers. The exposure measurements were recorded as percentages of the 90 dBA standard, and Figures 55-58 give the log-probability plots for the exposure data from the four craft groups. The geometric means were 89 percent, 140 percent, 102 percent, and 85 percent for the AUO's, AO's, HEO's, and laborers respectively, and geometric standard deviations were 2.5, 2.2, 3.2, and 2.2.

The Figures 55-58 and the goodness-of-fit tests show that these noise data fit the log-normal frequency distribution very well even though there were spatial and temporal separations. Consequently, any inferences drawn from these log-probability plots would have to be general and take the location and time parameters into consideration. For example, it would not be possible to estimate the probability of a specific AUO being overexposed (>100%) to noise at TVA's Kingston plant for a given day based on the AUO frequency distribution, but the distribution does estimate the probability of overexposure for any TVA AUO at any TVA power plant during the five-year period when the noise data were gathered.

At all TVA coal-fired power plants there are hearing conservation programs in existence. The powerhouse, where most of the AUO's, AO's, and laborers work, is designated a high-noise area and hearing protection must be worn. The cabs of heavy equipment are also high-noise areas, and the HEO's must wear hearing protection, too. So exposure levels indicated here are not the dose levels actually received by TVA employees unless the required hearing protection was not properly used.

Ozone

Area sampling for ozone at the Allen, Johnsonville, and Shawnee power plants did not detect any ozone generated by plant operations. Surveys around the turbine/ generator units at Johnsonville and Shawnee were conducted in what are considered worst-case situations for the potential generation of ozone, but nothing was detected.

The only detectable exposures to ozone that have been measured in TVA have been to electric arc welders. Breathing zone concentrations from 0.05 to 1.0 ppm have been measured outside the welder's hood. Ozone exposures could also be expected in proximity to electrostatic precipitators, although these have not been measured.

Carbon Monoxide

Two general area surveys to detect and measure carbon monoxide (CO) were conducted at the Paradise power plant. One survey using detector tubes was done around unit 2 while it was operating in a steady state mode. The concentrations of CO ranged from 0 to 14 ppm with the higher concentrations found in direct combustion gas leaks. The concentrations found in the normal work areas around unit 2 were at the low end (0-2 ppm) of the range.

The second survey was conducted while unit 3 was being fired with number 2 fuel oil to light-off the pulverized coal. During the light-off is when most operating personnel believe the highest concentration of CO is generated. No detectable concentrations of CO were found during this survey, but that does not mean CO is not usually generated during unit startup.

EXPOSURE DATA SUMMARY

In order to facilitate extracting and using the exposure data that have been presented in this report, many of the exposure data tables have been repeated in this section. The reader is cautioned to remember that there are restrictive and disclaiming remarks written into the body of this report for much of these exposure data, and that the data should be interpreted in light of these remarks.

Table 20 gives a rundown of the cumulative respirable coal dust exposure. More details can be found in Tables 1 and 2.

Table 20. Respirable Coal Dust Exposure of TVA Craft Groups and Power Plants

Craft or Plant	GM(mg/m^3)	95% Confidence Limits Low	95% Confidence Limits High
Conveyor and Dumper Car Operators	0.9	0.8	1.0
Heavy Equipment Operators	0.5	0.4	0.7
Allen	1.4	1.1	1.8
Bull Run	0.6	0.4	0.9
Colbert	0.4	0.3	0.5
Cumberland	0.9	0.7	1.2
Gallatin	0.4	0.3	0.6
Johnsonville	0.8	0.7	1.0
John Sevier	0.7	0.5	1.0
Kingston	1.1	0.9	1.4
Paradise	1.3	1.1	1.5
Shawnee	1.2	1.0	1.4
Watts Bar	1.0	0.8	1.2
Widows Creek	1.6	1.2	2.1

The condensed results from respirable fly ash sampling are presented in Table 21, and more details are given in Table 5.

Sulfur dioxide exposure levels for the craft group at Paradise Power Plant are presented in Table 22. It should be recalled that these geometric mean SO_2 exposures were calculated using a trimmed data analysis technique.

A consolidation of the annual geometric mean exposures of insulation workers to airborne asbestos is given in Table 23.

Table 21. Respirable Fly Ash Exposure of Seven Craft Groups at Johnsonville and Paradise Power Plants

Craft	Plant	GM(mg/m^3)	95% Confidence Limits Low	High
Operators	Johnsonville	0.21	0.17	0.27
	Paradise	0.37	0.27	0.50
Electricians	Johnsonville	0.23	0.18	0.30
	Paradise	0.40	0.30	0.54
Machinists	Johnsonville	0.20	0.16	0.26
	Paradise	0.40	0.28	0.57
Instrument Mechanics	Johnsonville	0.21	0.16	0.27
	Paradise	0.33	0.24	0.45
Steamfitters	Johnsonville	0.24	0.19	0.31
	Paradise	0.32	0.24	0.43
Boilermakers	Johnsonville	0.50	0.36	0.69
	Paradise	0.40	0.30	0.54
Laborers	Johnsonville	0.37	0.27	0.51
	Paradise	0.40	0.30	0.53

Table 22. SO_2 Exposures for Craft Groups at Paradise Power Plant

Craft Groups	GM(ppm)	95% Confidence Limits Low	High
Boilermakers	0.11	0.04	0.27
Steamfitters	0.06	0.02	0.16
Machinists	0.13	0.04	0.45
Electricians	0.07	0.02	0.31
Laborers	0.16	0.08	0.34
Inst. Mechanics	0.09	0.03	0.27
Operators	0.07	0.02	0.24

Table 23. Annual Asbestos Exposure Levels for TVA Asbestos Workers

Year	GM (f/ml)	95% Confidence Limits Low	High
1973	1.1	0.85	1.4
1974	0.73	0.54	1.0
1975	0.29	0.16	0.51
1976	0.22	0.17	0.28
1977	0.03	0.02	0.04
1978	0.06	0.04	0.09
1979	0.05	0.04	0.06

REFERENCE LIST

1. AMA Council on Scientific Affairs, 1979. Health Evaluation of Energy-Generating Sources. Combustion 50(10):20-22.

2. Straub, W.E., et. al. 1975. Health Hazard Evaluation/Toxicity Determination Report H.H.E. 74-106-223. McGraw Edison Company, Cannonsburg, Pennsylvania. NIOSH.

3. Rosensteel, R.E., et. al. 1973. Health Hazard Evaluation/Toxicity Determination. Central Maine Power Company, Wyman Station, Yarmouth, Maine. NIOSH.

4. Hirsch. A., et. al. 1979. Asbestos risk among full-time workers in an electricity-generating power station. Annals of New York Academy of Sciences. 77:137-145.

5. JRB Associates. 1977. Technological Feasibility Assessment and Inflationary Impact Statement of the Proposed Standard for Sulfur Dioxide. Prepare for USDL/OSHA.

6. Communications. 1980. Bureau of Labor Statistics, Washington, DC.

7. Friedlander, G.D. 1979. 21st steam station cost survey. Electric World.

8. Annual Report. 1979. Tennessee Valley Authority. Knoxville, Tennessee.

9. Babcock and Wilcox Co. 1971. Steam - Its Generation and Use. 38th Ed.

10. Bureau of Mines. 1971. Sampling and Evaluating Respirable Coal Mine Dust. IC-8503.

11. Quartz in coal by infrared spectroscopy. NIOSH Manual of Analytical Methods. P&CAM 110, Vol. 1, 2nd Ed., 1977.

12. Andersen Samplers, Inc. Particle Fractionating Sampler. Bulletin 176-3. Atlanta, Georgia.

13. Karasek, F.W., D.W. Denney, K.W. Cham, and R.E. Clement. 1978. Analysis of complex organic mixtures on airborne particulate matter. Analytical Chemistry. 50:82-7.

14. Guidelines establishing test procedures for the analysis of pollutants; proposed regulation. Federal Register. 44(233), Part III, 69514-7.

15. U.S. Environmental Protection Agency. 1980. Determination of lead concentration in ambient particulte matter by flame atomic absorption spectrometry following ultrasonic extraction with heated HNO_3-HCl, EPA designated method. EQL-0380-043. Research Triangle Park.

16. U.S. Environmental Protection Agency. 1979. Methods for Chemical Analysis of Water and Wastes. Cincinnati, Ohio.

17. Laboratory Quality Assurance Manual. Natural Resource Services, Laboratory Branch, TVA.

18. Sulfates, sulfites, and sulfur dioxide. NIOSH Manual of Analytical Methods. P&CAM 268, Vol. 5, 2nd Ed., 1979.

19. Palmes, E.D., A.F. Gunnison, J. DiMattio, and C. Tomczyk. 1976. Personal sampler for nitrogen dioxide. American Industrial Hygiene Journal. Vol 37(10):570-7.

20. Gamble, J., et. al. 1978. Acute changes in pulmonary function in salt mines. Proceeding: Industrial Hygiene for Mining and Tunneling. 119-128, November 6-7.

21. Nitrogen dioxide in air. NIOSH Manual of Analytical Methods. P&CAM 108, Vol 1, 2nd Ed., 1977.

22. Nitrogen dioxide and nitric oxide in air. NIOSH Manual of Analytical Methods. P&CAM 231, Vol. 1, 2nd Ed., 1977.

23. Sampling Data Sheet #2.02, Asbestos. NIOSH Manual of Sampling Data Sheets. 1977 Edition, 1977.

24. Edwards, G.H., and J.R. Lynch. 1968. The method used by the U.S. Public Health Service for enumeration of asbestos dust on membrane filters. Annals of Occupational Hygiene. 11:1-6.

25. Asbestos. NIOSH Manual of Analytical Methods. P&CAM 239, Vol. 1, 2nd Ed., 1977.

26. Mercury in urine. NIOSH Manual of Analytical Methods. P&CAM 145, Vol. 1, 2nd Ed., 1977.

27. General Industry Standards. 1976. 29 CFR 1910. U.S. Department of Labor, Occupational Safety and Health Administration, OSHA 2206.

28. Leidel, N.A., K.A. Busch, and J.R. Lynch. 1977. Occupational Exposure Sampling Manual. DHEW (NIOSH) Pub. No. 77-173.

29. Coenen, W. 1966. The confidence limits for the mean values of dust concentration. Staub (English translation). 26:39-45.

30. Jones, A.R., and R.D. Brief. 1971. Evaluating benzene exposures. Am. Ind. Hyg. J. 32:610-613.

31. Sherwood, R.J. 1971. The monitoring of benzene exposure by air sampling. Am. Ind. Hyg. J. 32:840-846.

32. PLOT 50, Statistics, Volumes 1-3, Copyright Tektronix, Inc. 1975.

33. Hahn, G.J., and S.S. Shapira. 1967. Statistical Models in Engineering. John Wiley and Sons, Inc. New York.

34. Inhaled Particles IV. 1977. Edited by W.H. Walton. Pergamon Press. Oxford, England.

35. Gibra, I.N. 1973. Experimental Statistics and Inference for Scientists and Engineers. Prentice-Hall, Inc. New Jersey.

36. TLV's Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1979. ACGIH. P.O. Box 1937. Cincinnati, Ohio.

37. Henry, W.H. and K.T. Knapp. 1980. Compound forms of fossil fuel fly ash emissions. Environmental Science and Technology. 14(4):450-456.

38. Davison, R.L., Natusch, D.F.S., and J.R. Wallace. 1974. Trace elements in fly ash, dependence of concentration on particle size. Environmental Science and Technology. 8(13):1107-1113.

39. Smith, R.D., Campbell, J.A., and K.K. Nielson. 1979. Concentration dependence upon particle size of volatilized elements in fly ash. Environmental Science and Technology. 13:553-558.

40. Ray, S.S., and F.G. Parker. 1977. Characterization of Ash from Coal-Fired Power Plants. Environmental Protection Technology Series, EPA-600/7-77-010.

41. Field Testing: Trace Element and Organic Emissions from Industrial Boilers. 1976. Environmental Protection Technology Series, EPA-600:2-76-086b. EPA. Research Triangle Park, North Carolina.

42. Sources of Polynuclear Hydrocarbons in the Atmosphere. 1967. U.S. Public Health Service Publication 999-AP-33. Cincinnati, Ohio.

43. Friendlander, S.K. 1973. Chemical element balances and identification of air pollution sources. Environmental Science and Technology. 7:235-240.

44. Standard for Protection Against Radiation, 10 CFR 20, 1972.

45. Barber, D.E., and H.R. Giorgio. 1977. Gamma-ray activity in bituminous, subbituminous, and lignite coals. Health Physics. 32:83-88.

46. Coles, D.G., Ragaini, R.C., and J.M. Ondov. 1978. Behavior of natural radionuclides in western coal-fired power plants. Environmental Science and Technology. 12(4):442-446.

47. Willey, M.A., C.S. McCammon, and L.J. Doemeny. 1977. A solid sorbent personal sampling method for simultaneous collection of nitrogen dioxide and nitric oxide in air. Am. Ind. Hyg. J. 38:358-363.

48. Fontaine, J.H. and D.M. Trayer. 1975. Asbestos control in steam-electric generation plants. Am. Ind. Hyg. J. 36:126-130.

49. Goldwater, J.L. 1972. Mercury, A History of Quicksilver. York Press, Inc. Baltimore, Maryland.

APPENDIX A. Description of TVA's 12 Coal-Fired Power Plants

Plant	No. of Units	CAPACITY Maximum (MW) Unit	Maximum (MW) Total	Normal (MW) Unit	Normal (MW) Total	Boiler Draft
Allen	3	3 @ 330	990	3 @ 282	846	Positive
Bull Run	1	950	950	900	900	Positive
Colbert	5	2 @ 200	1,396	2 @ 200	1,300	Balance
		2 @ 223		2 @ 200		
		550		500		Positive
Cumberland	2	2 @ 1,274	2,548	2 @ 1,274	2,548	Positive
Gallatin	4	2 @ 300	1,256	2 @ 250	1,050	Balance
		2 @ 328		2 @ 275		
John Sevier	4	1 @ 223	823	4 @ 200	800	Balance
		3 @ 200				
Johnsonville	10	4 @ 125	1,486	6 @ 125	1,350	Balance
		2 @ 147		4 @ 150		
		4 @ 173				
Kingston	9	4 @ 175	1,700	4 @ 150	1,600	Balance
		5 @ 200		5 @ 200		
Paradise	3	2 @ 704	2,558	2 @ 690	2,455	Positive
		1 @ 1,150		1 @ 1,075		
Shawnee	10	10 @ 175	1,750	10 @ 150	1,500	Balance
Watts Bar	4	4 @ 60	240	4 @ 60	240	Balance
Widows Creek	8	5 @ 140	1,978	5 @ 135	1,850	Balance
		1 @ 150		1 @ 130		
		1 @ 575*		1 @ 525		
		1 @ 550*		1 @ 525		

*Units were converted from positive pressure to balanced draft.

Appendix B

The following tables list the job titles and job code numbers for the occupations that were studied by this investigation and covered by this report.

Table B-1. Job Titles and Codes for the Asbestos Workers/Insulator Craft Group

Job Title	Job Code
Asbestos Worker Foreman	4060
Asbestos Worker	4070
Asbestos Worker Assignee	4071
Asbestos Worker Improver	4072
Asbestos Worker Improver AP4G	4073
Asbestos Worker Improver AP4	4074
Asbestos Worker Improver AP3	4075
Asbestos Worker Improver AP2	4076
Asbestos Worker Improver AP1B	4077
Asbestos Worker Improver AP1A	4078

Table B-2. Job Titles and Codes for the Boilermaker Craft Group

Job Title	Job Code
Boilermaker Foreman	4380
Boilermaker Welder Foreman	4390
Boilermaker Assistant Foreman	4400
Boilermaker Instructor	4405
Boilermaker	4410
Boilermaker Assignee	4411
Boilermaker Cable Splicer	4420
Boilermaker Certified Welder	4430
Boilermaker Certified Welder - Assignee	4431
Boilermaker - Layout	4440
Boilermaker - Layout Assignee	4441
Boilermaker Rigger	4442
Boilermaker Welder	4450
Boilermaker Welder - Assignee	4451
Boilermaker Welder - Helper	4452
Boilermaker Welder - Apprentice	4459
Boilermaker AP4G	4459
Boilermaker AP4	4460
Boilermaker AP4 LTD	4465
Boilermaker AP3	4470
Boilermaker AP3 LTD	4475
Boilermaker AP2	4480
Boilermaker AP2 LTD	4485
Boilermaker AP1B	4490
Boilermaker AP1B LTD	4495
Boilermaker AP1A	4500
Boilermaker AP1A LTD	4505
Boilermaker Helper	4510
Boilermaker Trainee I	4511
Boilermaker Trainee II	4512
Boilermaker Trainee II (CW)	4513
Boilermaker Student B	4514
Boilermaker Student	4515

Table B-3. Job Titles and Codes for the Electrician Craft Group

Job Title	Job Code
Electrician Foreman	5190
Electrician Subforeman	5190
Electrician Foreman HVMC	5200
Electrician Foreman Instructor	5205
Electrician Welder Foreman	5210
Electrician Welder Helper	5211
Electrician Instructor	5215
Electrician 1st, 2nd, 3rd Class	5220
Electrician Assignee	5222
Electrician Welder	5230
Electrician Welder Assignee	5231
Electrician Welder Apprentice	5239
Electrician Apprentice 5-G	5239
Electrician Apprentice 5	5240
Electrician Apprentice 4-G	5249
Electrician Apprentice 4	5250
Electrician Apprentice 4 - LTD	5255
Electrician Apprentice 3	5260
Electrician Apprentice 3 - LTD	5265
Electrician Apprentice 2	5270
Electrician Apprentice 2 - LTD	5275
Electrician Apprentice 1-B	5280
Electrician Apprentice 1-B - LTD	5285
Electrician Apprentice 1-A	5290
Electrician Apprentice 1-A - LTD	5295
Electrician Student B	5299
Electrician Student A	5300
Electrician Helper	5301
Electrician Helper Class A	5301
Electrician Tender	5301
Apprentice Electrician	5290
Assistant Electrician	5220

Table B-4. Job Titles and Codes for Instrument Mechanic Craft Group

Job Title	Job Code
Instrument Mechanic Foreman	5810
Instrument Mechanic	5820
Instrument Mechanic Specialist	5820
Instrument Man	5820
Instrument Repairman	5820
Instrument Mechanic Apprentice 4-G	5829
Instrument Mechanic Apprentice 4	5830
Instrument Mechanic Apprentice 3	5840
Instrument Mechanic Apprentice 2	5850
Instrument Mechanic Apprentice 1-B	5860
Instrument Mechanic Apprentice 1-A	5870
Instrument Mechanic Assignee	5871
Instrument Mechanic Trainee C	5840
Instrument Mechanic Trainee B	5850
Senior Instrument Mechanic	7513
Senior Instrument Mechanic Foreman	7516

Table B-5. Job Titles and Codes for Powerhouse Laborer Craft Group

Job Title	Job Code
Labor Foreman	5900
Labor Subforeman	5900
Laborer (u)	5910
Laborer - Ash Pit	5911
Steam Plant Laborer	7741
Boiler House Laborer	7741
Boiler Room Laborer	7741
Laborer - General	5910
Senior Laborer Foreman	5900

Table B-6. Job Titles and Codes for the Machinists Craft Group

Job Title	Job Code
Machinist Foreman	6110
Machinist Foreman Instructor	6110
Machinist Shop Foreman	6110
Machinist Subforeman	6110
Machinist Welder Foreman	6120
Machinist Instructor	6125
Machinist Apprentice Instructor	6125
Machinist	6130
Machinist Pneumatic Tool Repair	6134
Machinist Welder Instructor	6139
Machinist Welder	6140
Machinist Welder Assignee	6141
Machinist Welder Apprentice	6149
Machinist Apprentice 4-G	6149
Machinist Apprentice 4	6150
Machinist Apprentice 3	6160
Machinist Apprentice 2	6170
Machinist Apprentice 1-B	6180
Machinist Apprentice 1-A	6190
Machinist Helper	6200
Machinist Welder Helper	6201

Table B-7. Job Titles and Codes for the Steamfitters Craft Group

Job Title	Job Code
Steamfitter	7770
Steamfitter Assignee	7771
Steamfitter Foreman	7750
Steamfitter Subforeman	7750
Steamfitter Welder Foreman	7760
Steamfitter Instructor	7765
Steamfitter Certified Welder	7780
Steamfitter Certified Welder Assignee	7781
Steamfitter Sketch	7785
Steamfitter Welder Assignee	7791
Steamfitter Welder	7800
Steamfitter Welder Helper	7801
Steamfitter Apprentice	7809
Steamfitter AP5G	7809
Steamfitter AP5	7810
Steamfitter AP5 - LTD	7815
Steamfitter AP4	7820
Steamfitter AP4 - LTD	7825
Steamfitter AP3	7830
Steamfitter AP3 - LTD	7835
Steamfitter AP2	7840
Steamfitter AP2 - LTD	7845
Steamfitter AP1B	7850
Steamfitter AP1B - LTD	7855
Steamfitter AP1A	7860
Steamfitter AP1A - LTD	7865
Steamfitter Student	7870
Steamfitter Helper	7871
Steamfitter Plumber Helper	7871
Steamfitter Plumber Helper 1	7872
Steamfitter Plumber Helper 2	7873
Steamfitter Plumber Helper 3	7874
Steamfitter Plumber Helper 4	7875
Steamfitter Plumber Helper S	7876
Steamfitter Plumber Helper P	7876

Table B-8. Job Titles and Codes for the Operator Craft Group

Job Title	Job Code
Apprentice Operator	8040
Apprentice Generating Plant Operator	8040
Assistant Pulverized Fuel Boiler Operator	4160
Assistant Shift Engineer	4120
Assistant Shift Engineer RL	4121
Assistant Shift Engineer SRL	4122
Assistant Shift Engineer NRL	4123
Assistant Turbine Operator - Steam	8430
Assistant Unit Operator	4160
Assistant Unit Operator Trainee	4160
Unit Operator	8430
Auxiliary Operator	4250
Auxiliary Operator Trainee	4251
Boiler Auxiliary Operator (Pulv. Fuel)	4350
Boiler Feed Operator	4160
Boiler Feed Pump Operator	4160
Boiler House Auxiliary Operator	4350
Boiler House Foreman	4370
Boiler House Operator	4360
Boiler House Shift Foreman	4370
Boiler Operator	8430
Boiler Operator A or B	8430
Junior Shift Engineer	7680
Junior Turbine Operator - Steam	8430
Operator A, B, or C	8430
Operator - Small Steam	8430
Operator - Steam	8430
Plant Operator - Small Steam	8430
Pulverized Fuel Boiler Operator	4160
Pulverizing Operator (Power)	4160
SGPO 1st PD	8040
SGPO 2nd PD	8050
SGPO 3rd PD	8060
SGPO 4th PD	8070
Senior Pulverized Fuel Boiler Operator	8430
Senior Shift Engineer	7680
Senior Turbine Operator - Steam	8430
Unit Operator Instructor	6657
Shift Engineer	7680
Shift Engineer I-III	7680
Shift Engineer Steam- New Type	7680
Shift Engineer Steam - Old Type	7680
Shift Engineer RL	7681
Shift Engineer SRL	7682
Shift Engineer SRL - TRG	7683

(Continued)

Table B-8 (Continued)

Job Title	Job Code
Shift Engineer SRL - NSI	7684
Shift Engineer NSI	7685
Shift Engineer RL-NSI	7686
Shift Engineer Student Instructor NSRL	7687
Shift Engineer FSI	7688
SGPO (Oiler)	8040
SGPO 1st Pd.	8040
SGPO 2nd Pd.	8050
SGPO 3rd Pd.	8060
SGPO 4th Pd.	8070
SGPO - Steam	8070
SGPO 5th Pd.	8070
Fossil Shift Engineer Instructor	5513
Fossil Shift Engineer Student Inst.	5512
Senior Turbine Operator - Steam	8430
Steam Operator	8430
Steam Plant Operator	8430
Steam Plant Operator A or B	8430
Turbine Operator	8430
Turbine Operator - Steam	8430
Turbine Operator - Relief	8430

Table B-9. Job Titles and Codes for the Conveyor and Dumper Car Operators (Coal Handlers) Craft Group

Job Title	Job Code
Car Dumper Operator	5000
Coal and Ash Handler	5000
Coal and Ash Foreman	7510
Coal Crusher Operator	5065
Coal Handler	5000
Coal Passer	5000
Coal Tower Operator	4940
Coal Tower Foreman	4940
Coal Unloader	5000
Conveyor and Dumper Car Operator	5000
Conveyor Operator - Boiler House	5009
Conveyor Operator	5010
Conveyor Operator - Steam Generation	5000
Senior Coal and Ash Foreman	7510
Senior Coal and Tower Operator	4940

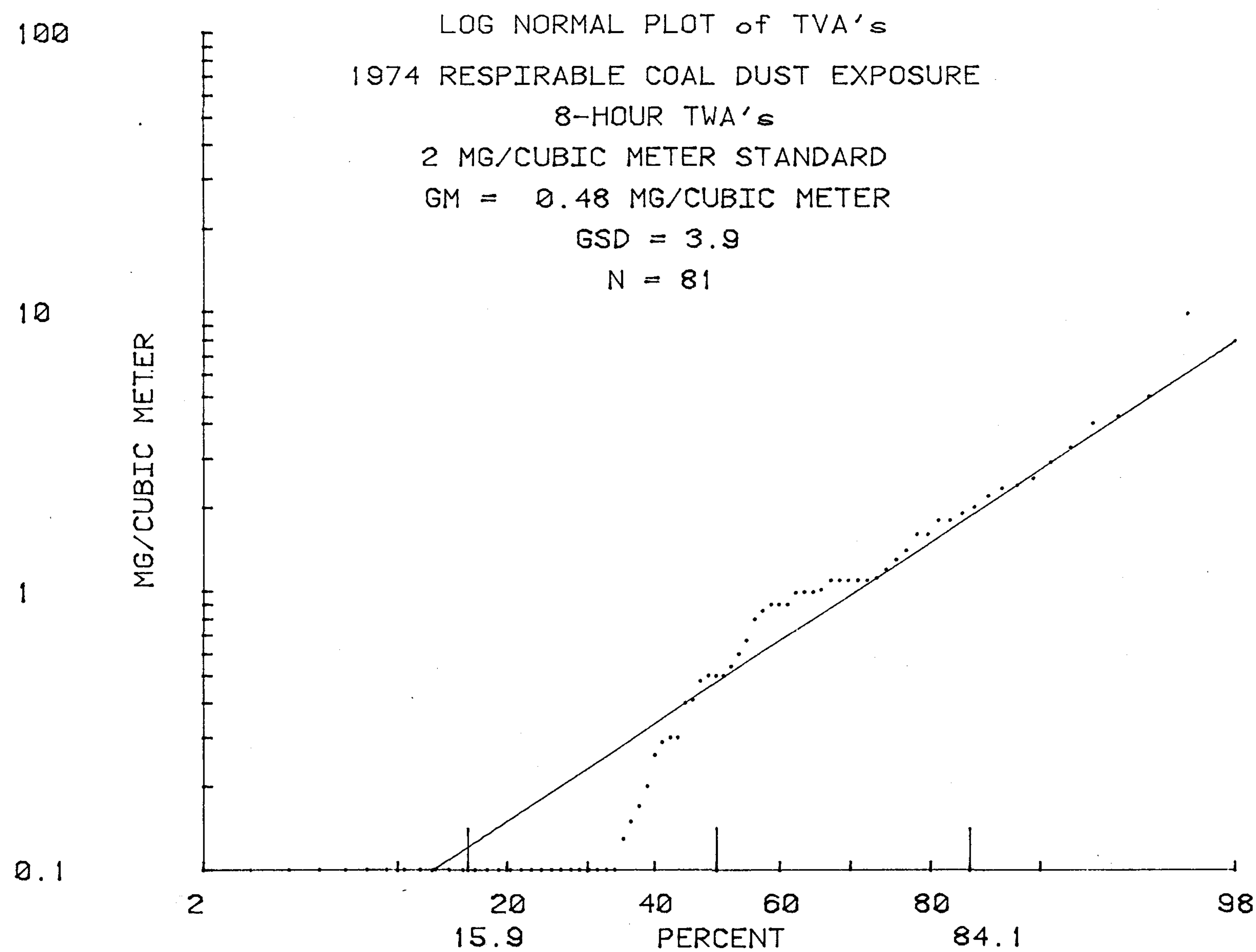

Figure 1. Log-probability plot of the 1974 respirable coal dust exposures of TVA's conveyor-dumper car operators, GM = 0.5 mg/m^3 and GSD = 3.9.

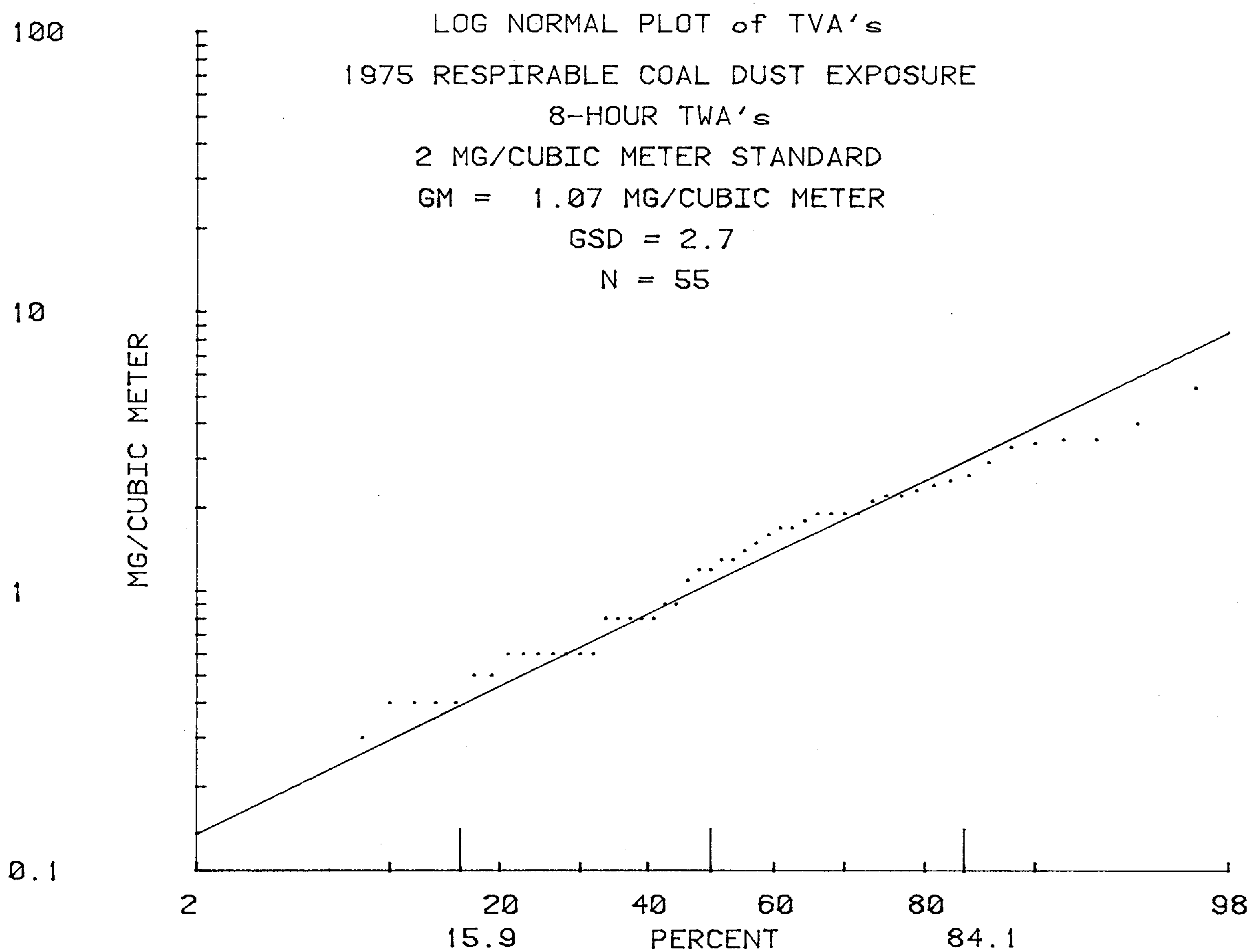

Figure 2. Log-probability plot of the 1975 respirable coal dust exposures of TVA's conveyor-dumper car operators, GM = 1.1 mg/m^3 and GSD = 2.7.

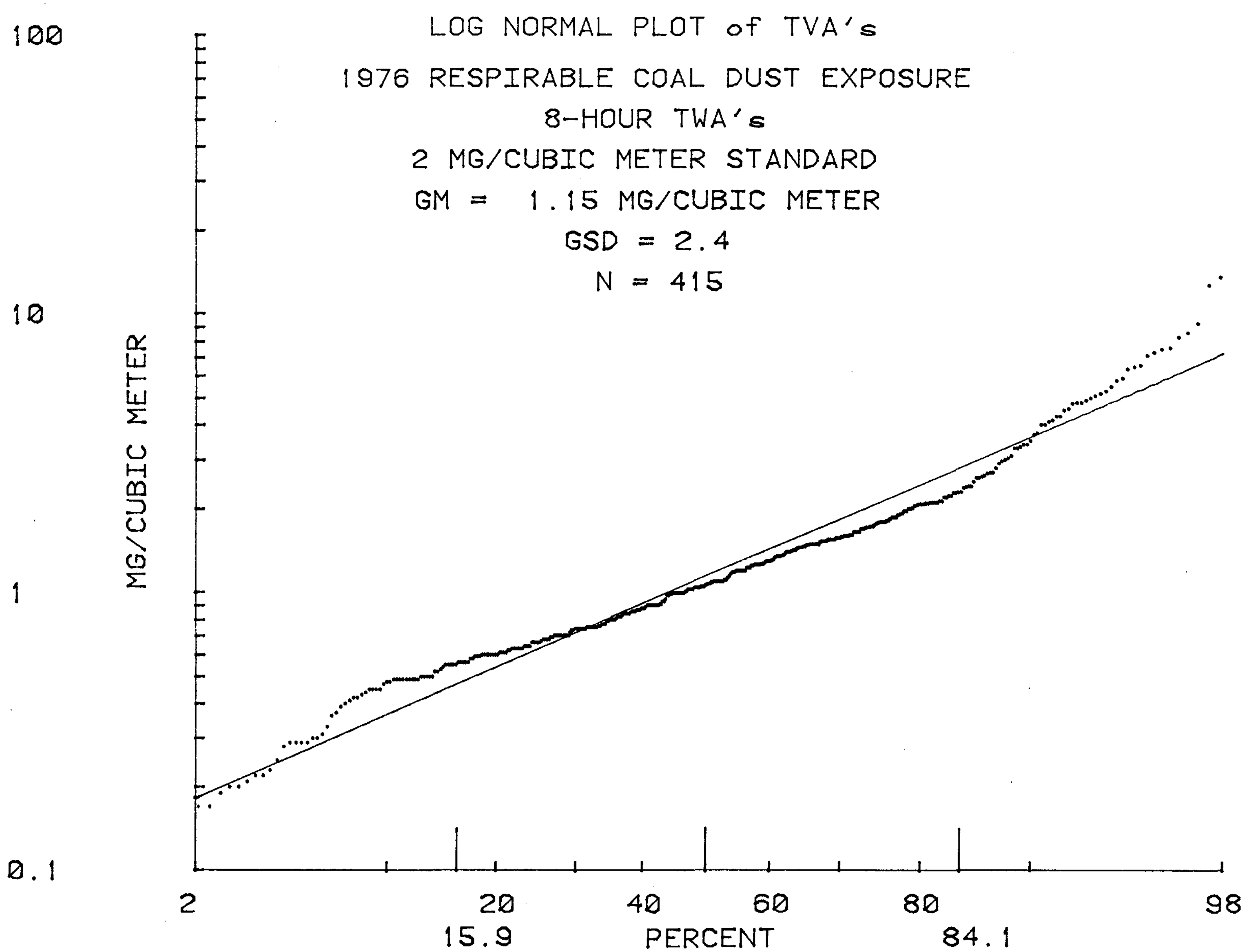

Figure 3. Log-probability plot of the 1976 respirable coal dust exposures of TVA's conveyor-dumper car operators, GM = 1.2 mg/m^3 and GSD = 2.4.

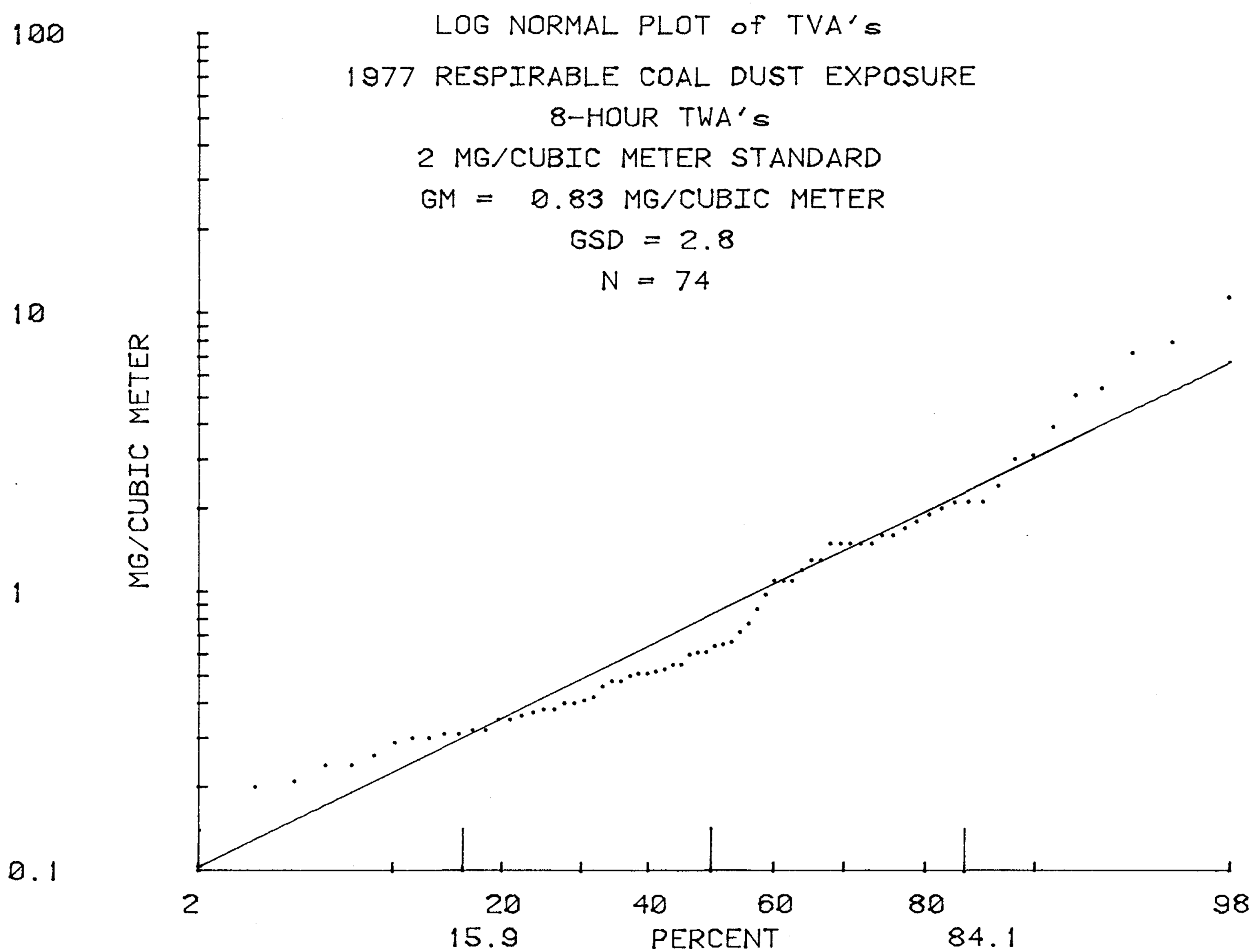

Figure 4. Log-probability plot of the 1977 respirable coal dust exposures of TVA's conveyor-dumper car operators, GM = 0.8 mg/m^3 and GSD = 2.8.

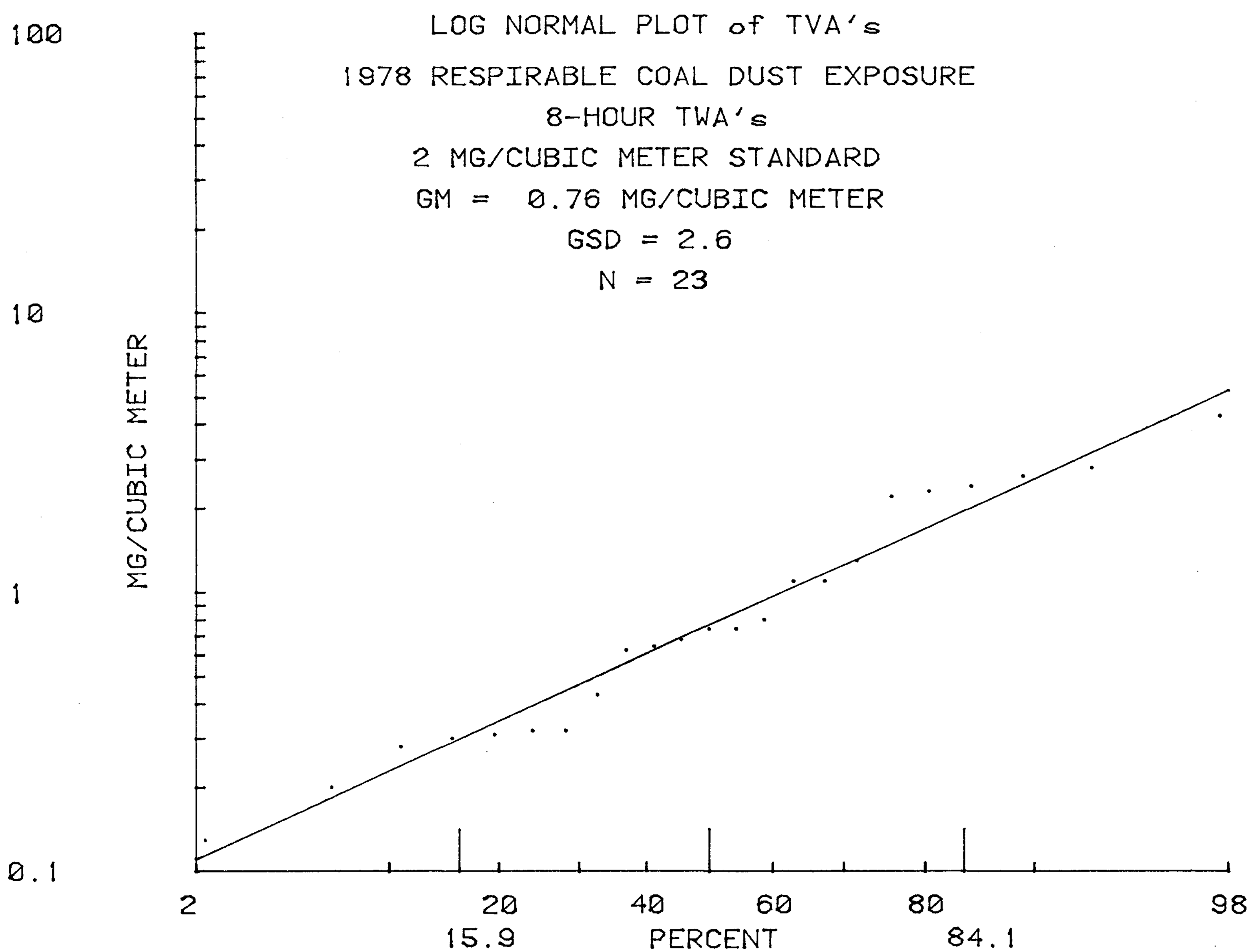

Figure 5. Log-probability plot of the 1978 respirable coal dust exposures of TVA's conveyor-dumper car operators, GM = 0.8 mg/m^3 and GSD = 2.6.

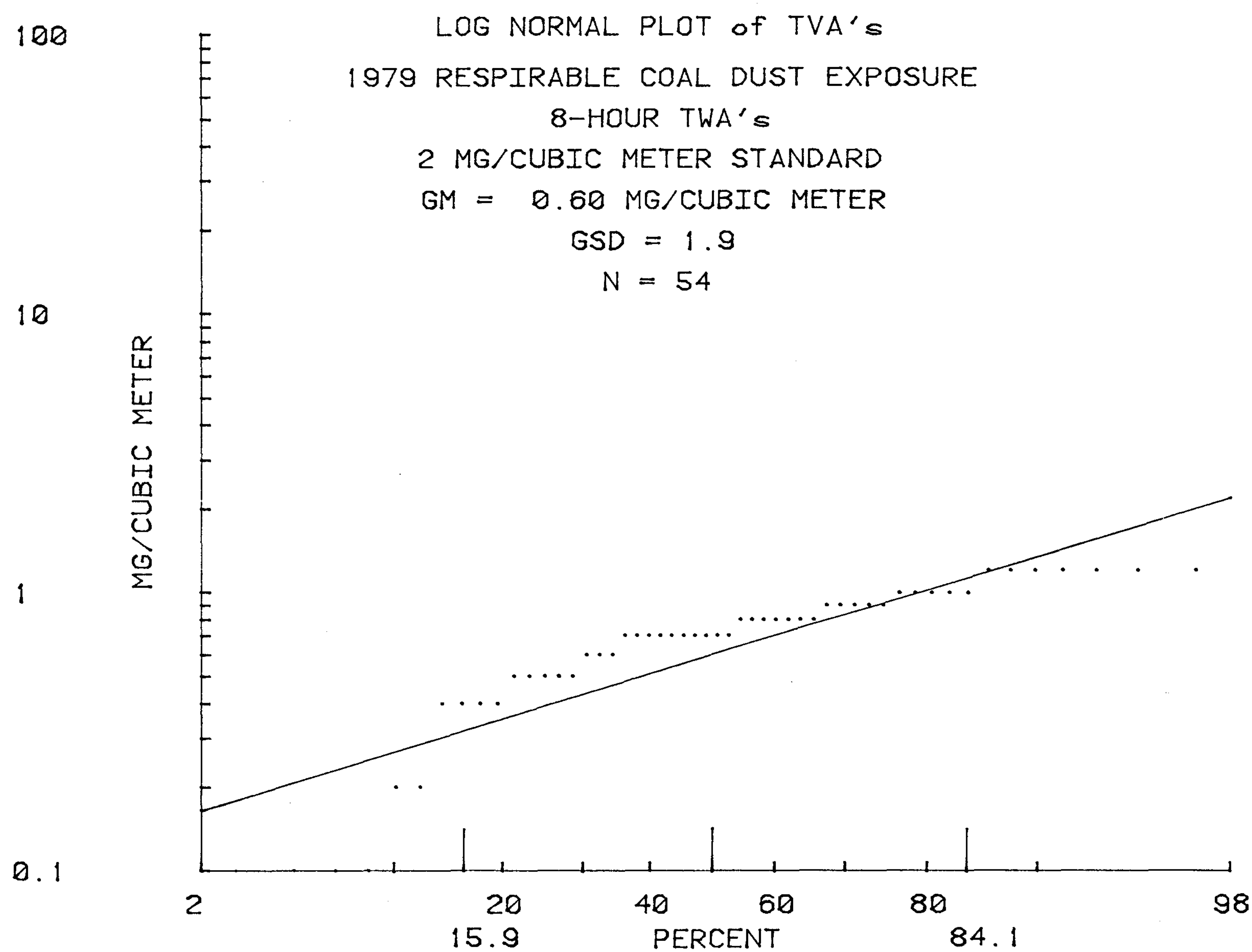

Figure 6. Log-probability plot of the 1979 respirable coal dust exposures of TVA's conveyor-dumper car operators, GM = 0.6 mg/m^3 and GSD = 1.9.

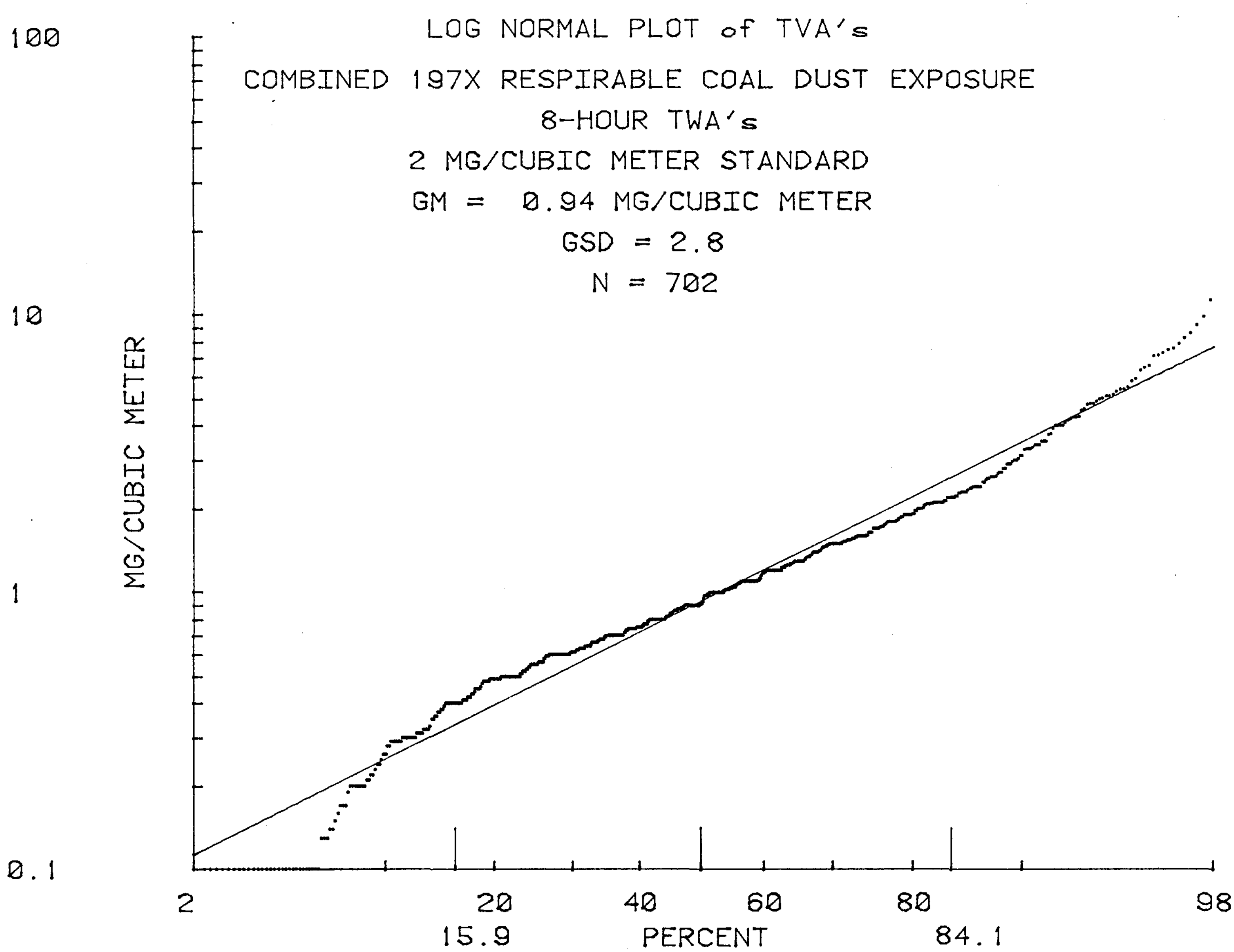

Figure 7. Log-probability plot of the cumulative (1974-1979) respirable coal dust exposure of TVA's conveyor-dumper car operators, GM = 0.9 mg/m^3 and GSD = 2.8.

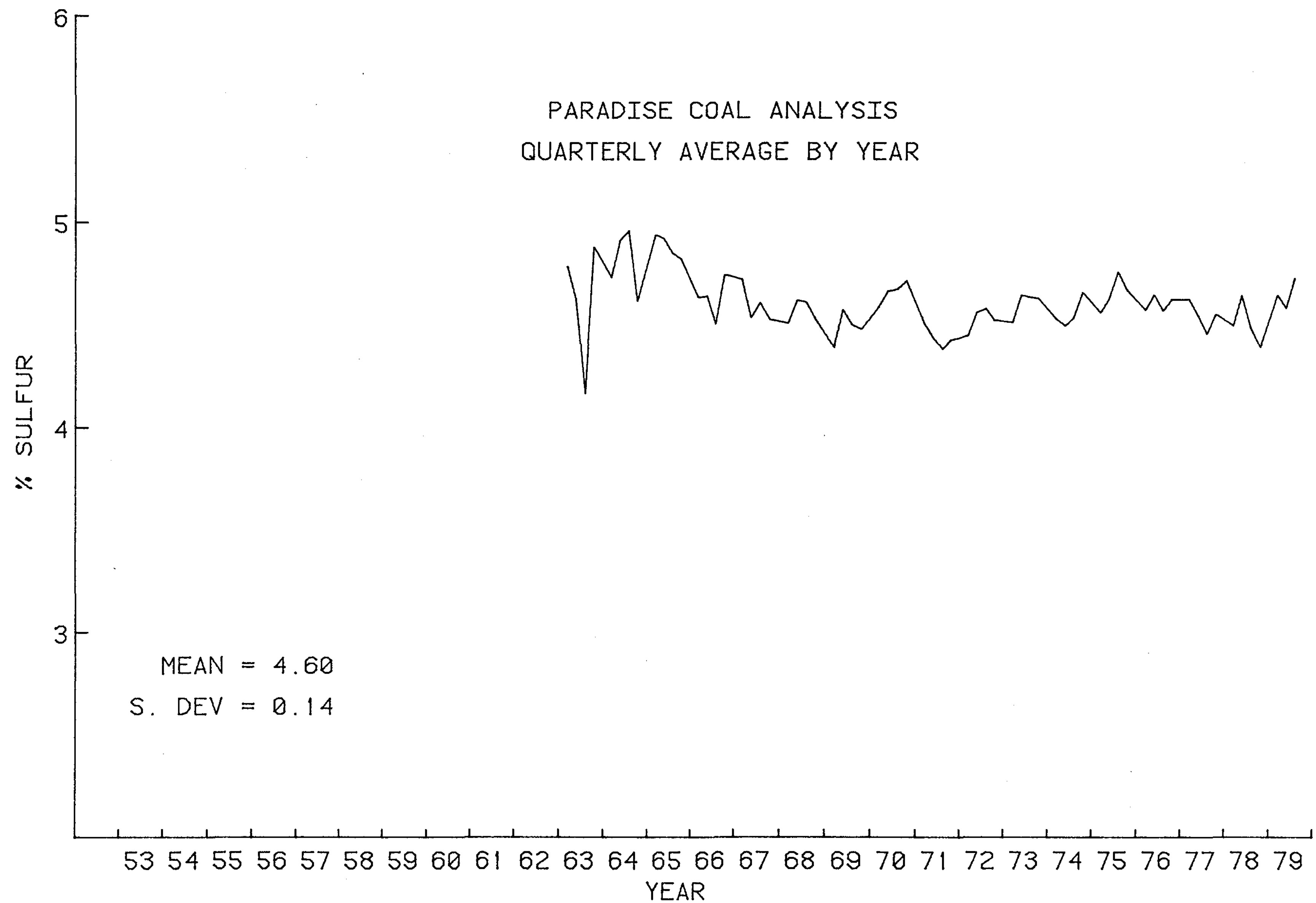

Figure 8. Quarterly averages of the percentage sulfur content of the coal burned at Paradise power plant, mean = 4.60% and standard deviation = 0.14%.

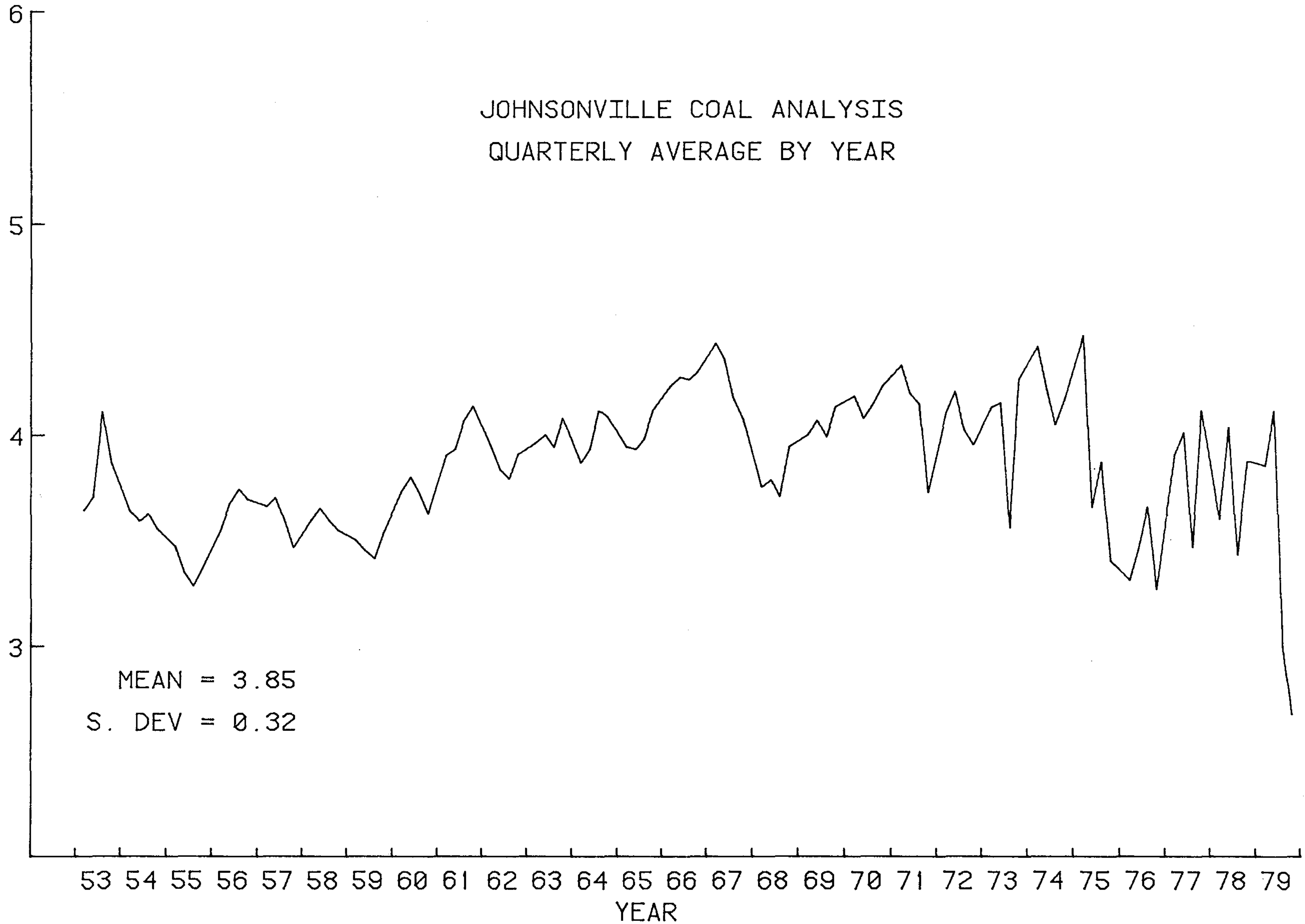

Figure 9. Quarterly averages of the percentage sulfur content of the coal burned at Johnsonville power plant, mean = 3.85% and standard deviation = 0.32%.

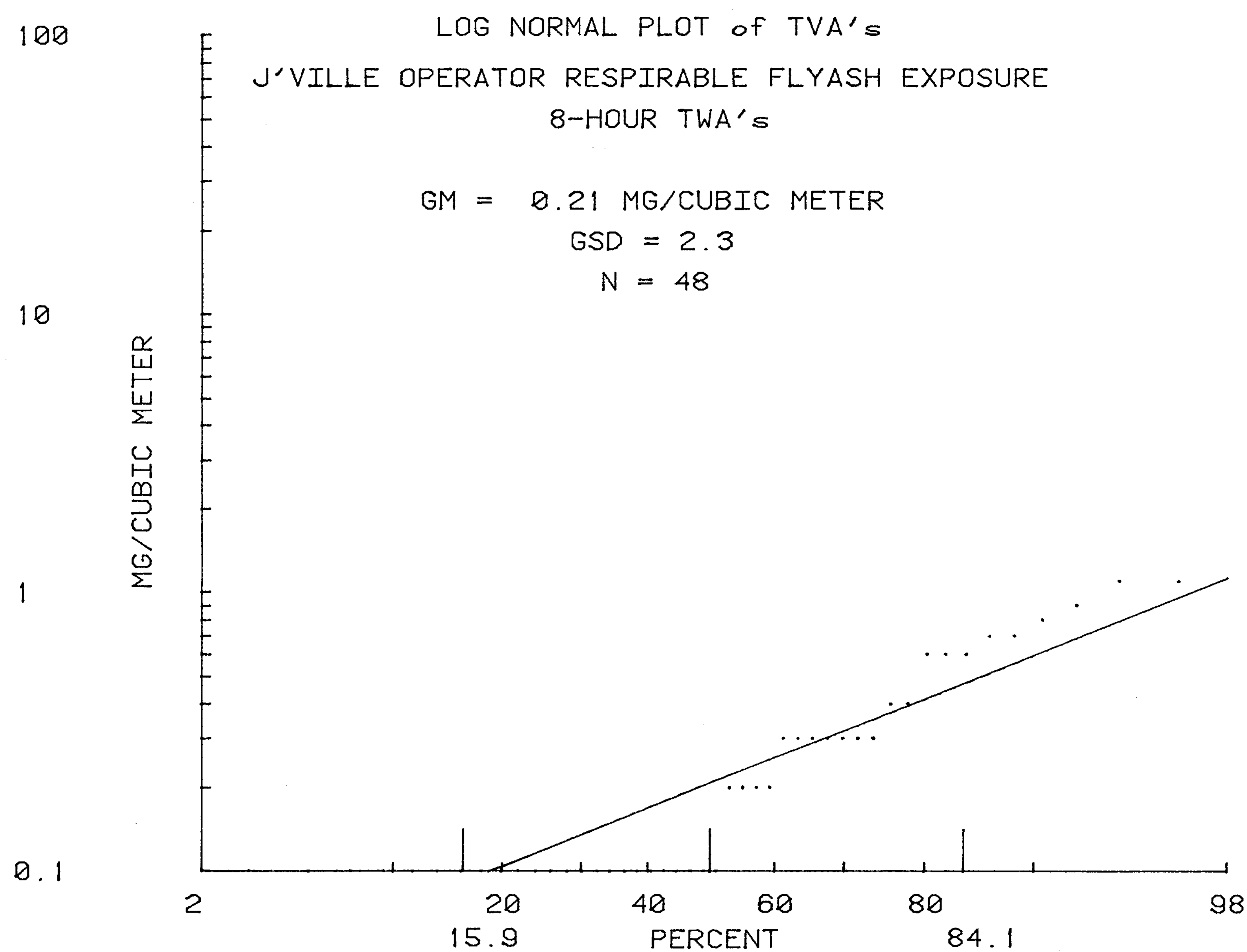

Figure 10. Log-probability plot of respirable fly ash exposures of operators at Johnsonville power plant, GM = 0.21 mg/m^3 and GSD = 2.3.

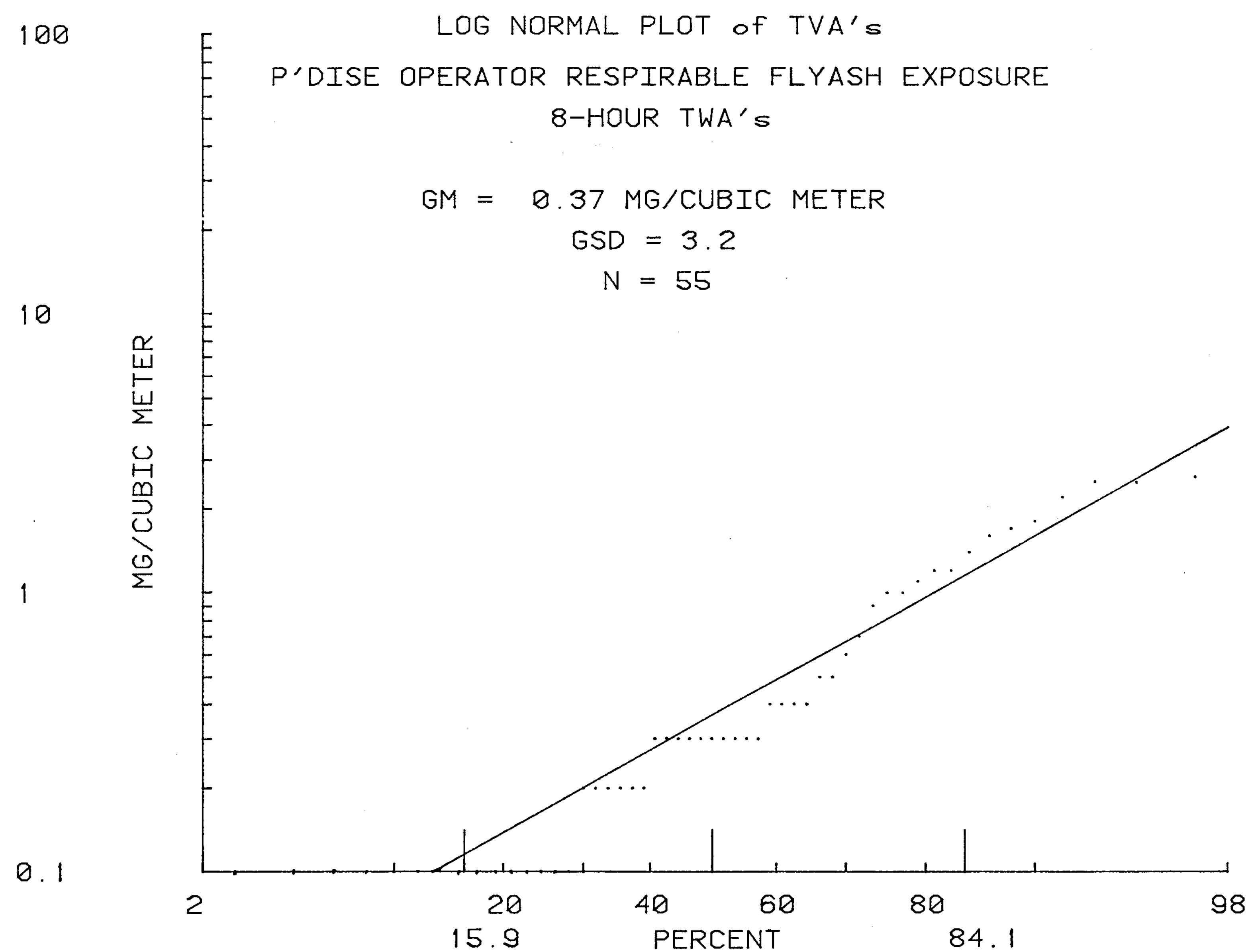

Figure 11. Log-probability of respirable fly ash exposures of operators at Paradise power plant, GM = 0.37 mg/m^3 and GSD = 3.2.

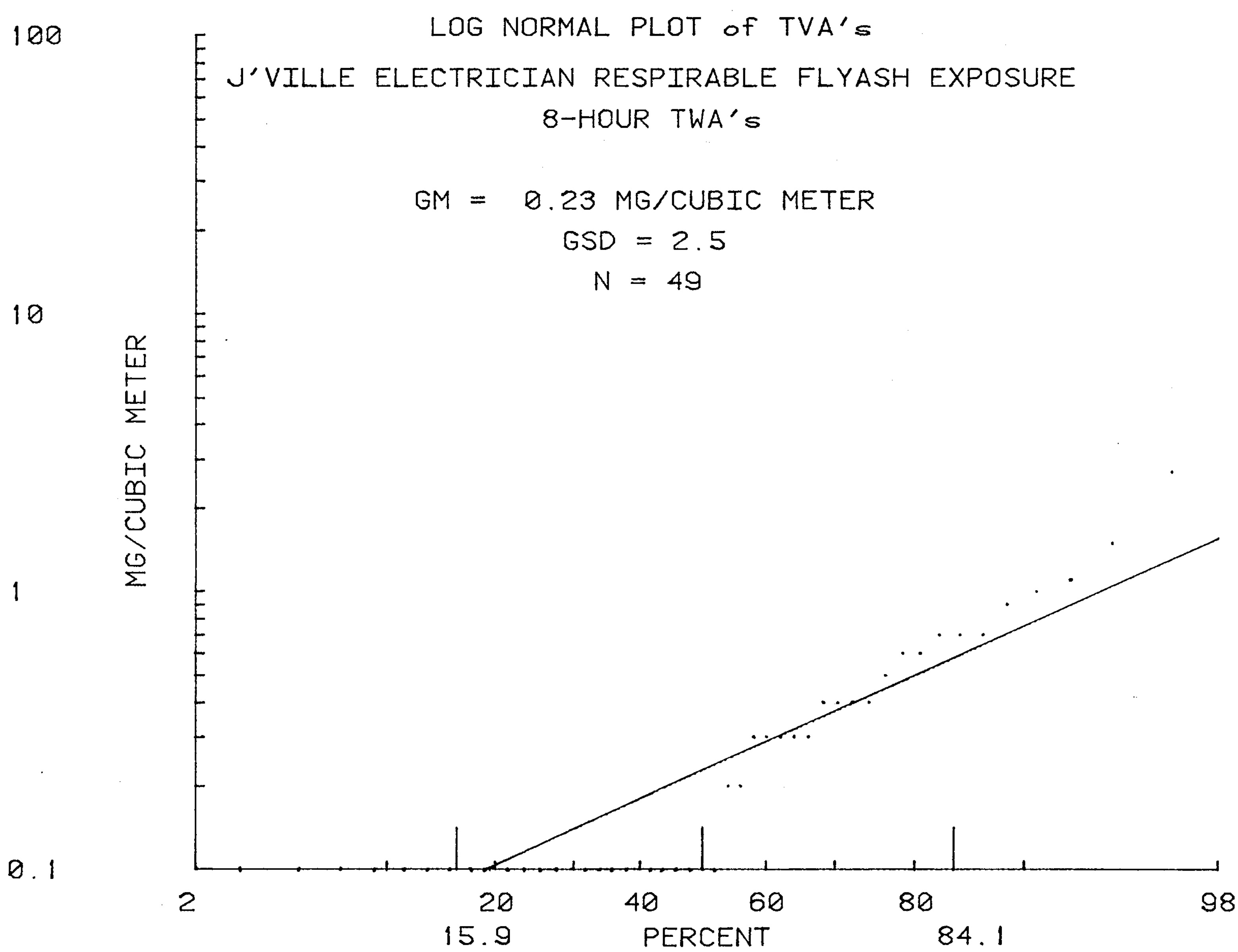

Figure 12. Log-probability plot of respirable fly ash exposure of electricians at Johnsonville power plant, GM = 0.23 mg/m^3 and GSD = 2.5.

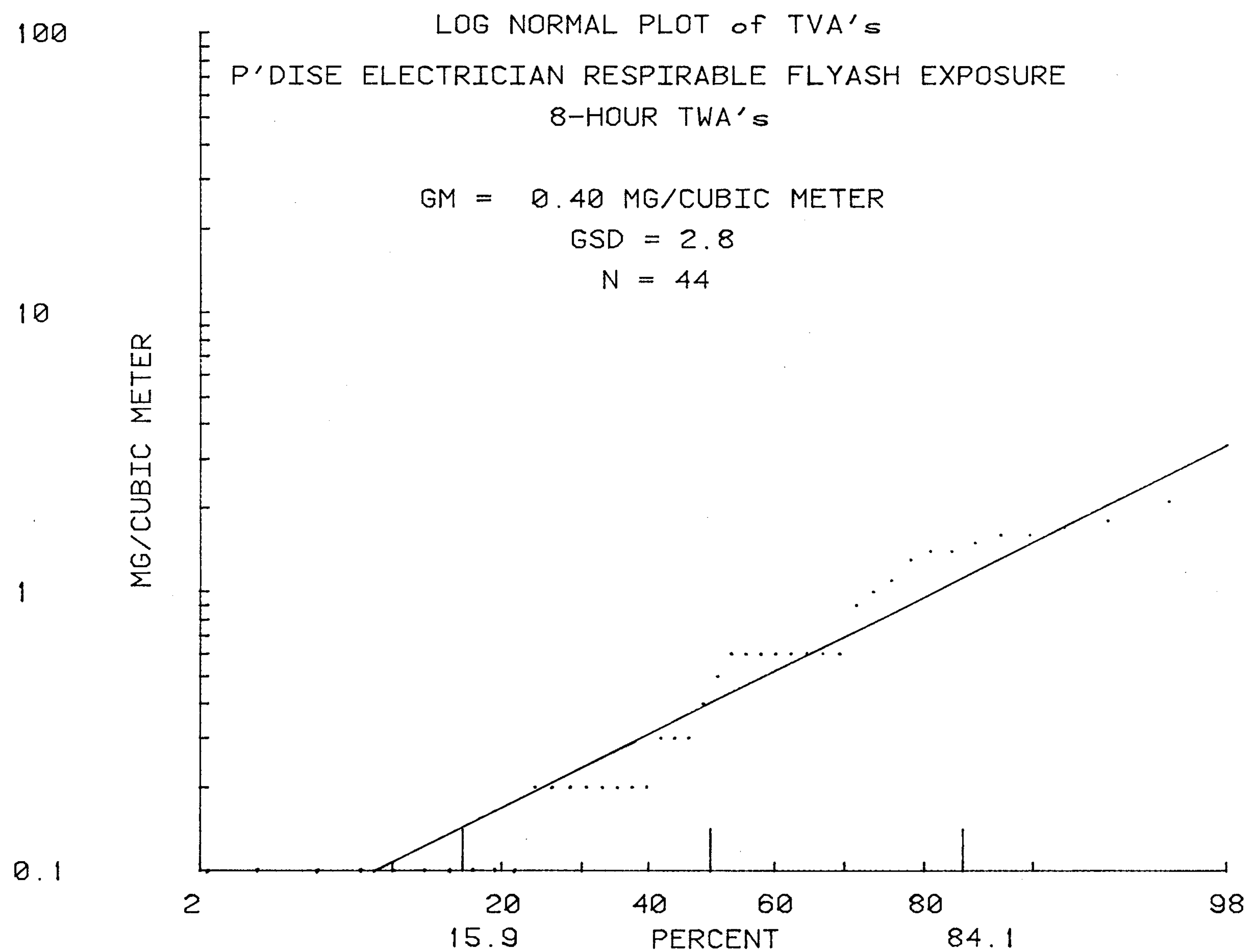

Figure 13. Log-probability plot of respirable fly ash exposure of electricians at Paradise power plant, GM = 0.40 mg/m^3 and GSD = 2.8.

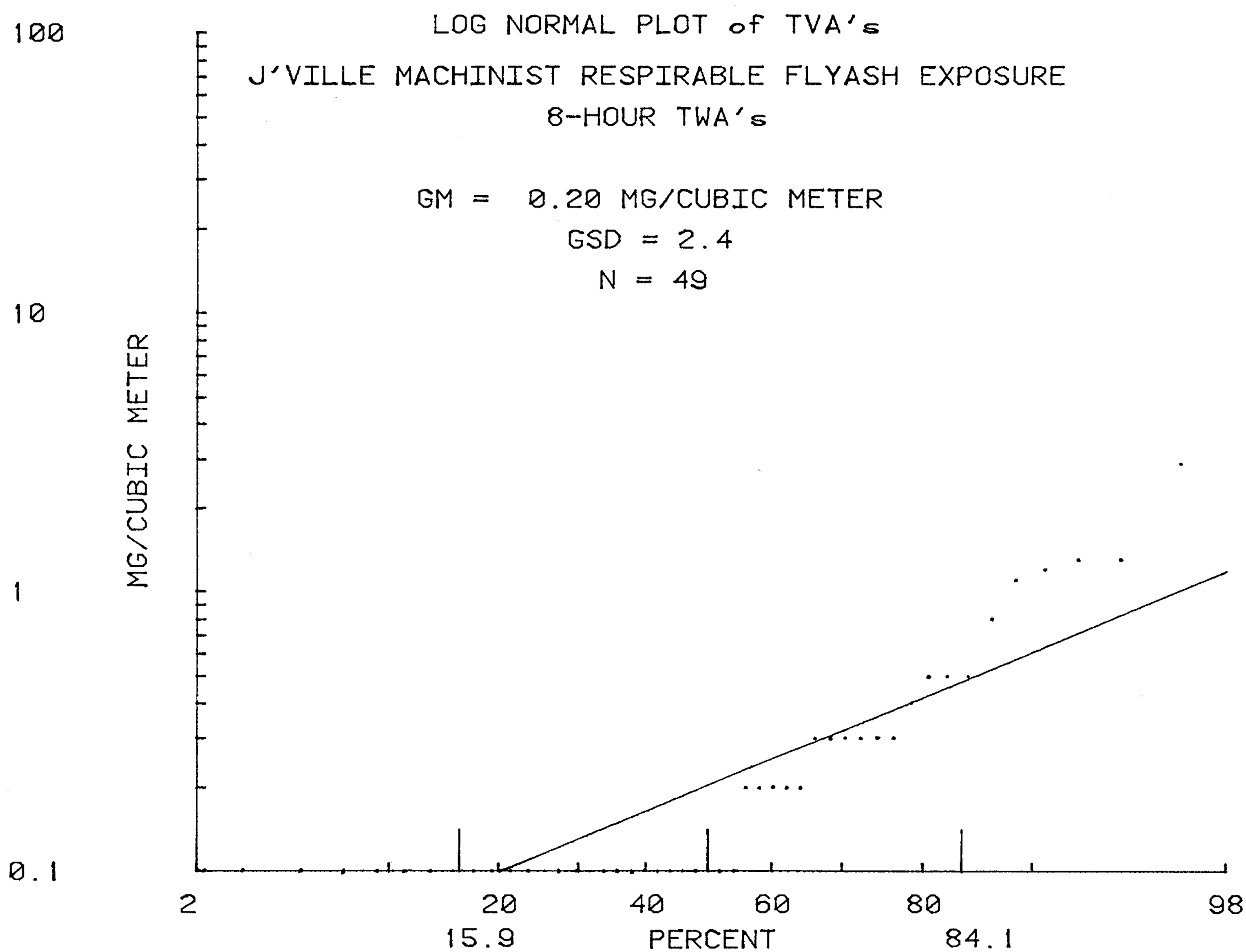

Figure 14. Log-probability plot of respirable fly ash exposure of machinists at Johnsonville power plant, GM = 0.20 mg/m^3 and GSD = 2.4.

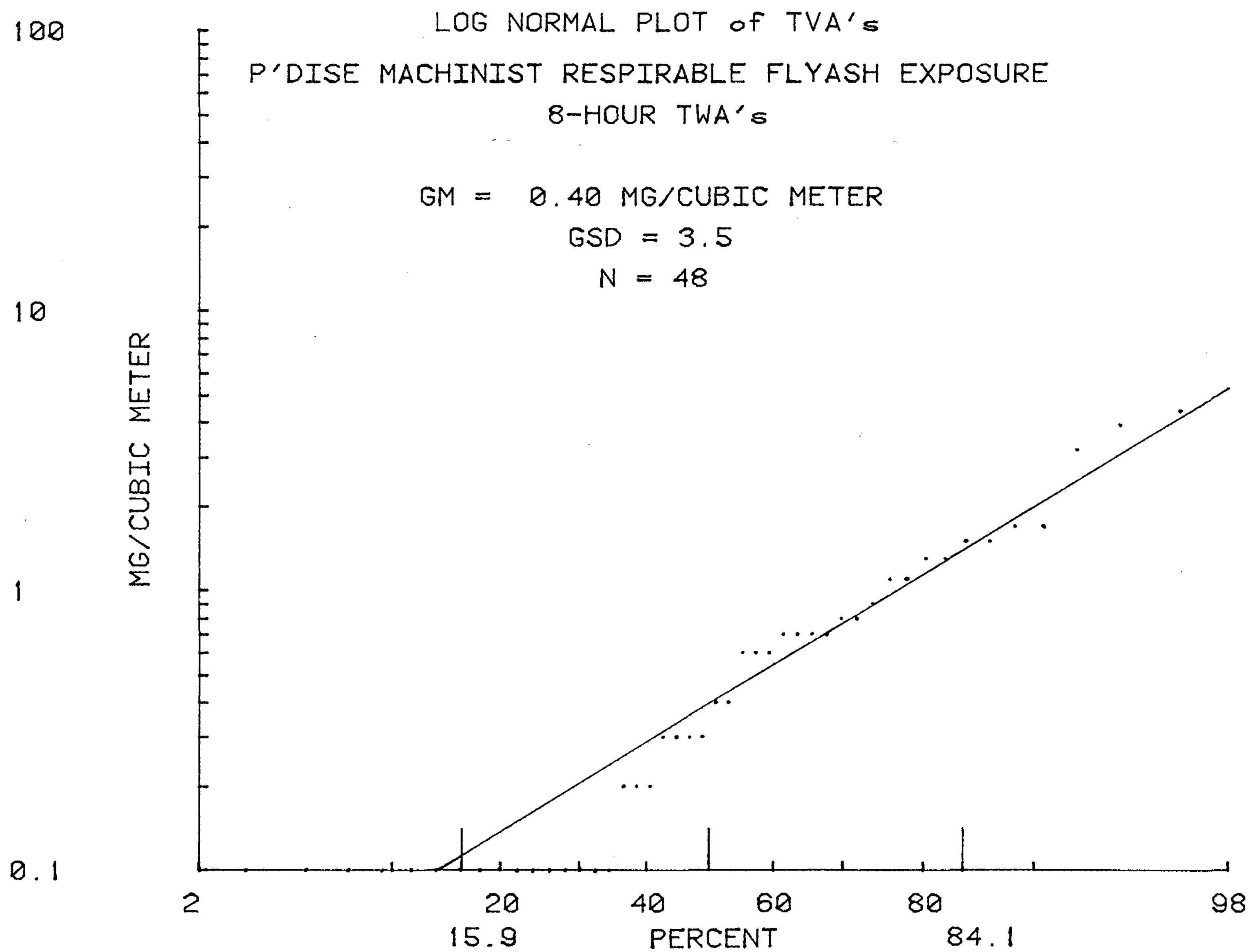

Figure 15. Log-probability plot of respirable fly ash exposure of machinists at Paradise power plant, GM = 0.40 mg/m^3 and GSD = 3.5.

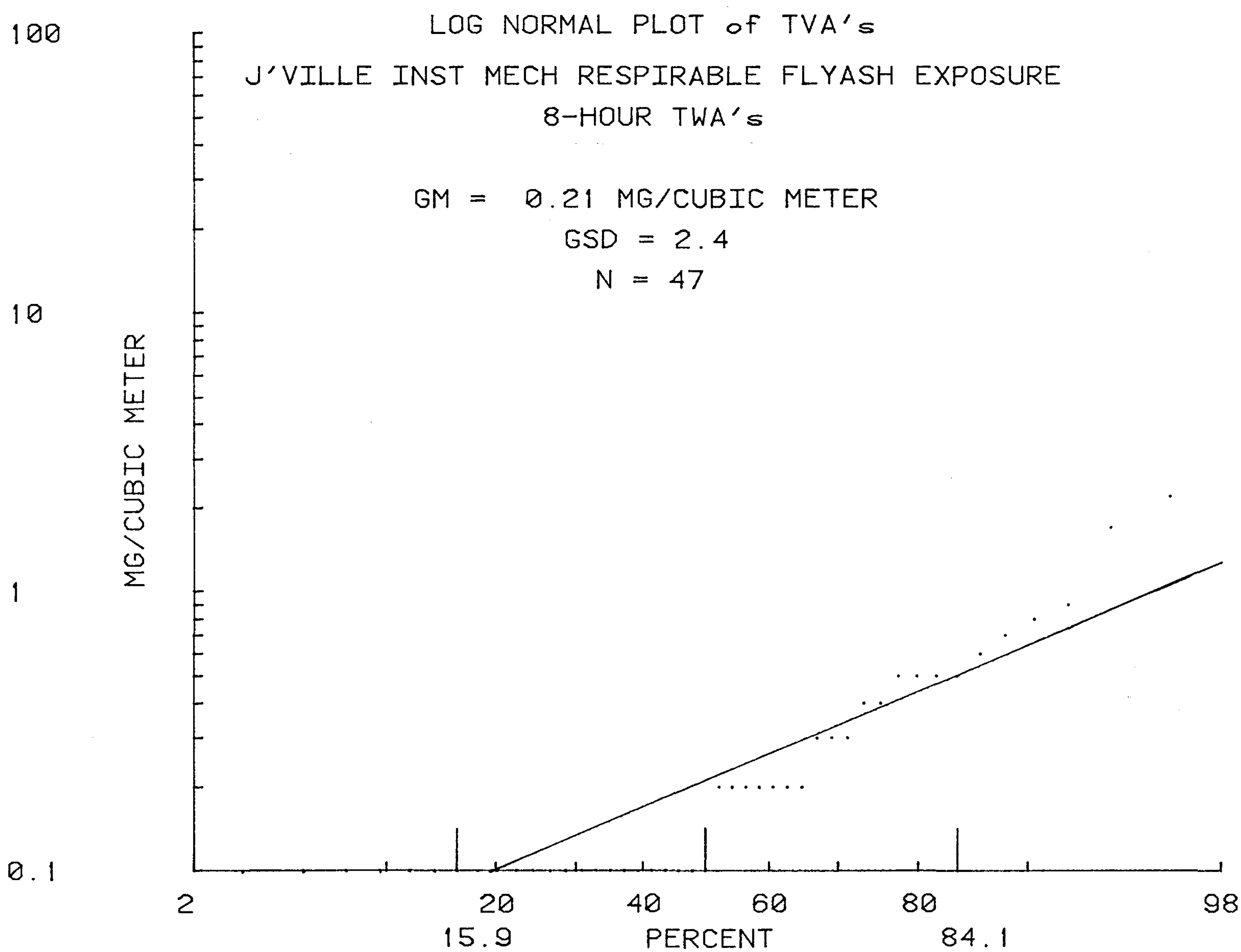

Figure 16. Log-probability plot of respirable fly ash exposures of instrument mechanics at Johnsonville power plant, GM = 0.21 mg/m^3 and GSD = 2.4.

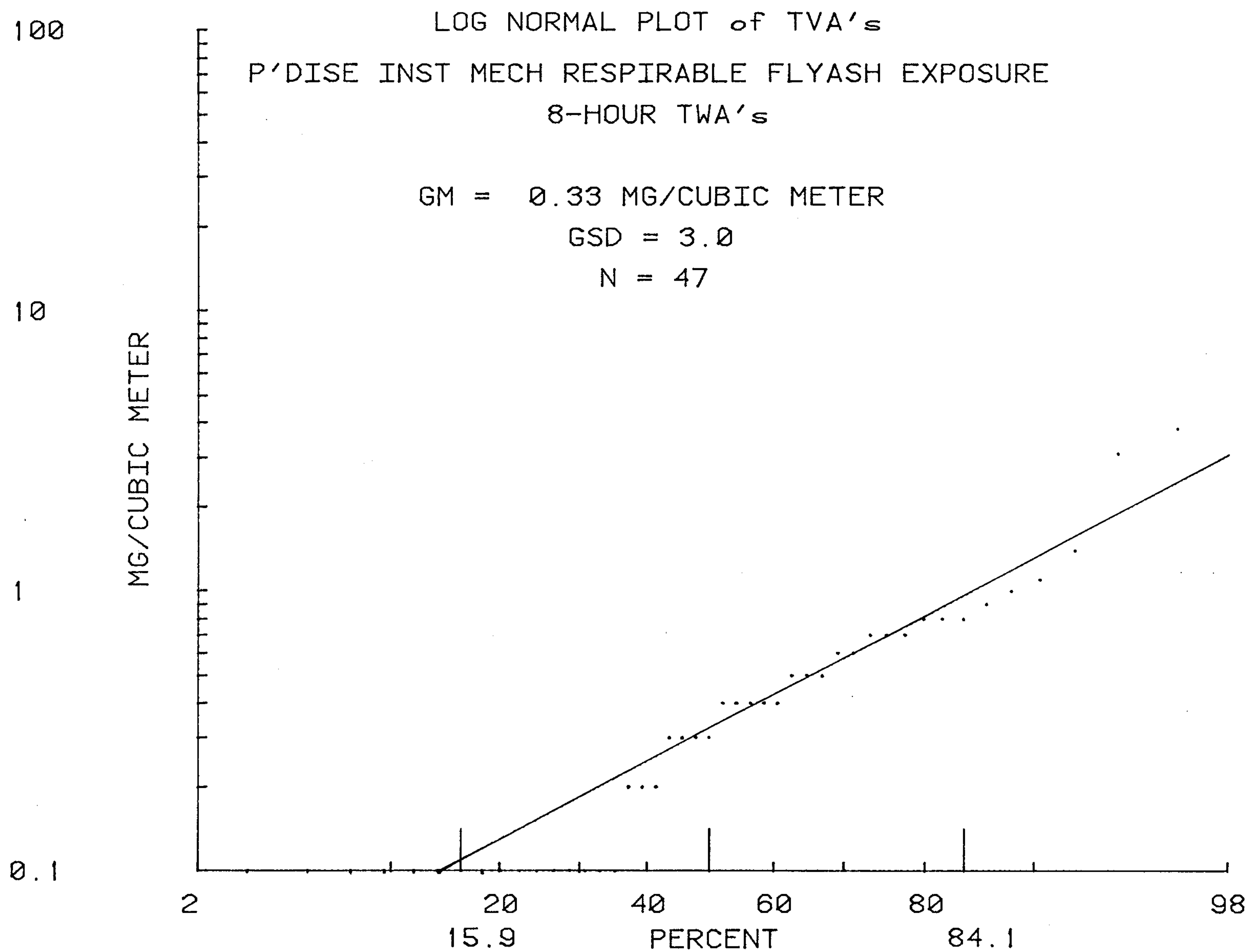

Figure 17. Log-probability plot of respirable fly ash exposures of instrument mechanics at Paradise power plant, GM = 0.33 mg/m^3 and GSD = 3.0.

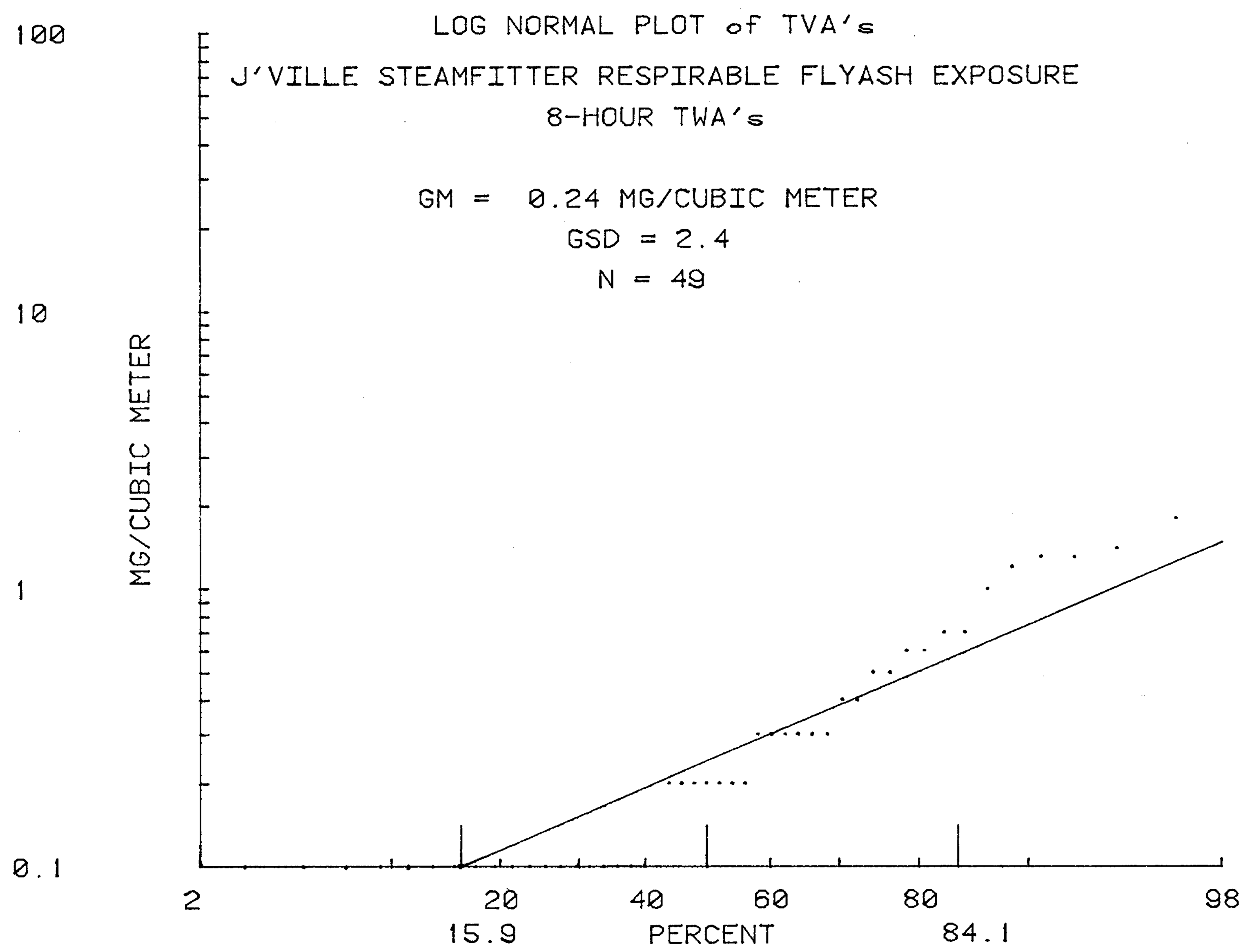

Figure 18. Log-probability plot of respirable fly ash exposures of steamfitters at Johnsonville power plant, GM = 0.24 mg/m^3 and GSD = 2.4.

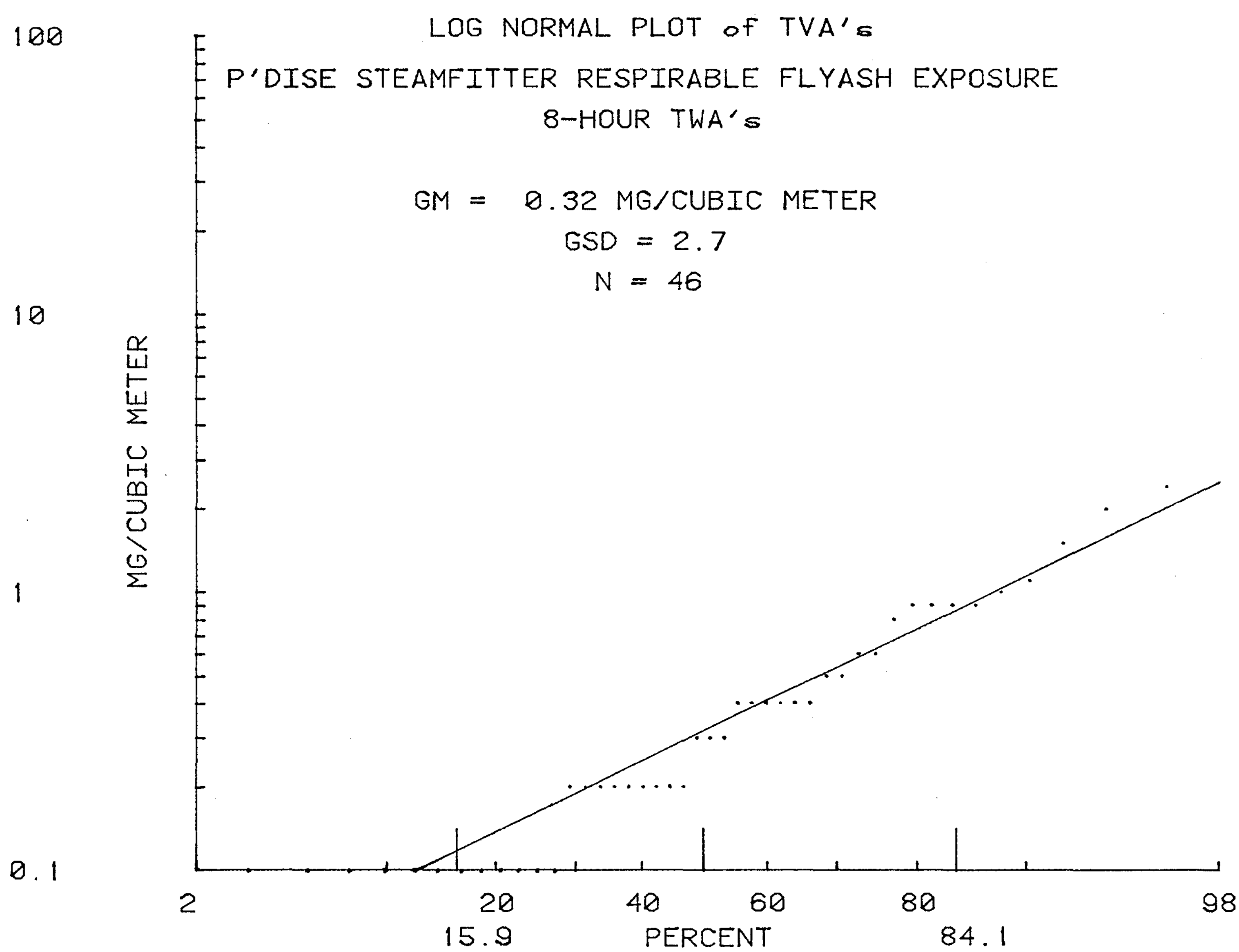

Figure 19. Log-probability of respirable fly ash exposures of steamfitters at Paradise power plant, GM = 0.32 mg/m^3 and GSD = 2.7.

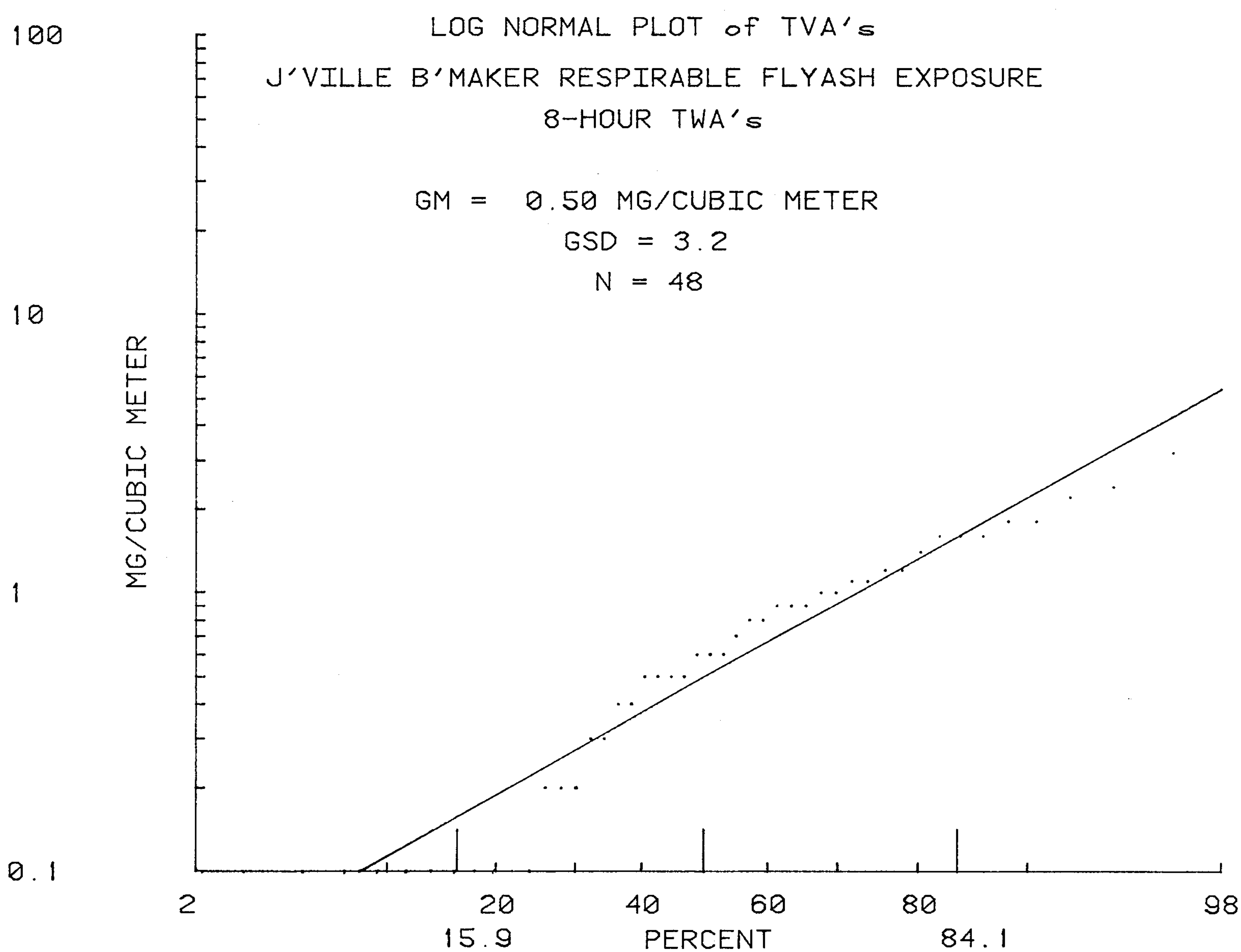

Figure 20. Log-probability plot of respirable fly ash exposure of boilermakers at Johnsonville power plant, GM = 0.50 mg/m^3 and GSD = 3.2.

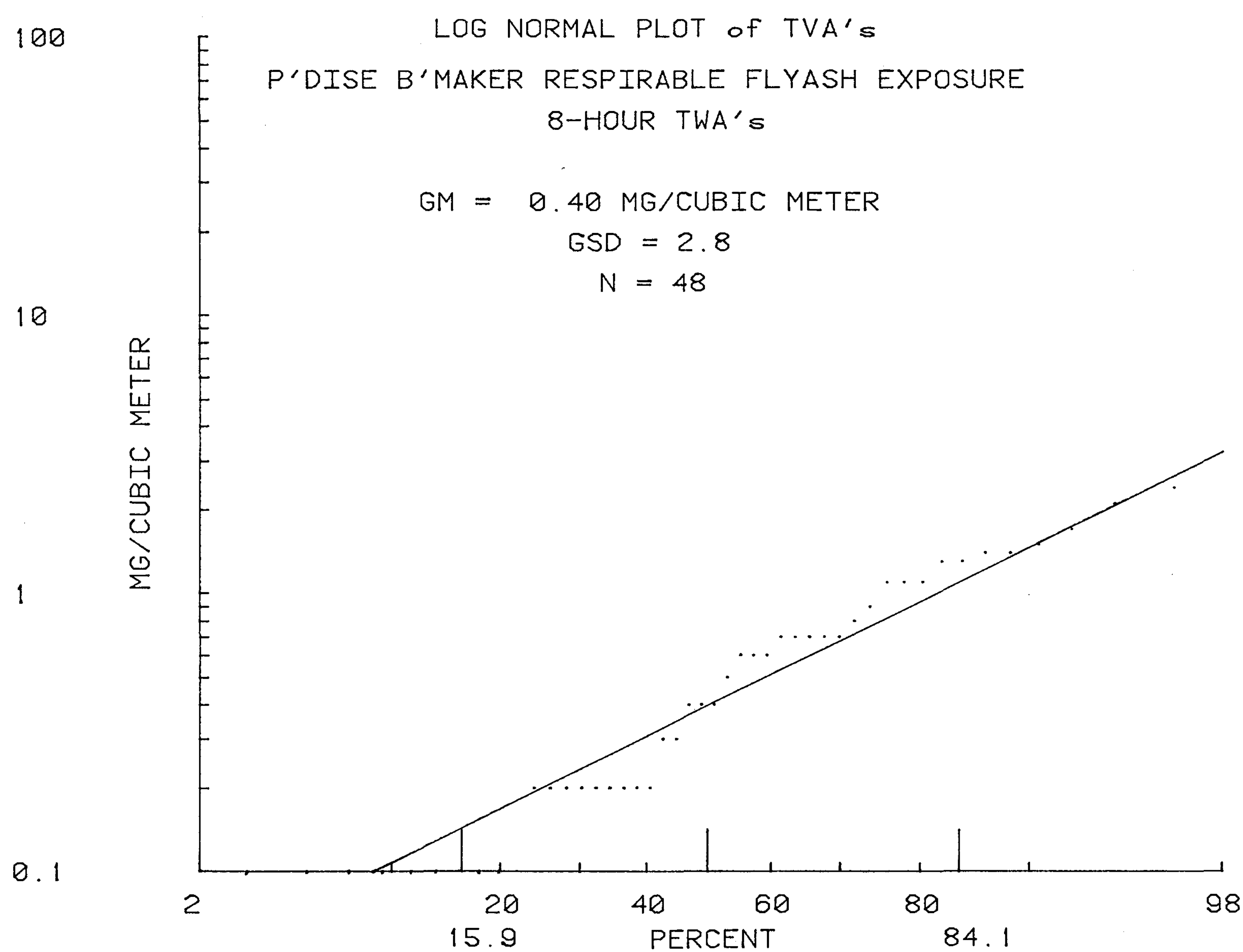

Figure 21. Log-probability of respirable fly ash exposures of boilermakers at Paradise power plant, GM = 0.40 mg/m^3 and GSD = 2.8.

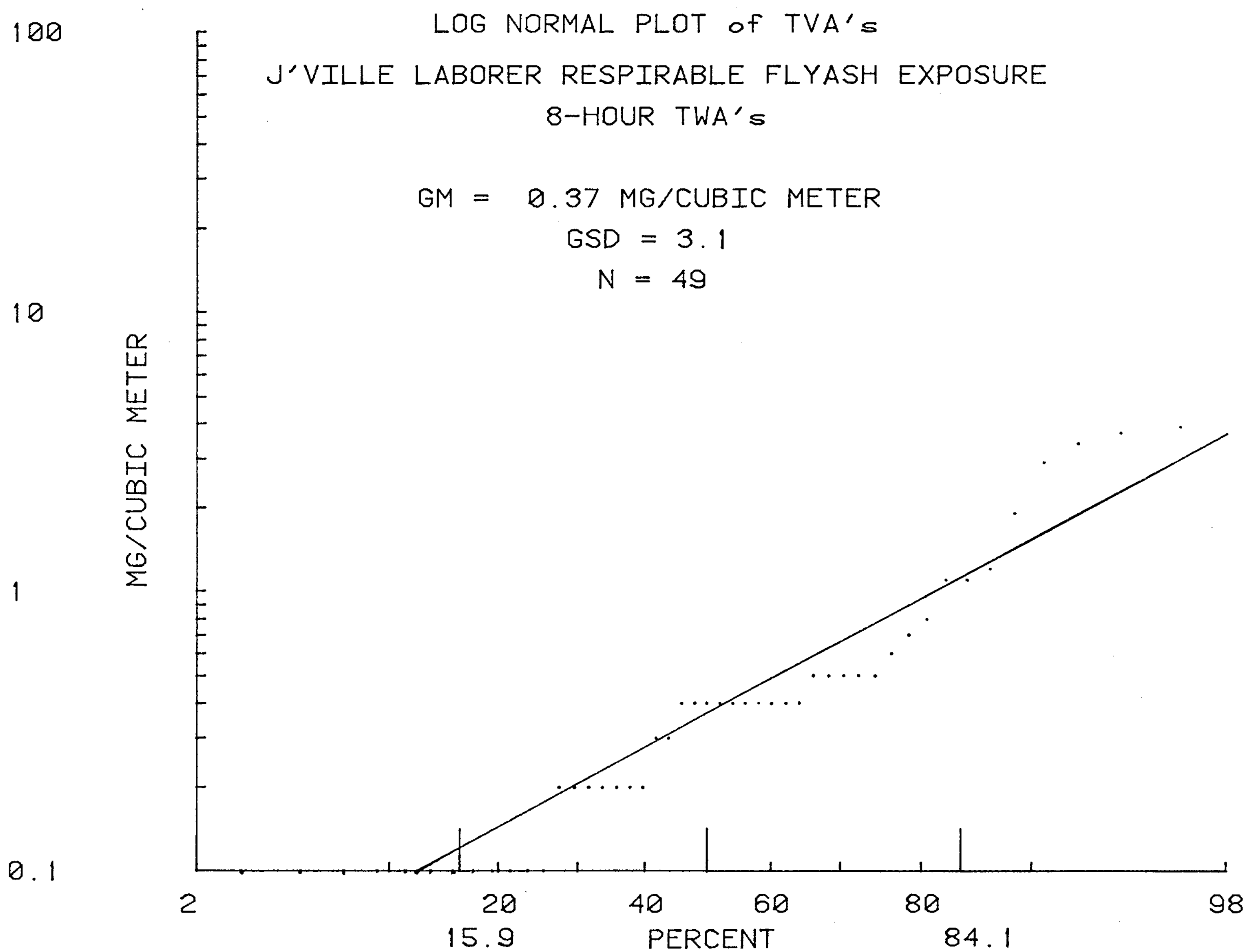

Figure 22. Log-probability plot of respirable fly ash exposures of powerhouse laborers at Johnsonville power plant, GM = 0.37 mg/m^3 and GSD = 3.1.

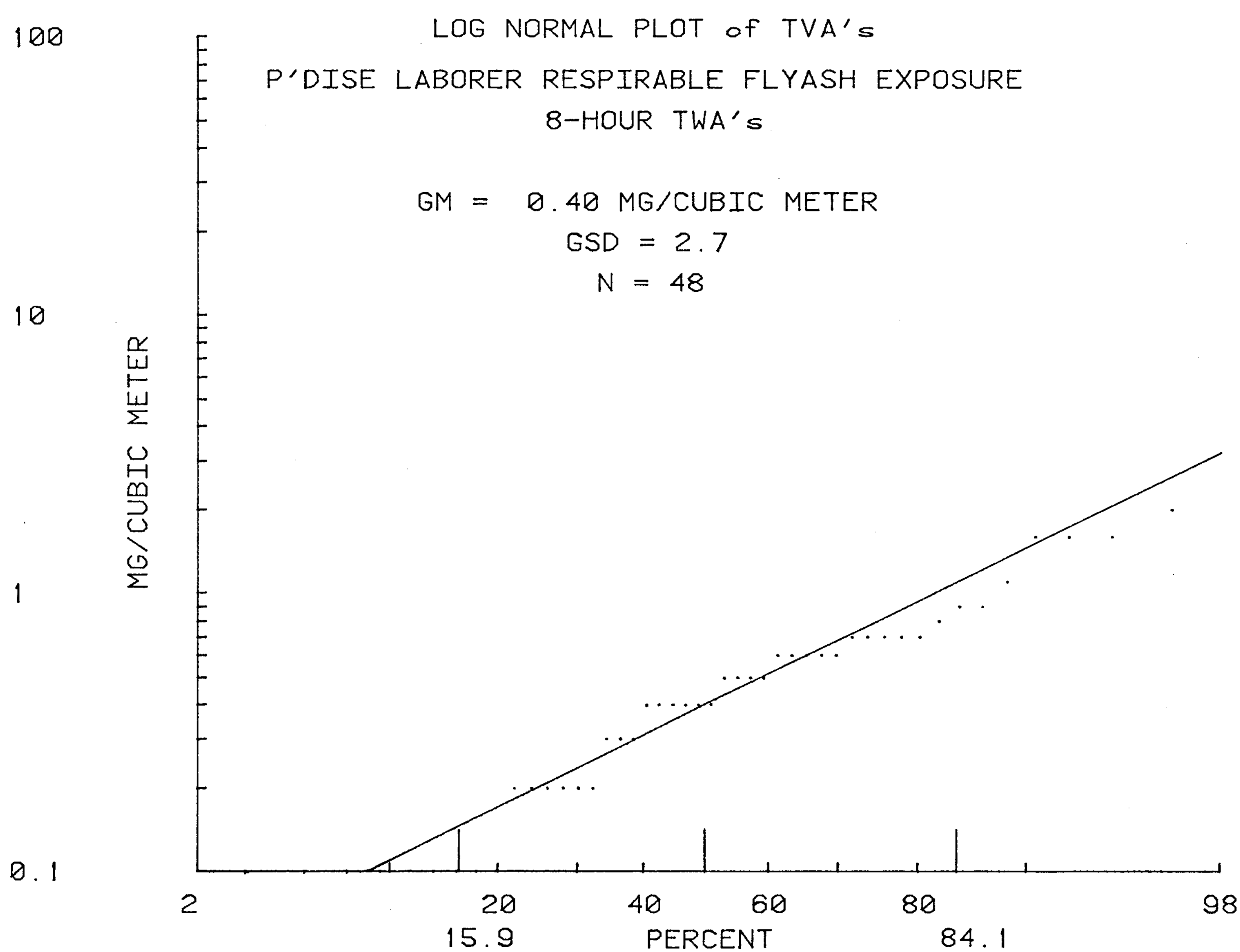

Figure 23. Log-probability plot of respirable fly ash exposures of powerhouse laborers at Paradise power plant, GM = 0.40 mg/m^3 and GSD = 2.7.

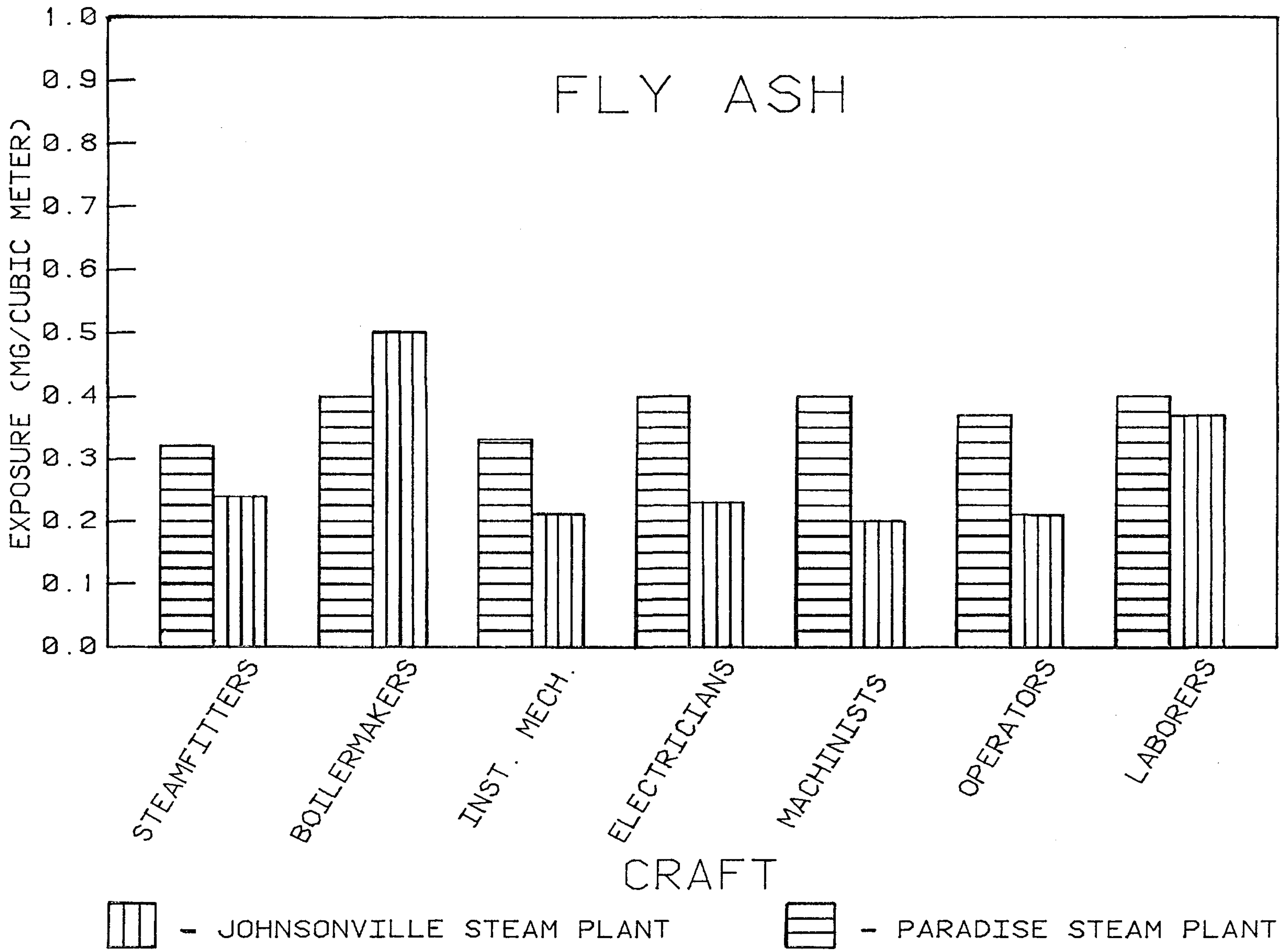

Figure 24. Comparison of respirable fly ash exposure levels of craft groups at Johnsonville and Paradise power plants.

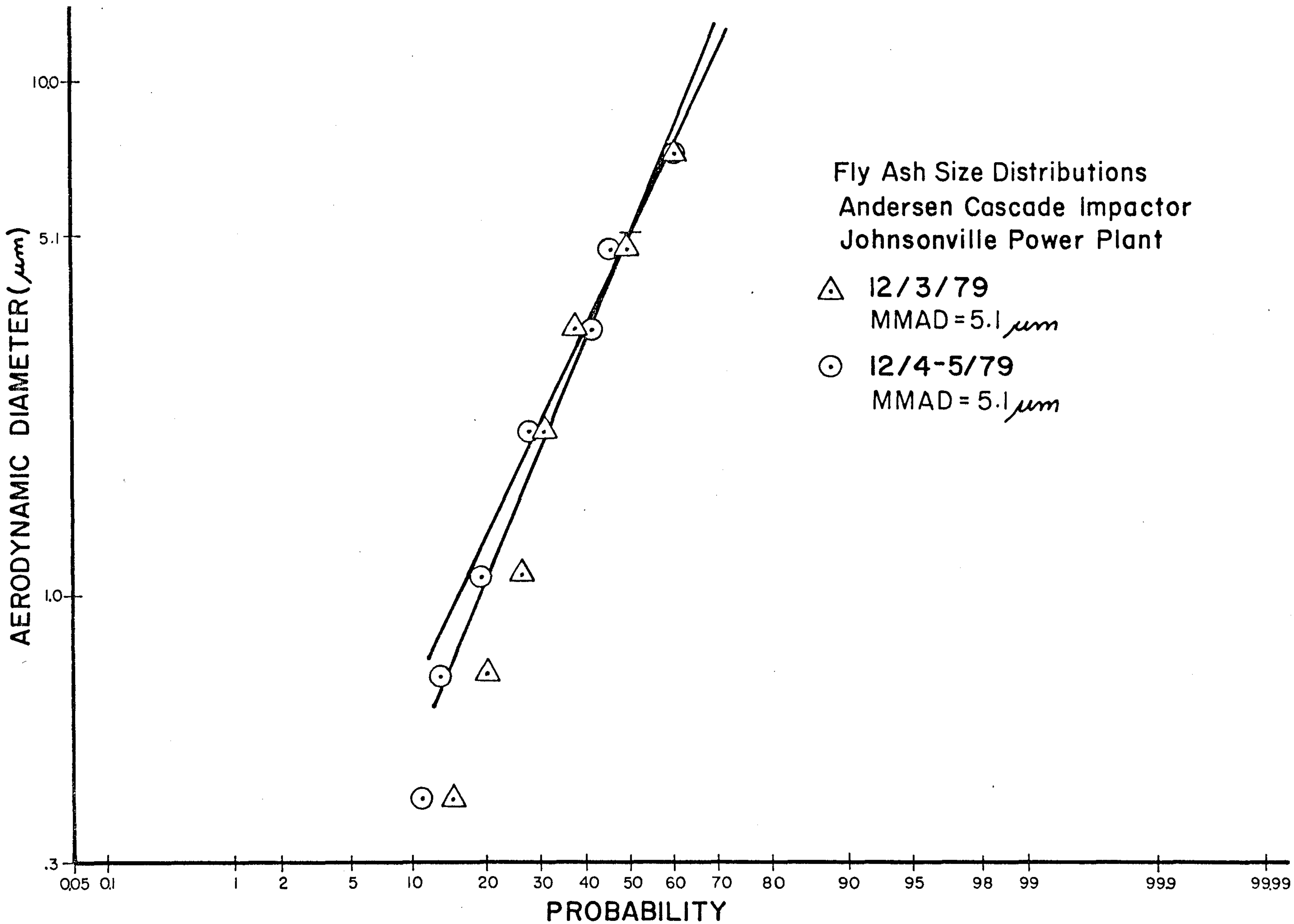

Figure 25. Fly ash size distributions at Johnsonville power plant, 6.3 hour sample on level 5 between units 2 and 3, 12/3/79; and 24 hour sample on level 4 of unit 2, 12/4 to 12/5/79.

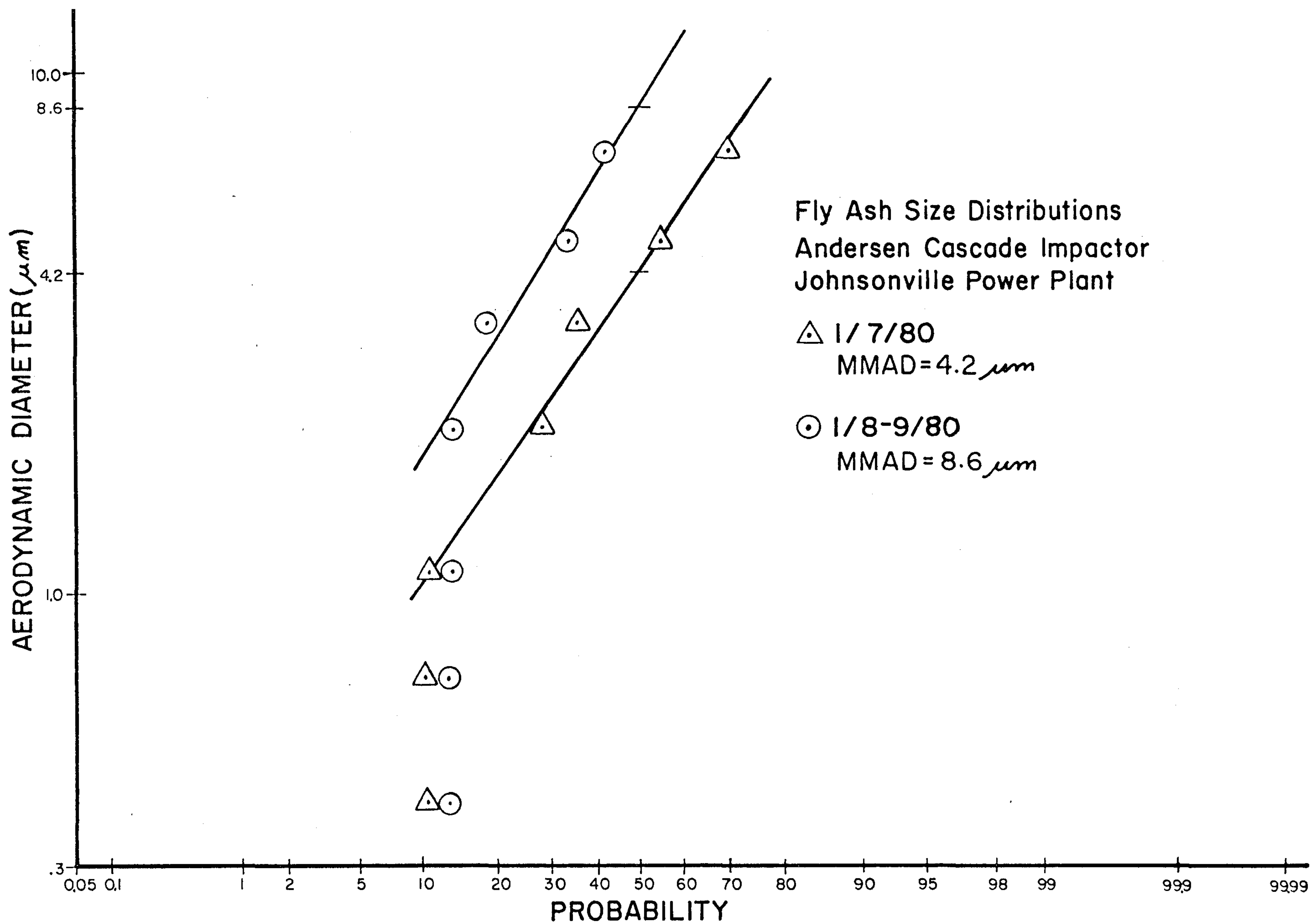

Figure 26. Fly ash size distribution at Johnsonville power plant, 6.1 hour sample on level 5, unit 5, 1/7/80; and 24 hour sample on level 4, unit 6, 1/8 to 1/9/80.

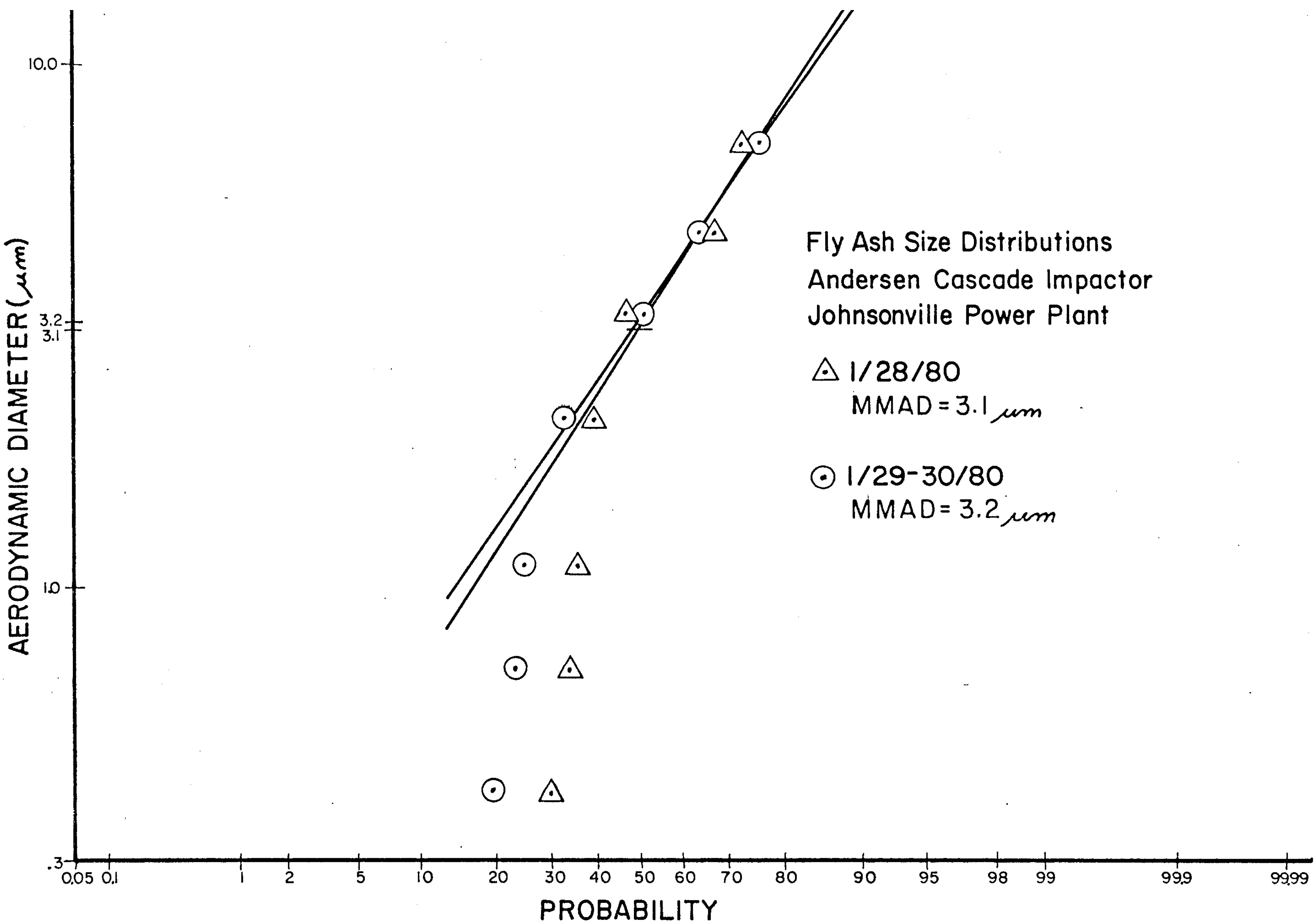

Figure 27. Fly ash size distribution at Johnsonville power plant, 6.9 hour sample on level 5 of unit 3, 1/28/80; and 24 hour sample on level 4 between units 3 and 4, 1/29 to 1/30/80.

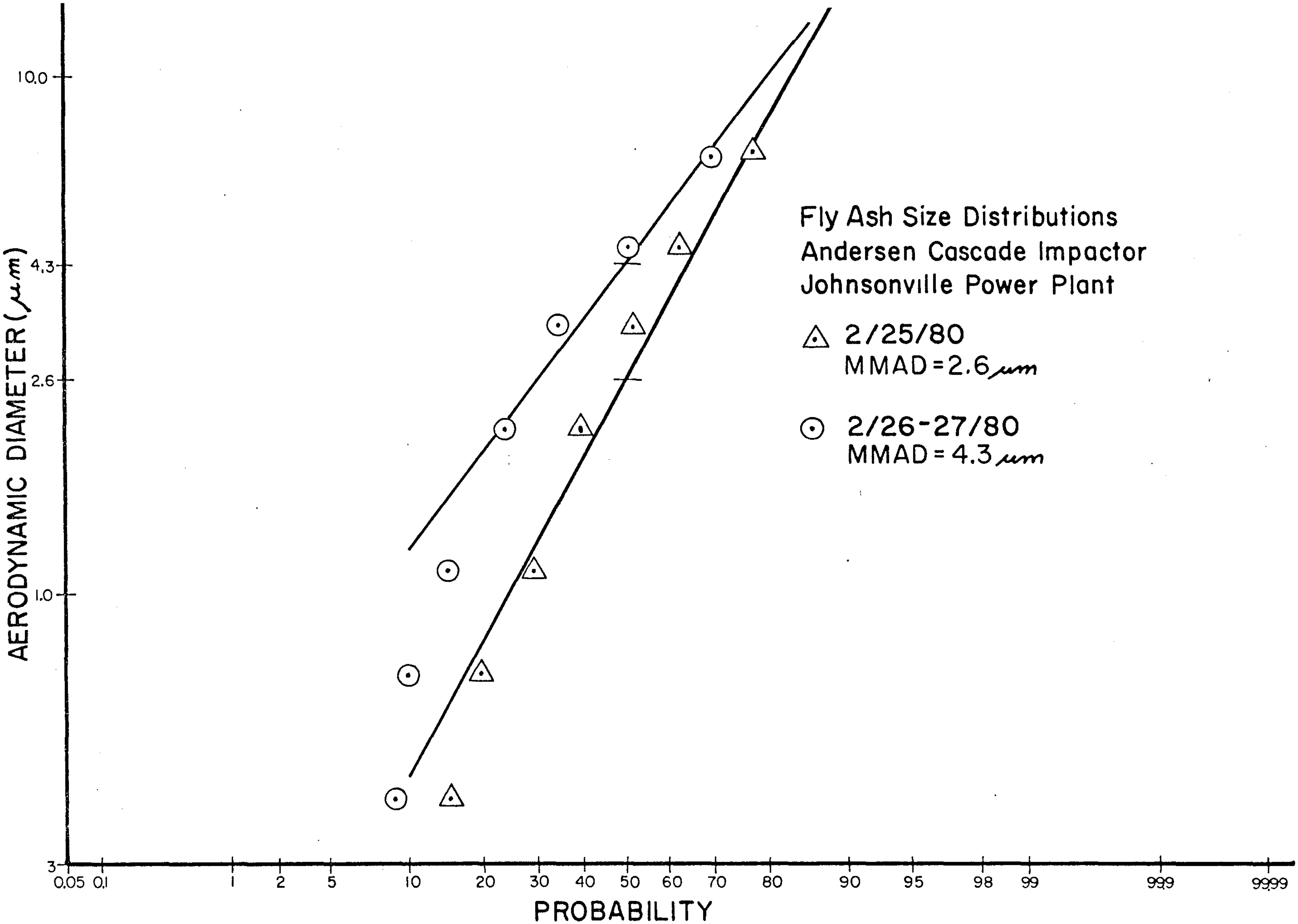

Figure 28. Fly ash size distribution at Johnsonville power plant, 5.8 hour sample on level 5 of unit 5, 2/25/80; and 24 hour sample on level 4 between units 5 and 6, 2/26 to 2/27/80.

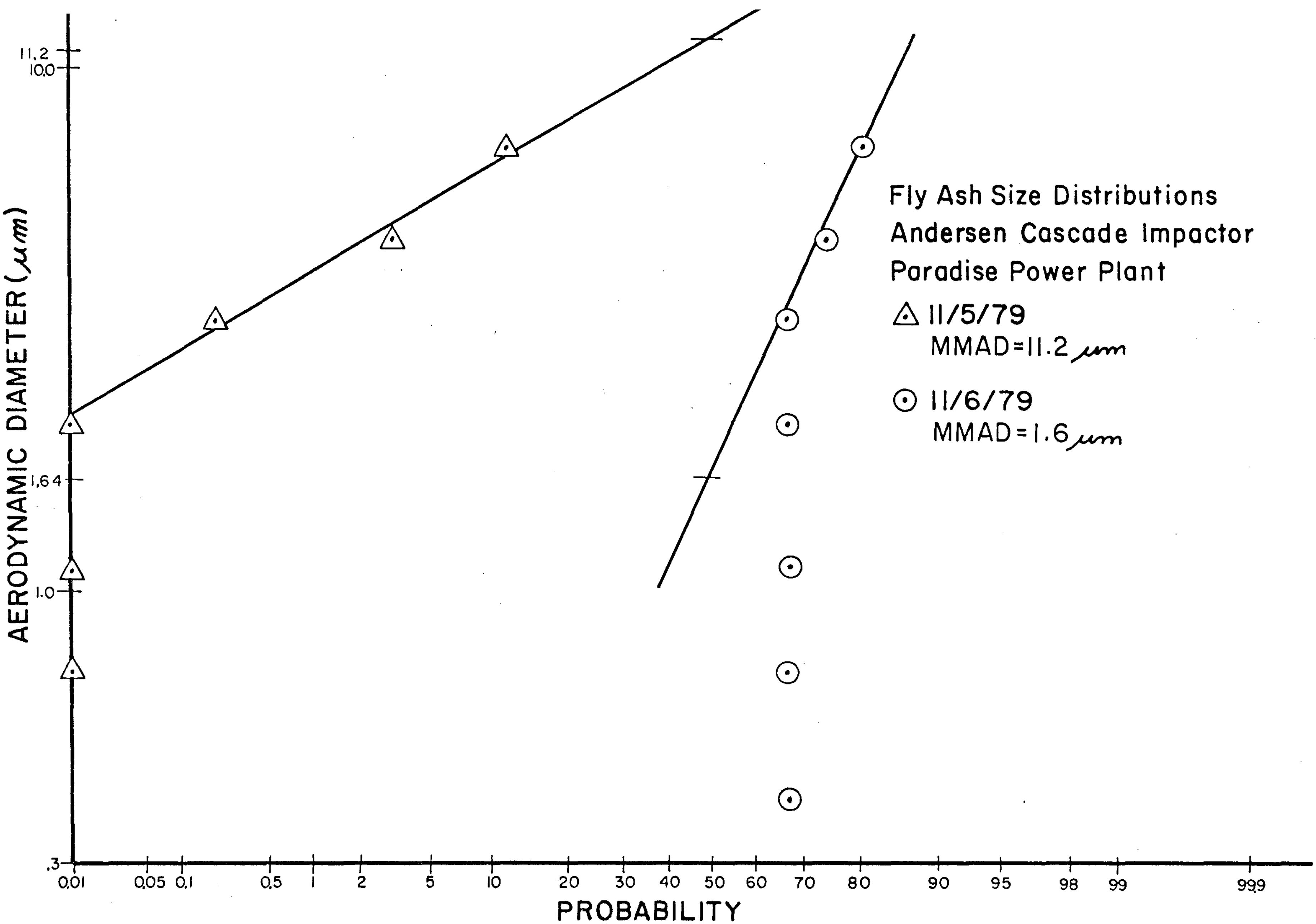

Figure 29. Fly ash size distribution at Paradise power plant, 5.1 hour sample on level 4, south side of unit 3, 11/5/79; and a sample on level 5, south side of unit 1 for an unknown time period, 11/6/79.

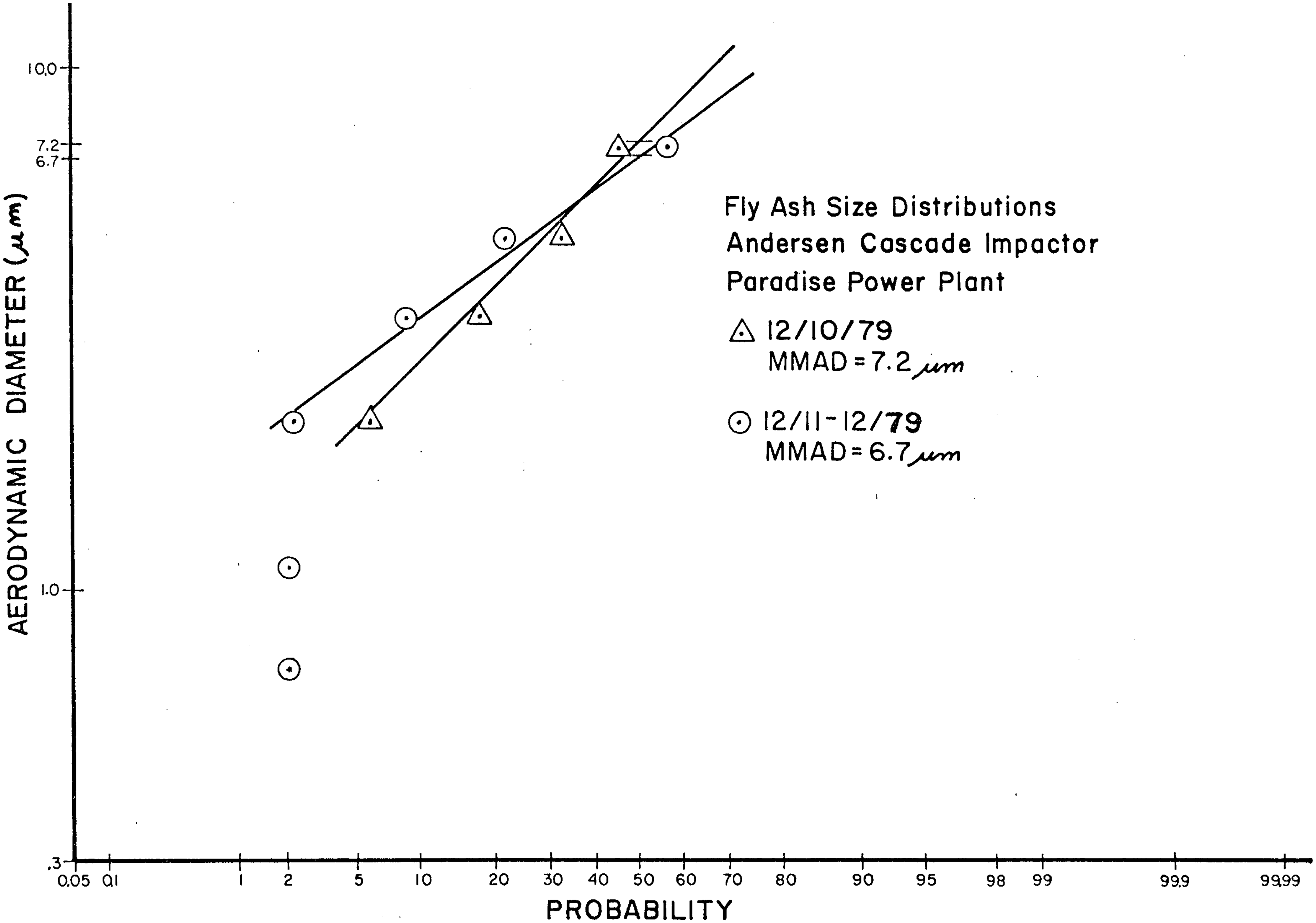

Figure 30. Fly ash size distributions at Paradise power plant, 4.0 hour sample on level 4, south side of unit 3, 12/10/79; and 24 hour sample on level 3, north side of unit 2, 12/11 to 12/12/79.

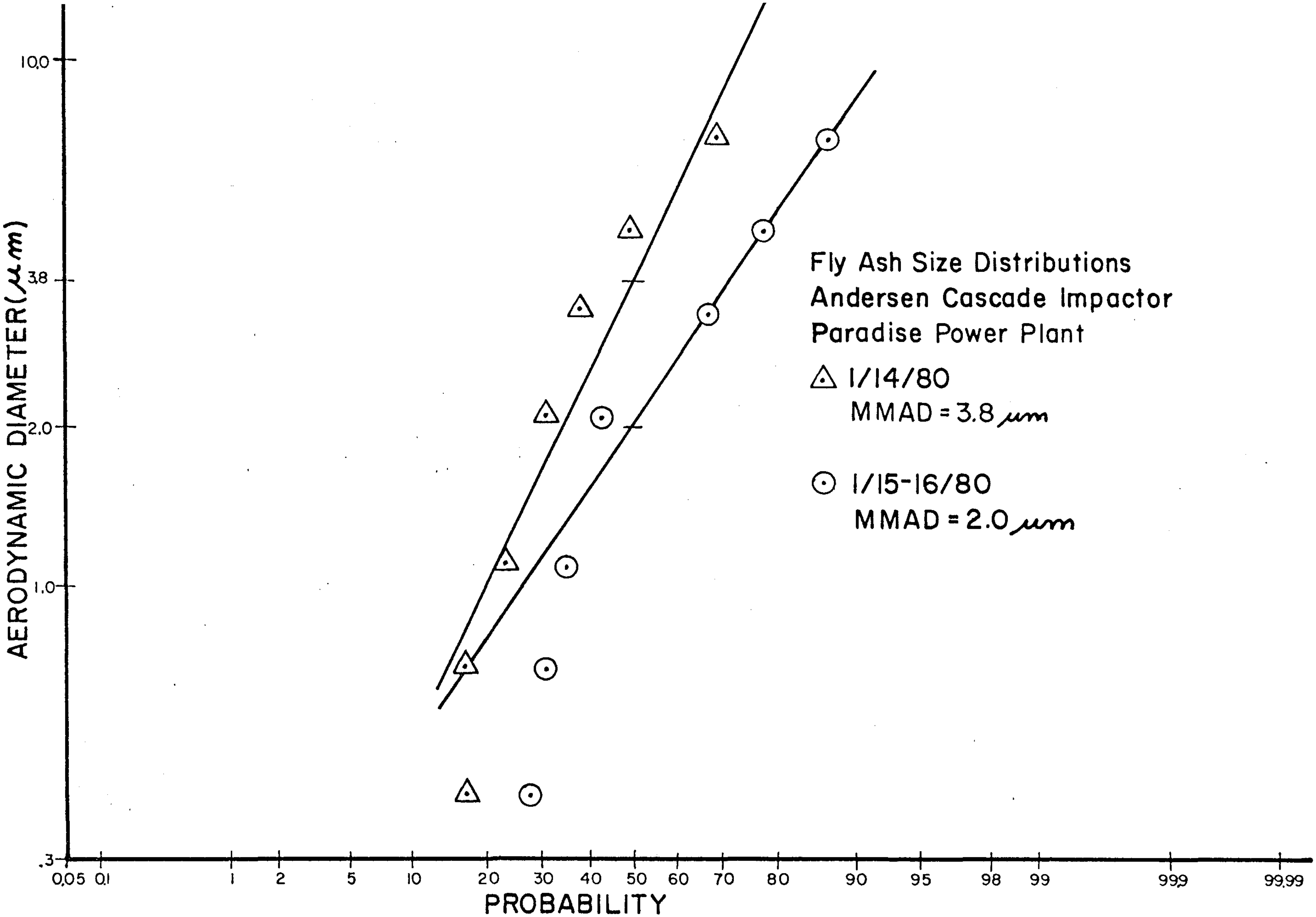

Figure 31. Fly ash size distribution at Paradise power plant, 6.7 hour sample on level 3, north side of unit 2, 1/14/80; and 24 hour sample on level 1, north side of unit 3, 1/15 to 1/16/80.

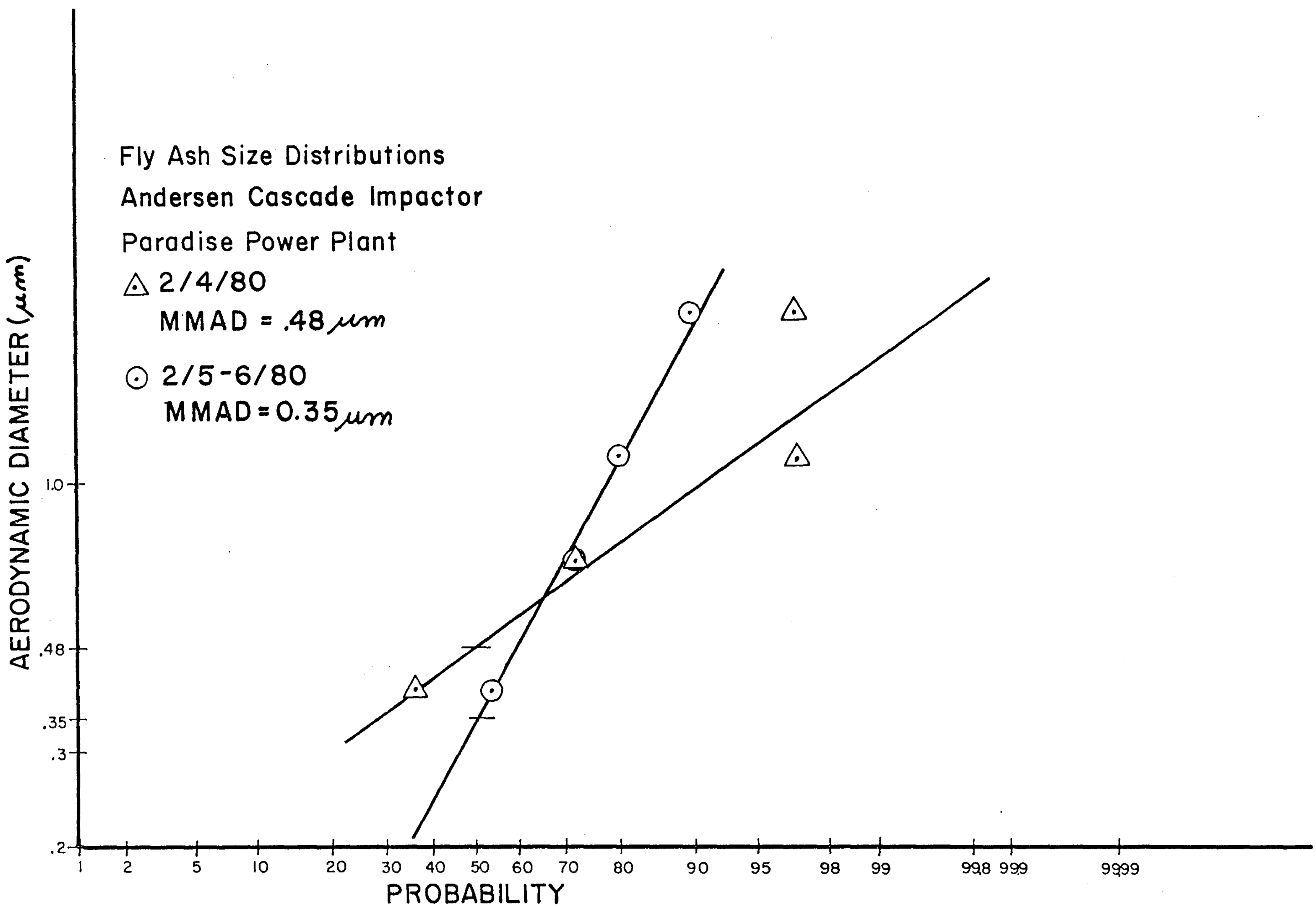

Figure 32. Fly ash size distribution at Paradise power plant, 6.8 hour sample on level 3, east side of unit 2, 2/4/80; and 24 hour sample on level 3 between units 2 and 3, 2/5 to 2/6/80.

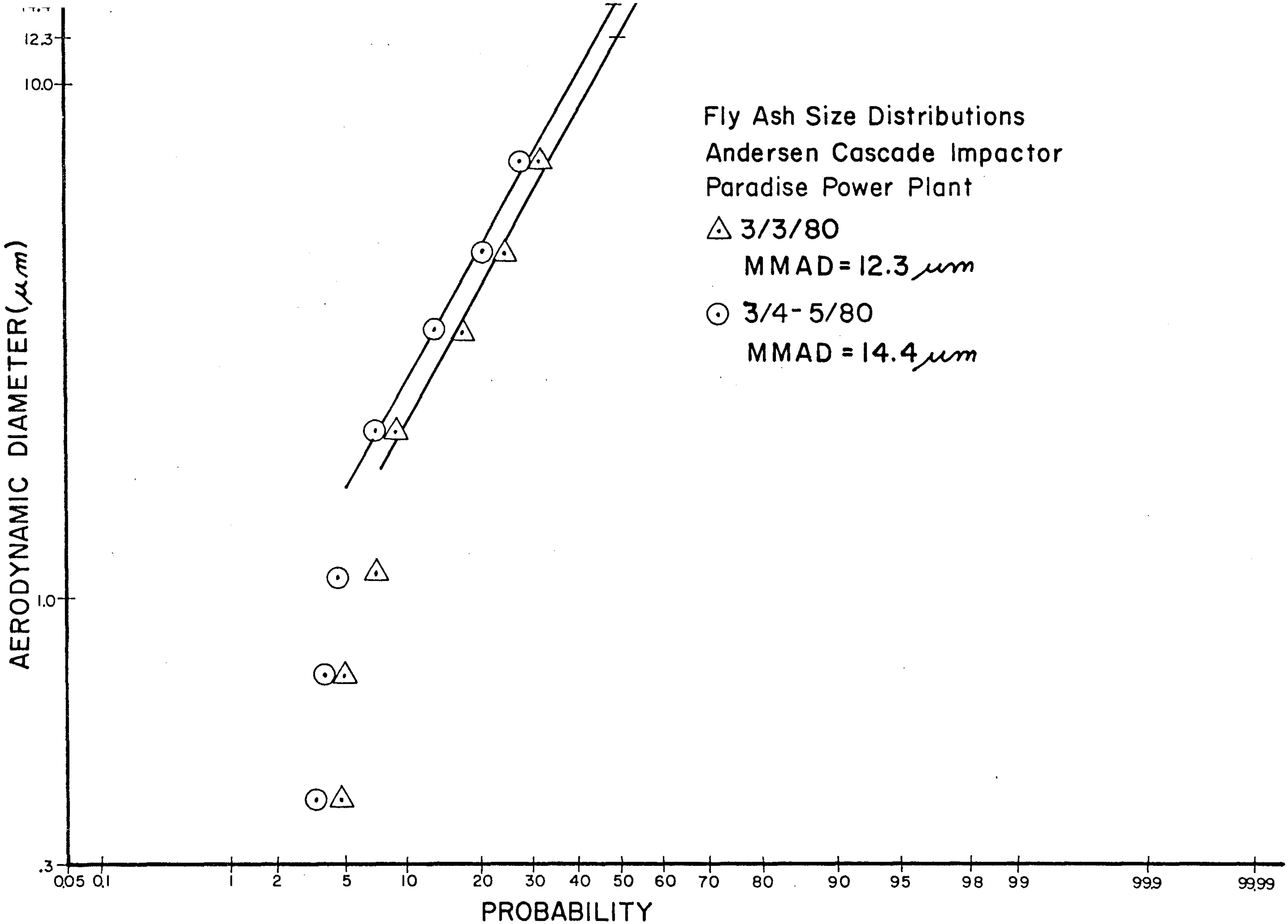

Figure 33. Fly ash size distribution at Paradise power plant, 5.8 hour sample on level 3, east side of unit 2, 3/3/80; and 24 hour sample on level 3 between units 2 and 3, 3/4 to 3/5/80.

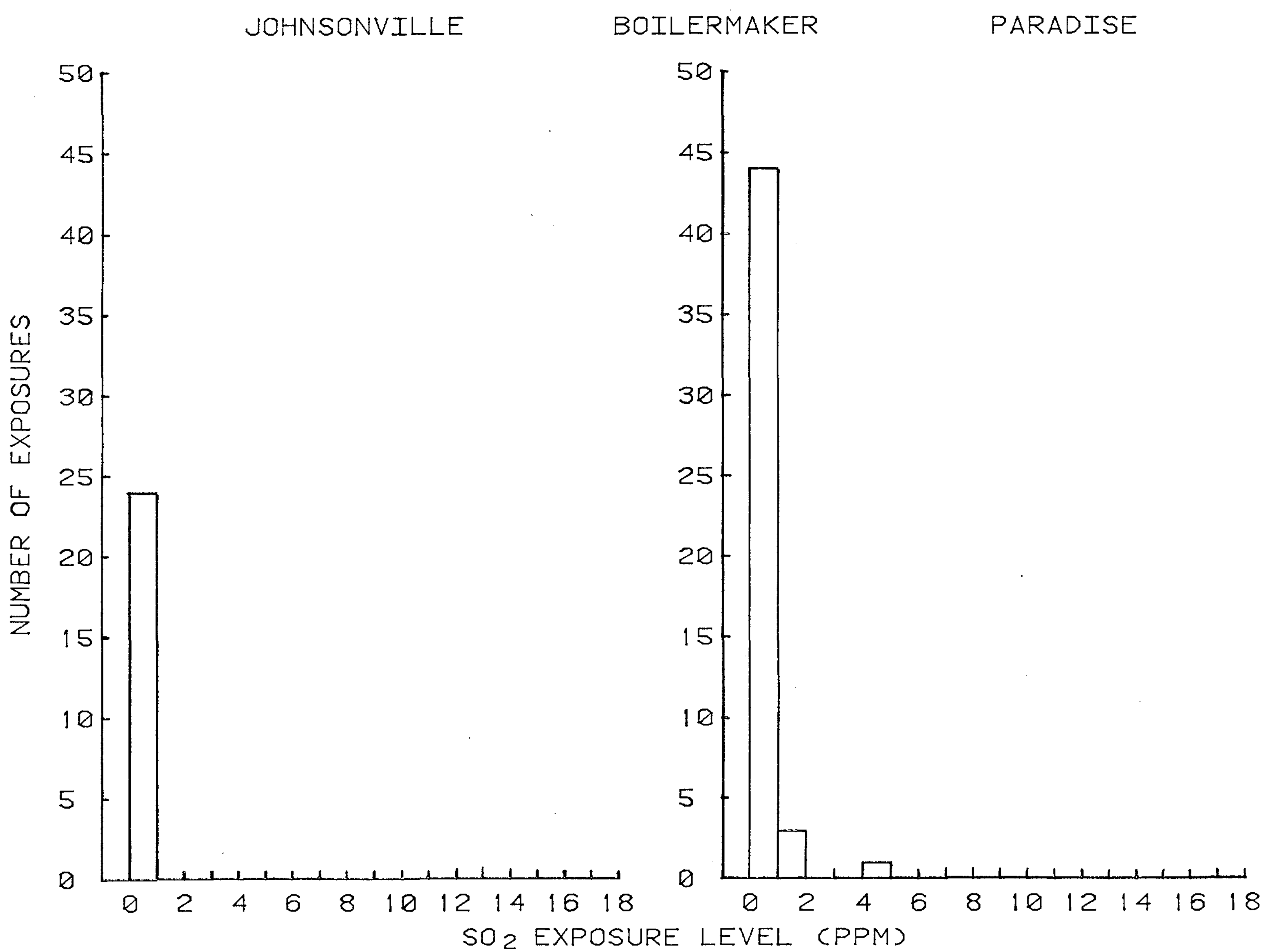

Figure 34. Frequency of sulfur dioxide exposures of boilermakers at Johnsonville and Paradise power plants.

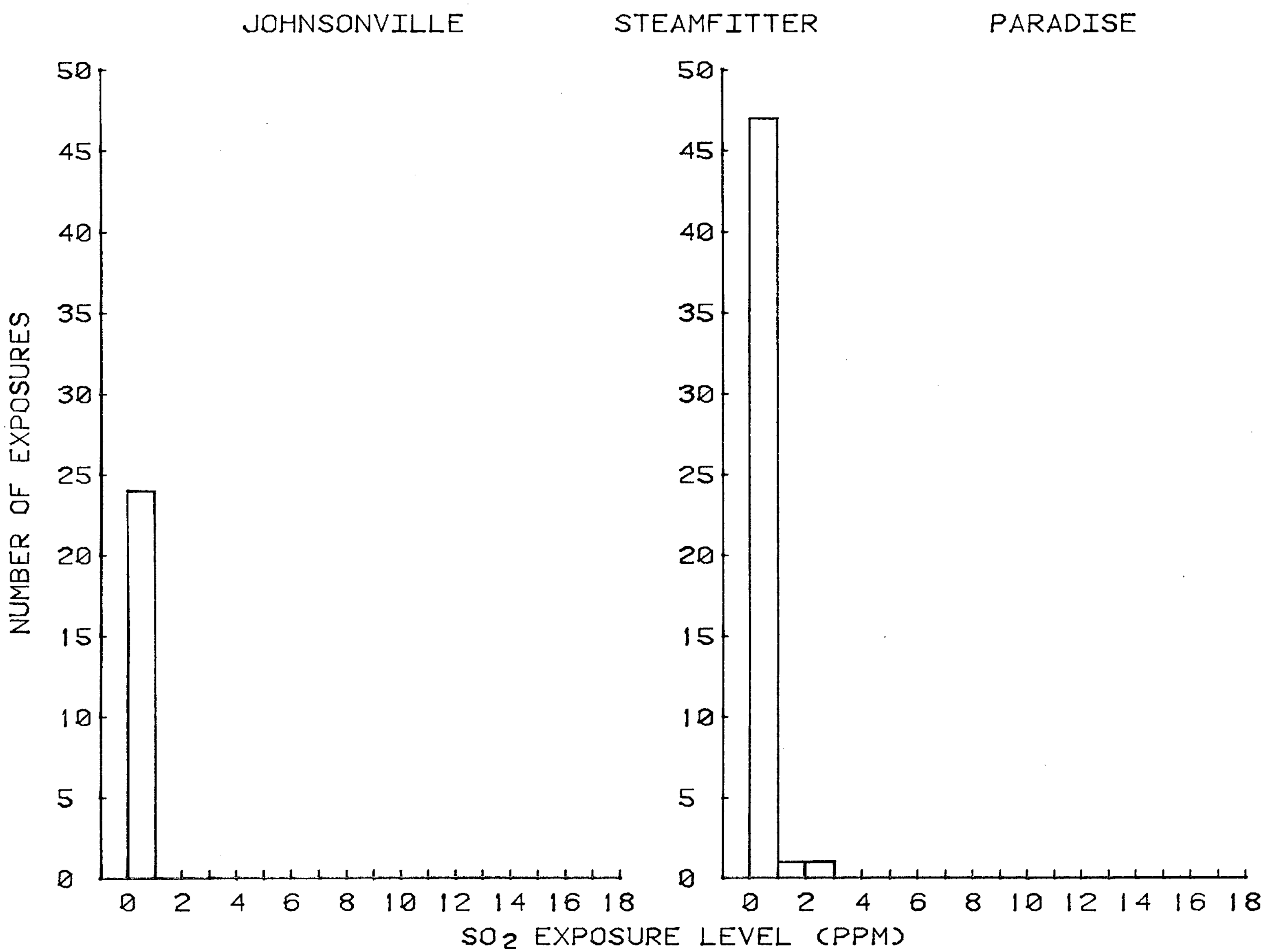

Figure 35. Frequency of sulfur dioxide exposures of steamfitters at Johnsonville and Paradise power plants.

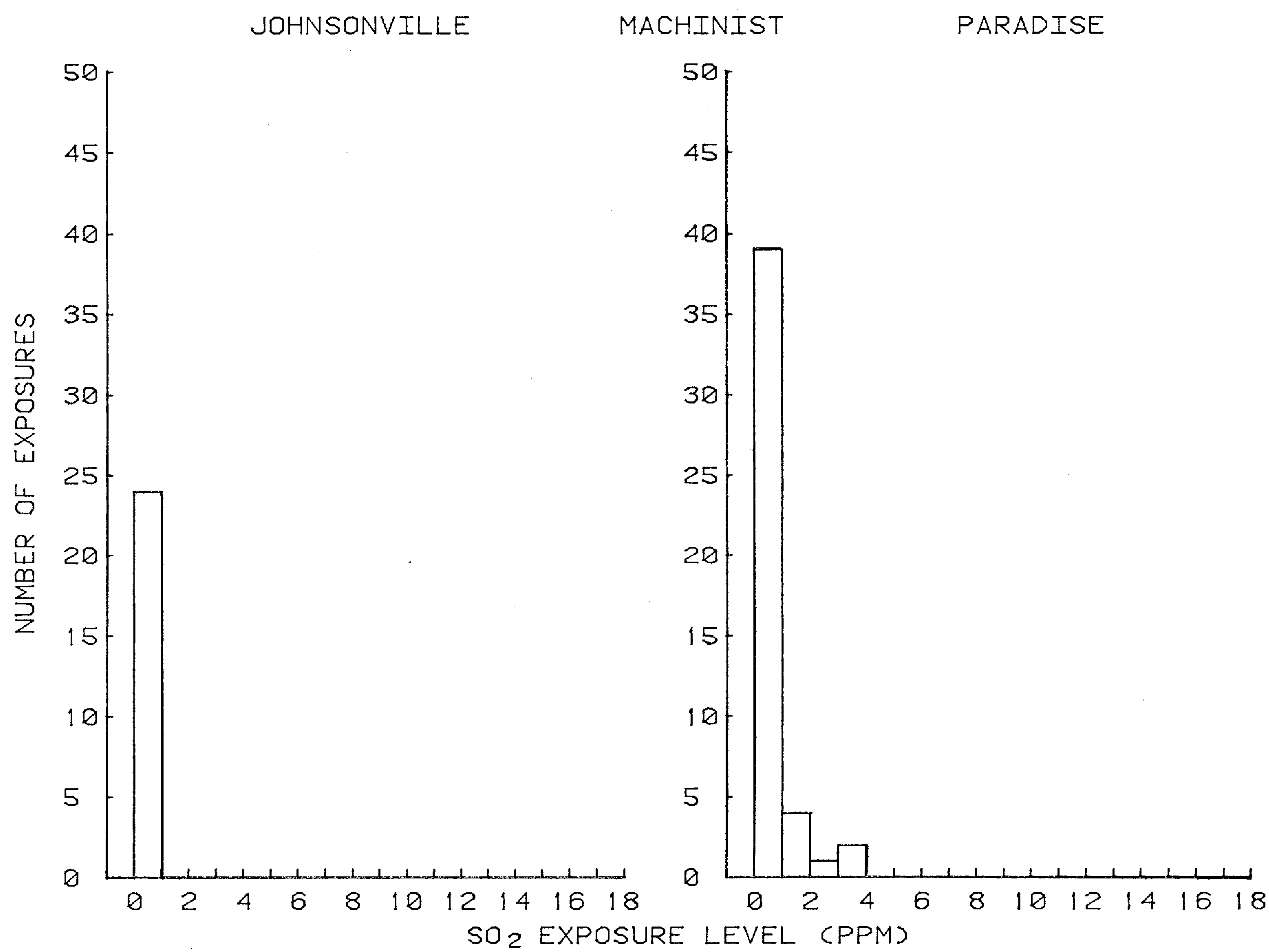

Figure 36. Frequency of sulfur dioxide exposures of machinists at Johnsonville and Paradise power plants.

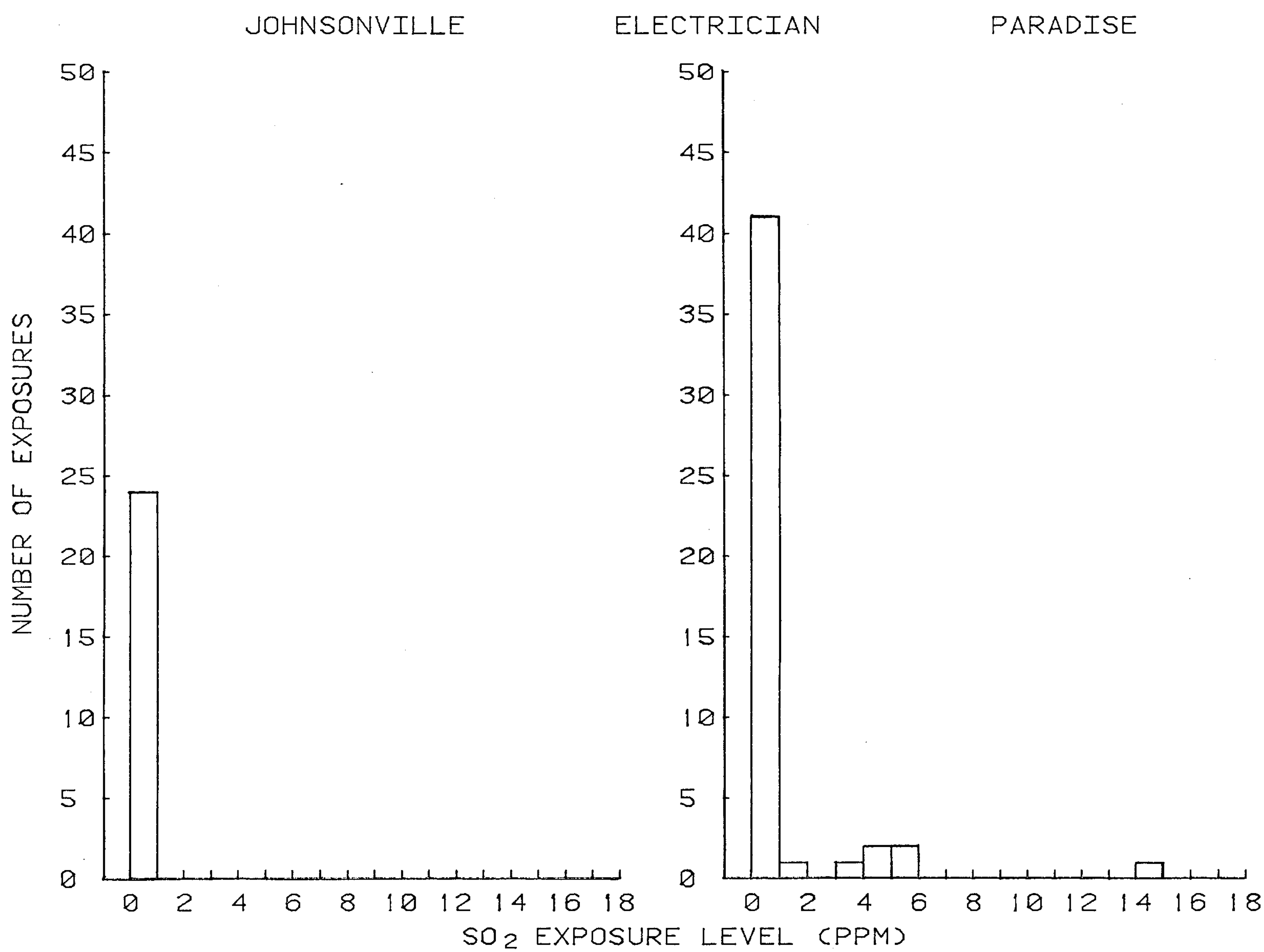

Figure 37. Frequency of sulfur dioxide exposures of electricians at Johnsonville and Paradise power plants.

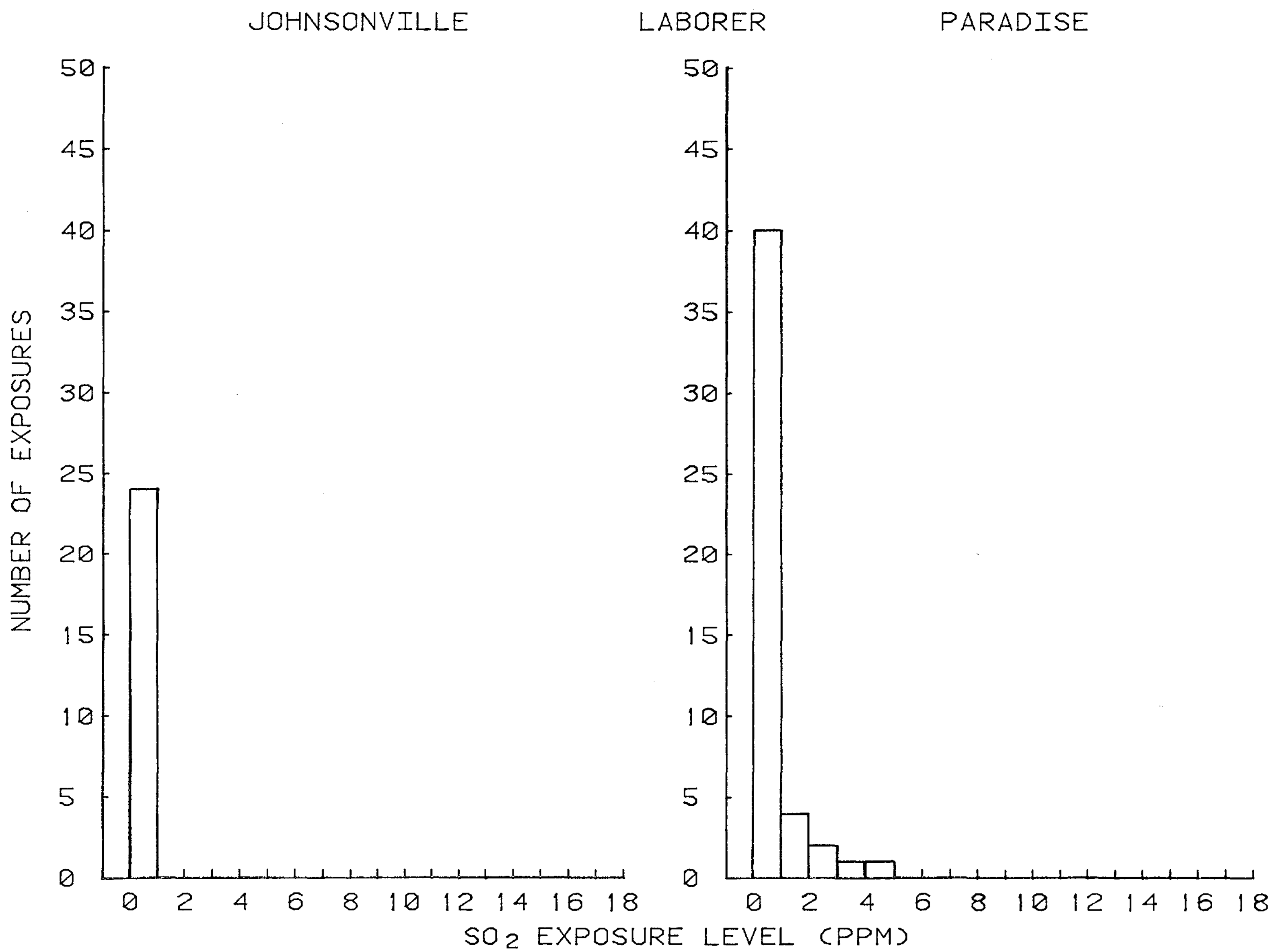

Figure 38. Frequency of sulfur dioxide exposures of laborers at Johnsonville and Paradise power plants.

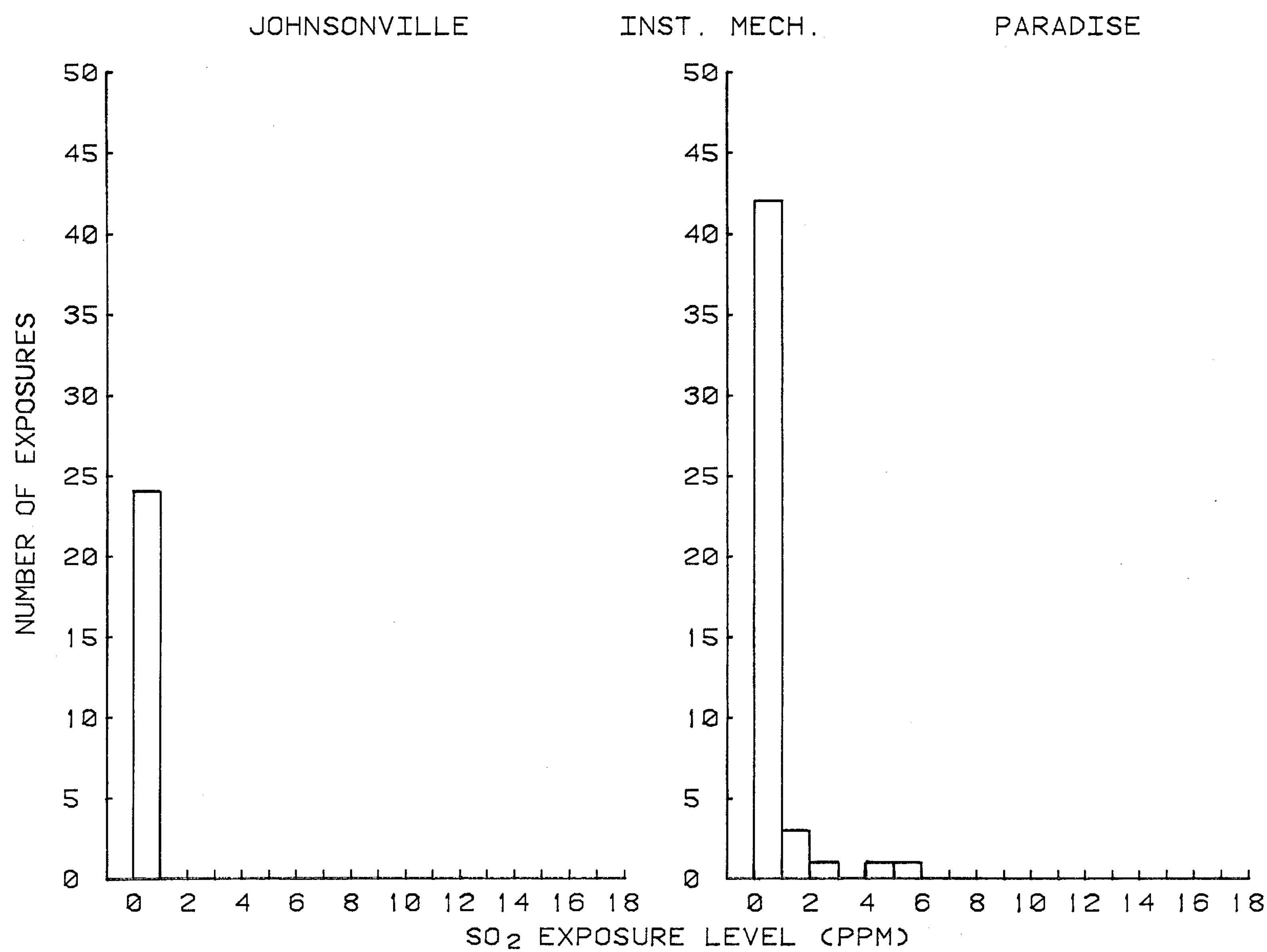

Figure 39. Frequency of sulfur dioxide exposures of instrument mechanics at Johnsonville and Paradise power plants.

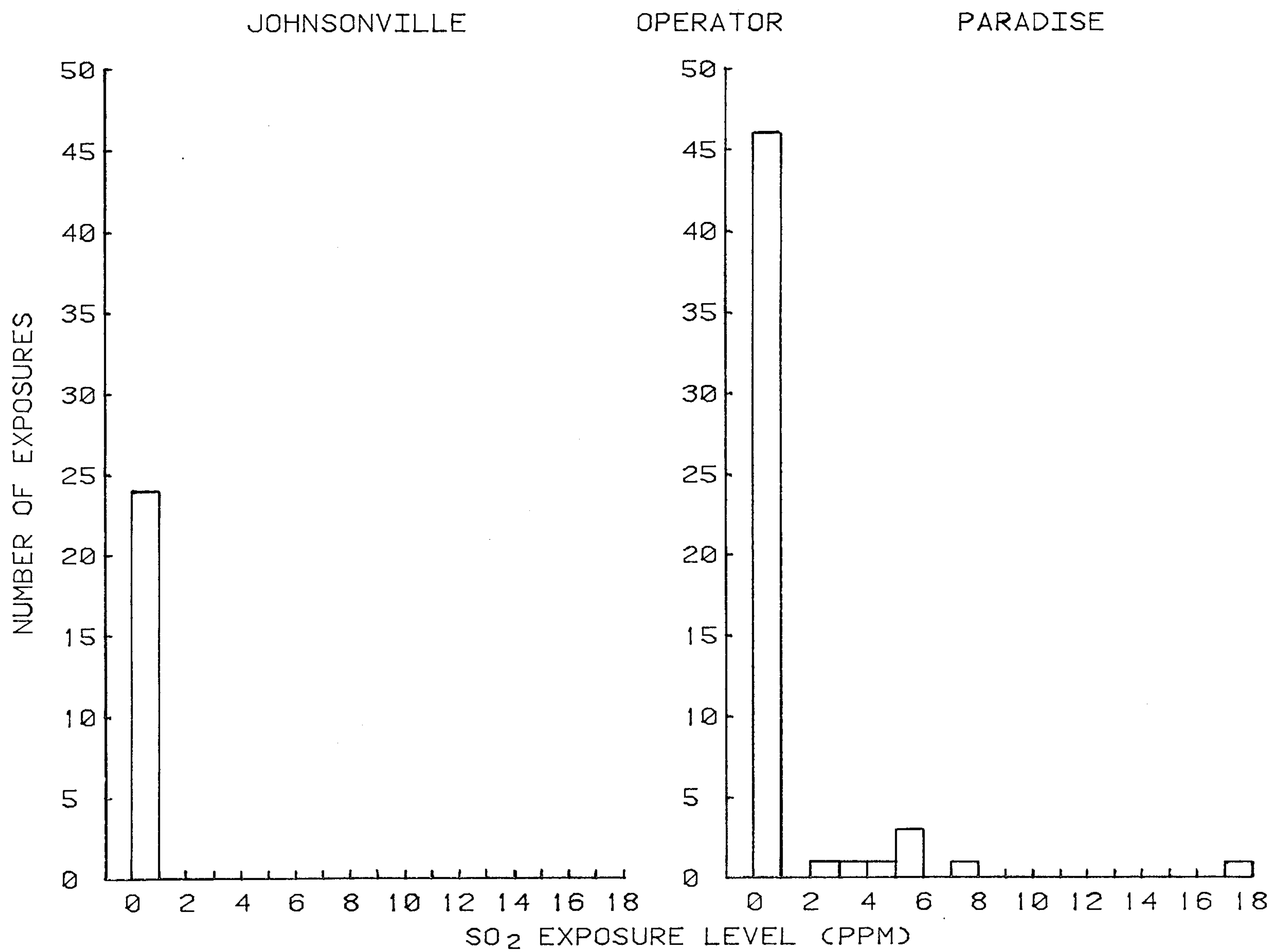

Figure 40. Frequency of sulfur dioxide exposures of operators at Johnsonville and Paradise power plants.

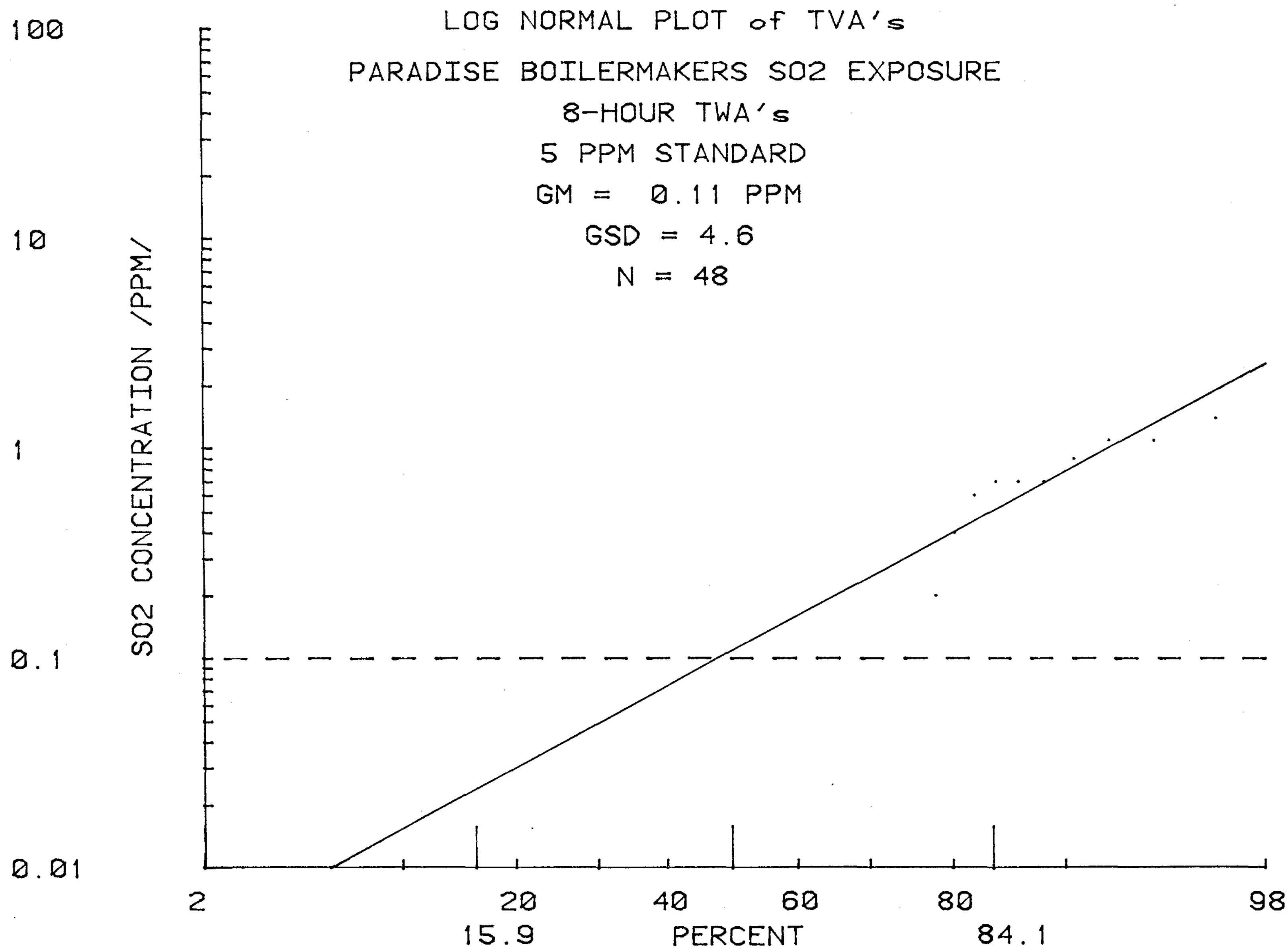

Figure 41. Log-probability plot of the Paradise boilermakers SO_2 exposure based on the trimmed data analysis.

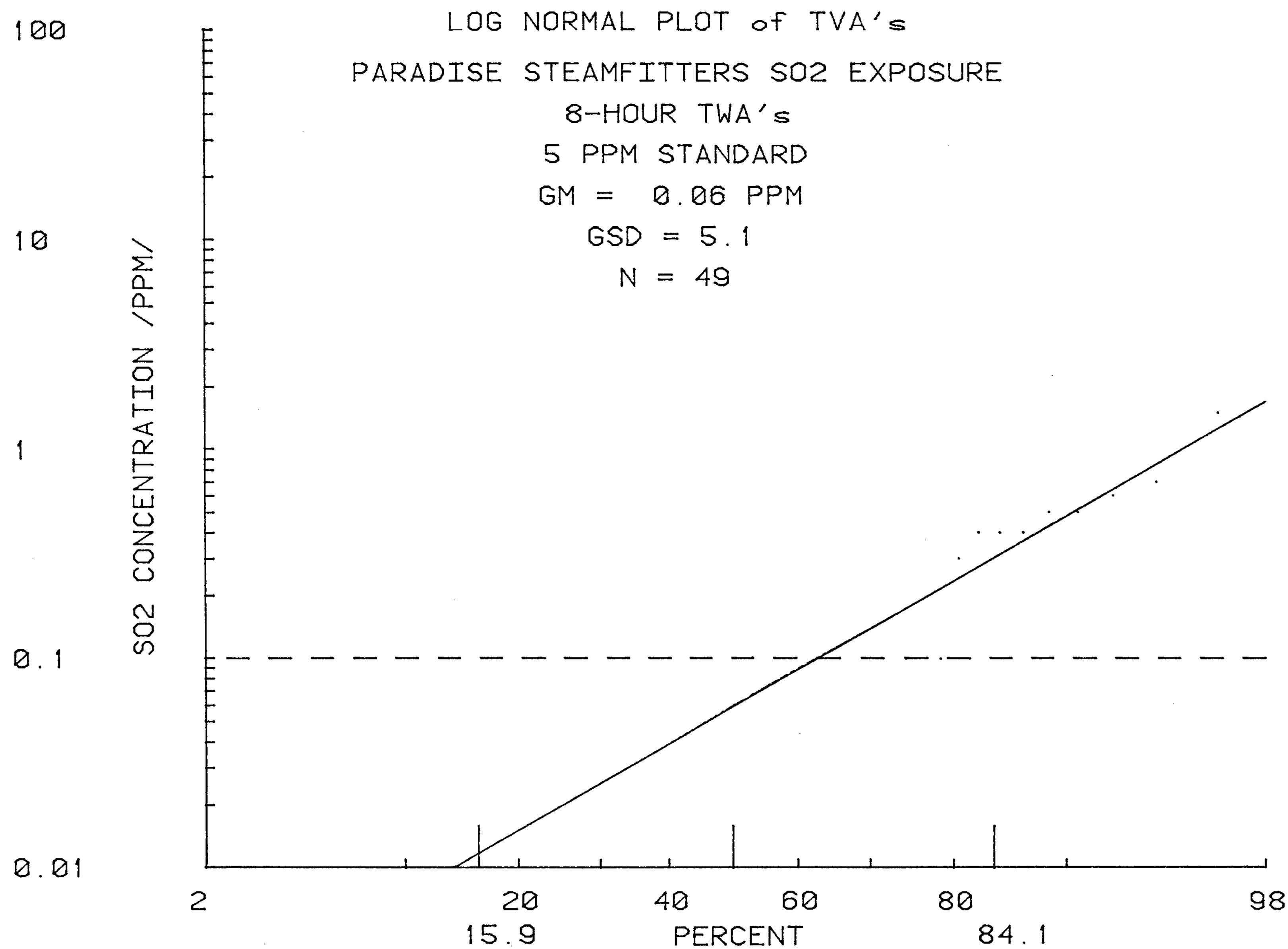

Figure 42. Log-probability of the Paradise steamfitters SO_2 exposure based on the trimmed data analysis.

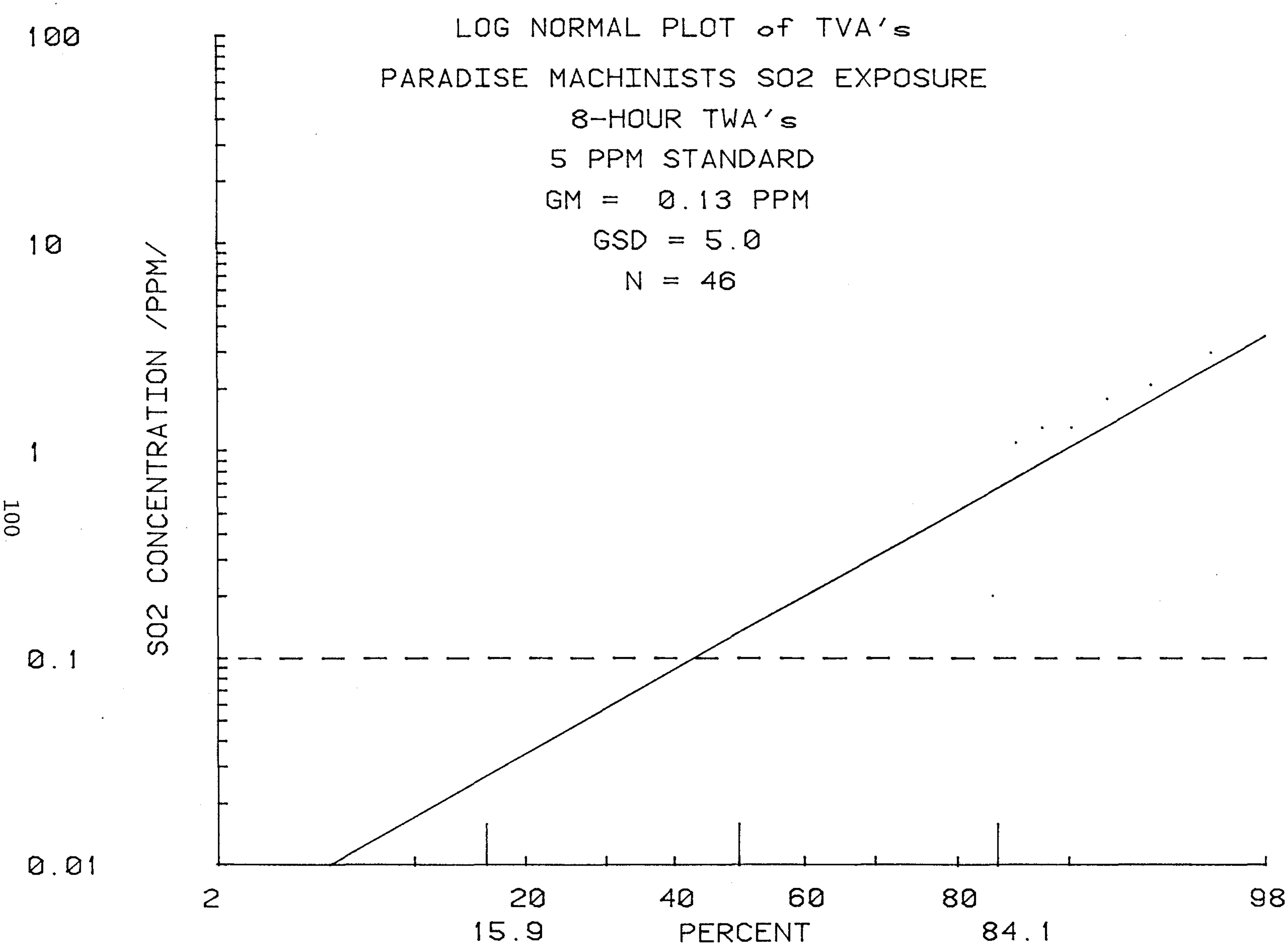

Figure 43. Log-probability plot of the Paradise machinists SO_2 exposure based on the trimmed data analysis.

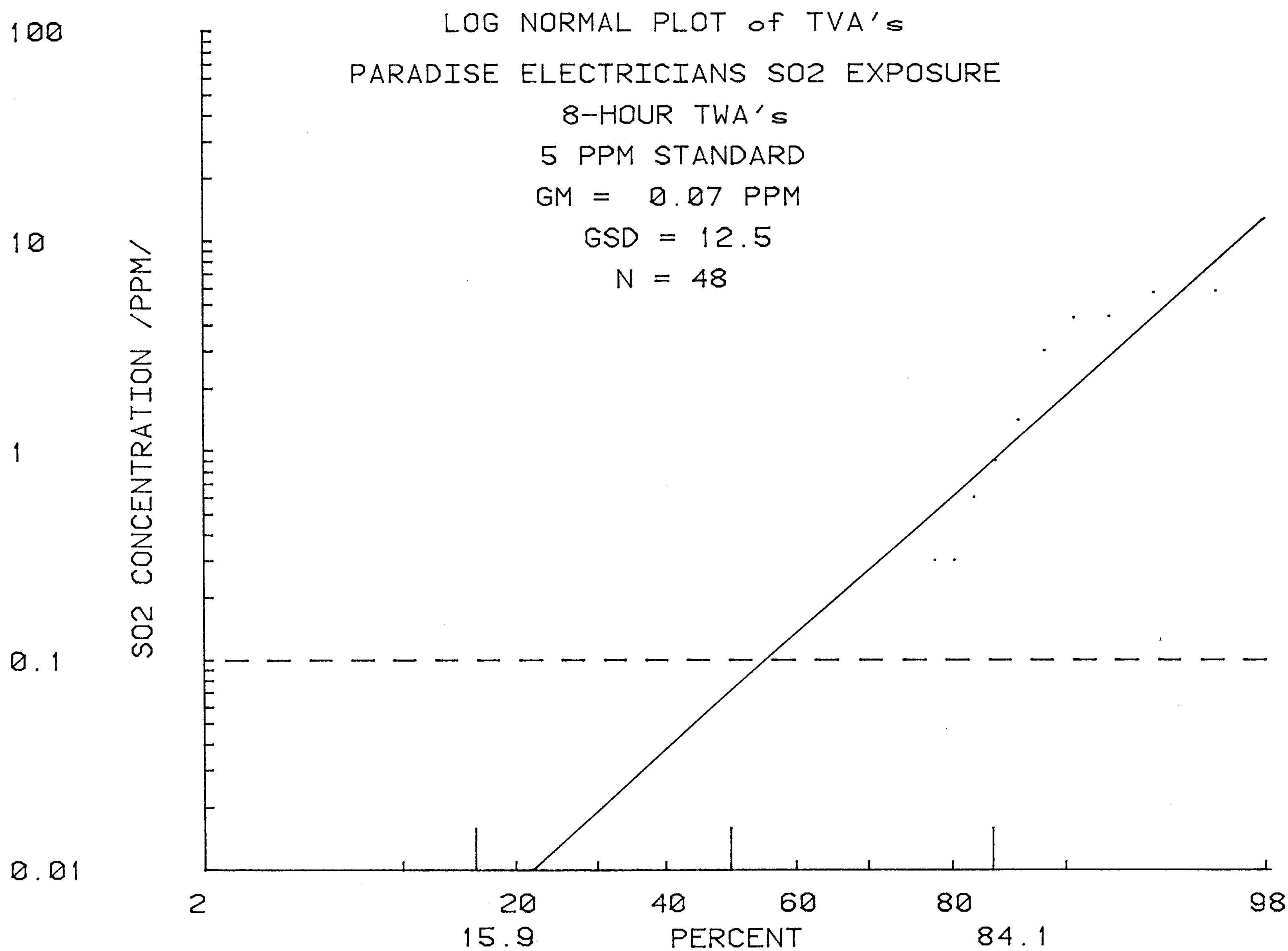

Figure 44. Log-probability plot of the Paradise electricians SO_2 exposure based on the trimmed data analysis.

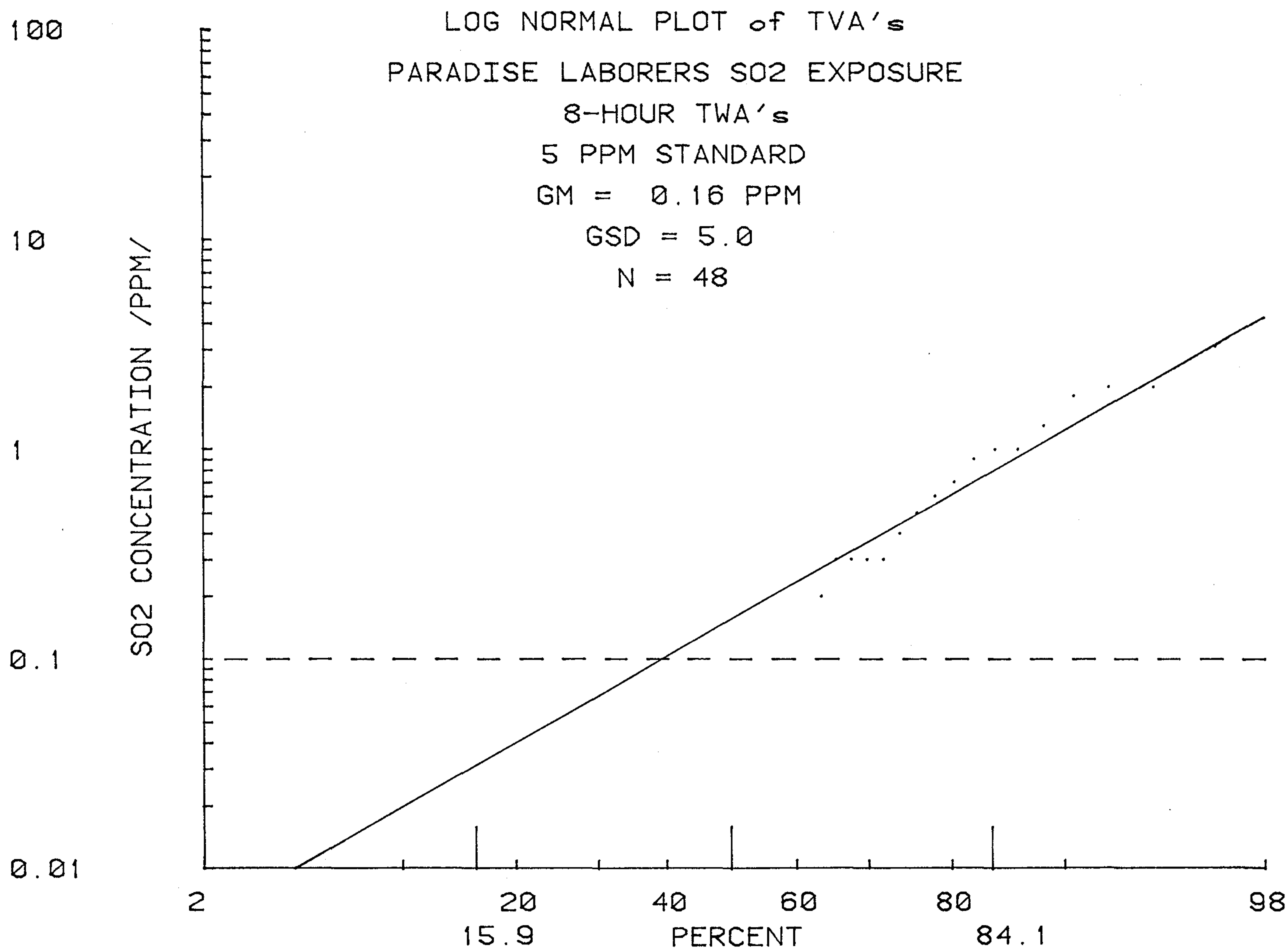

Figure 45. Log-probability plot of the Paradise laborers SO_2 exposure based on the trimmed data analysis.

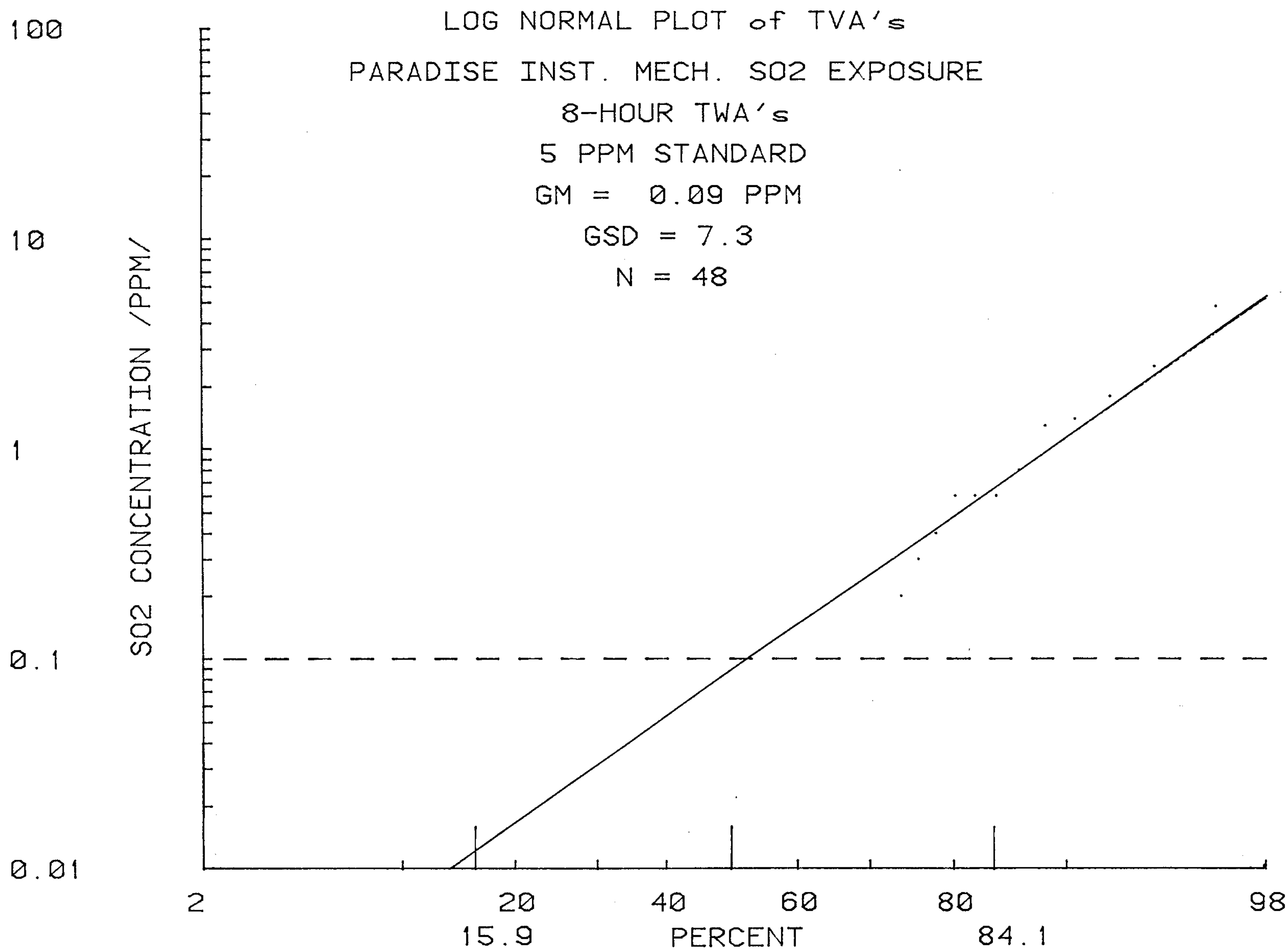

Figure 46. Log-probability plot of the Paradise instrument mechanics SO_2 exposure based on the trimmed data analysis.

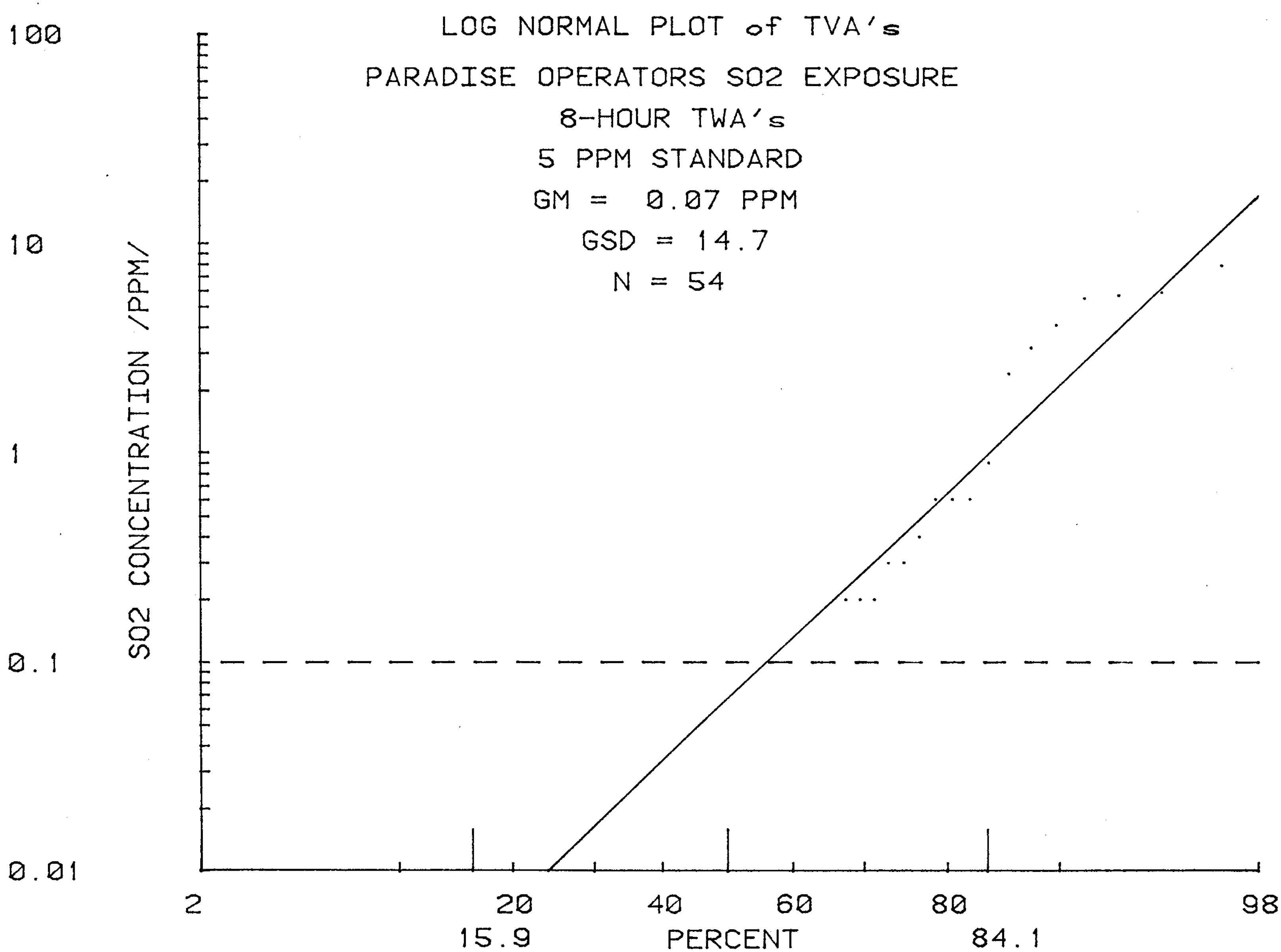

Figure 47. Log-probability plot of the Paradise operators SO_2 exposure based on the trimmed data analysis.

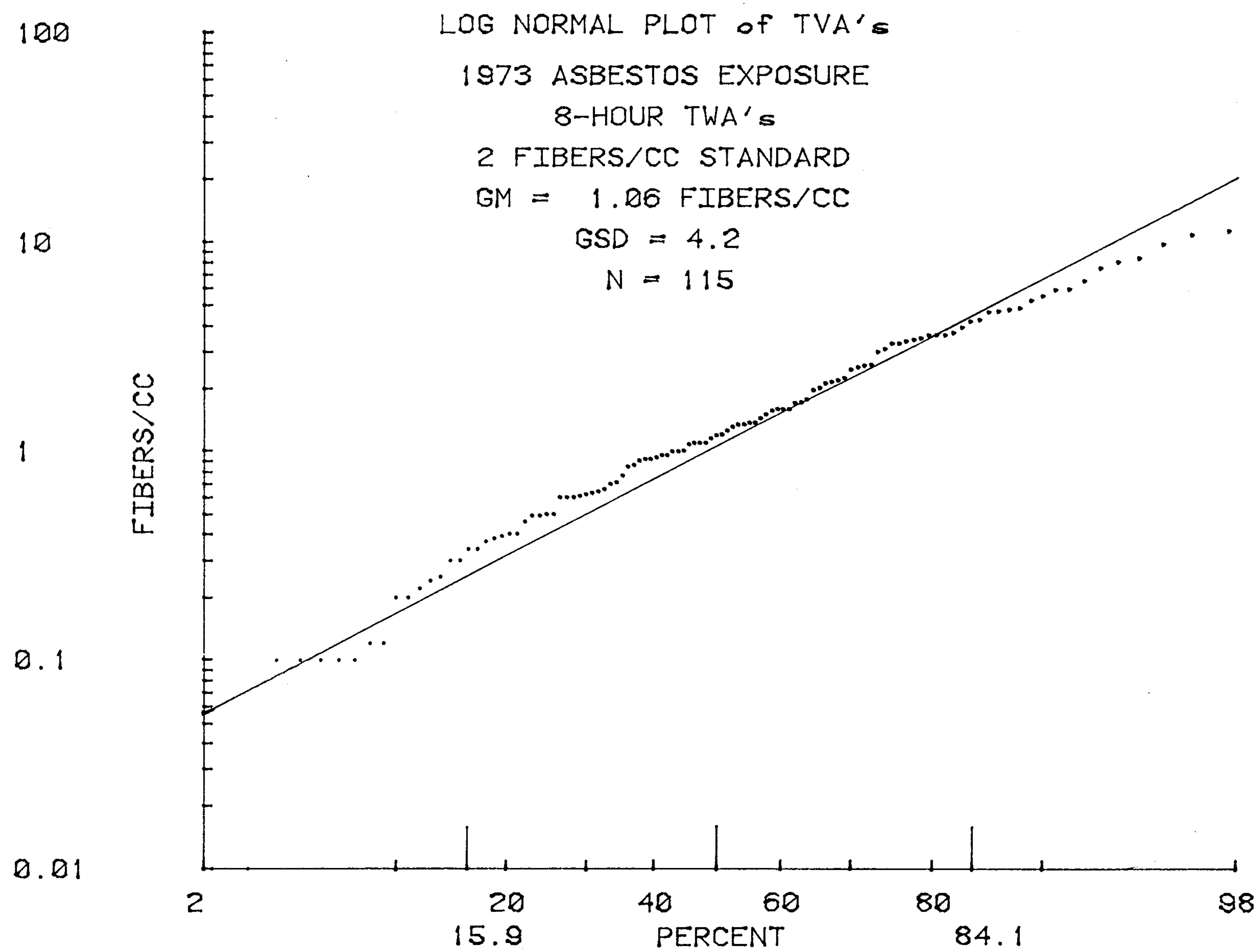

Figure 48. Log-probability plot of the 1973 asbestos exposures of TVA's asbestos workers in coal-fired power plants, GM = 1.1 f/cc and GSD = 4.2.

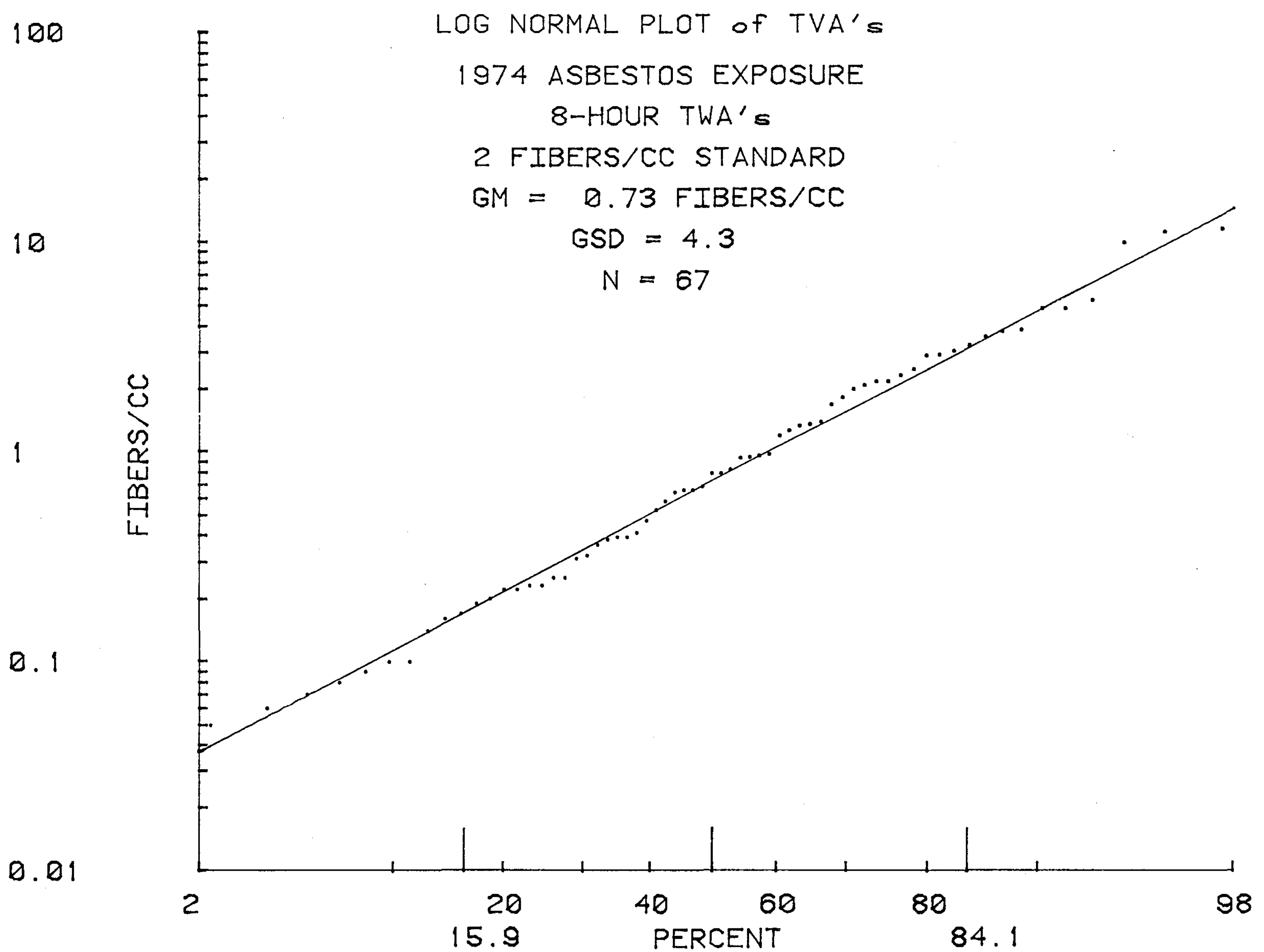

Figure 49. Log-probability plot of the 1974 asbestos exposures of TVA's asbestos workers in coal-fired power plants, GM = 0.7 f/cc and GSD = 4.3.

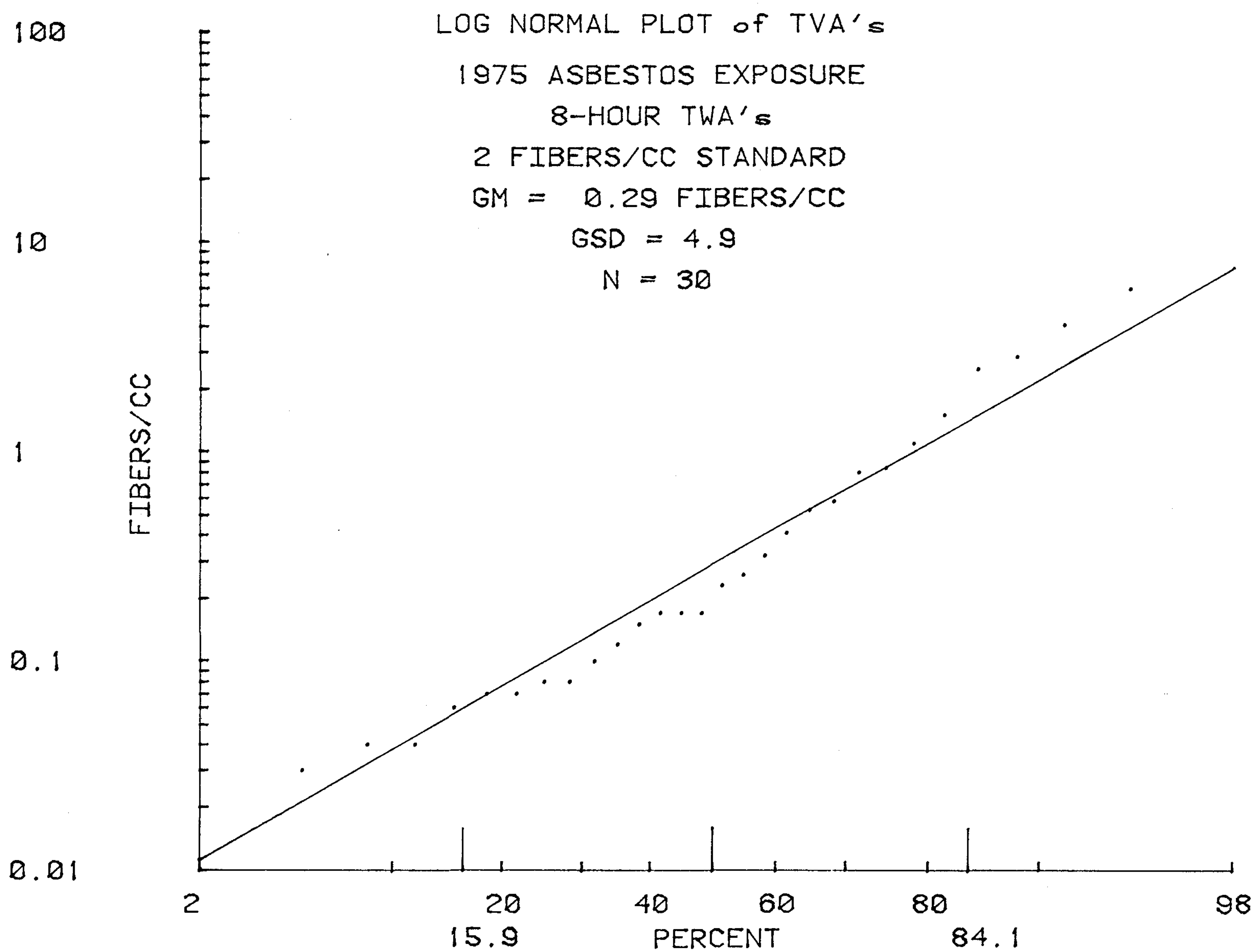

Figure 50. Log-probability plot of the 1975 asbestos exposures of TVA's asbestos workers in coal-fired power plants, GM = 0.3 f/cc and GSD = 4.9.

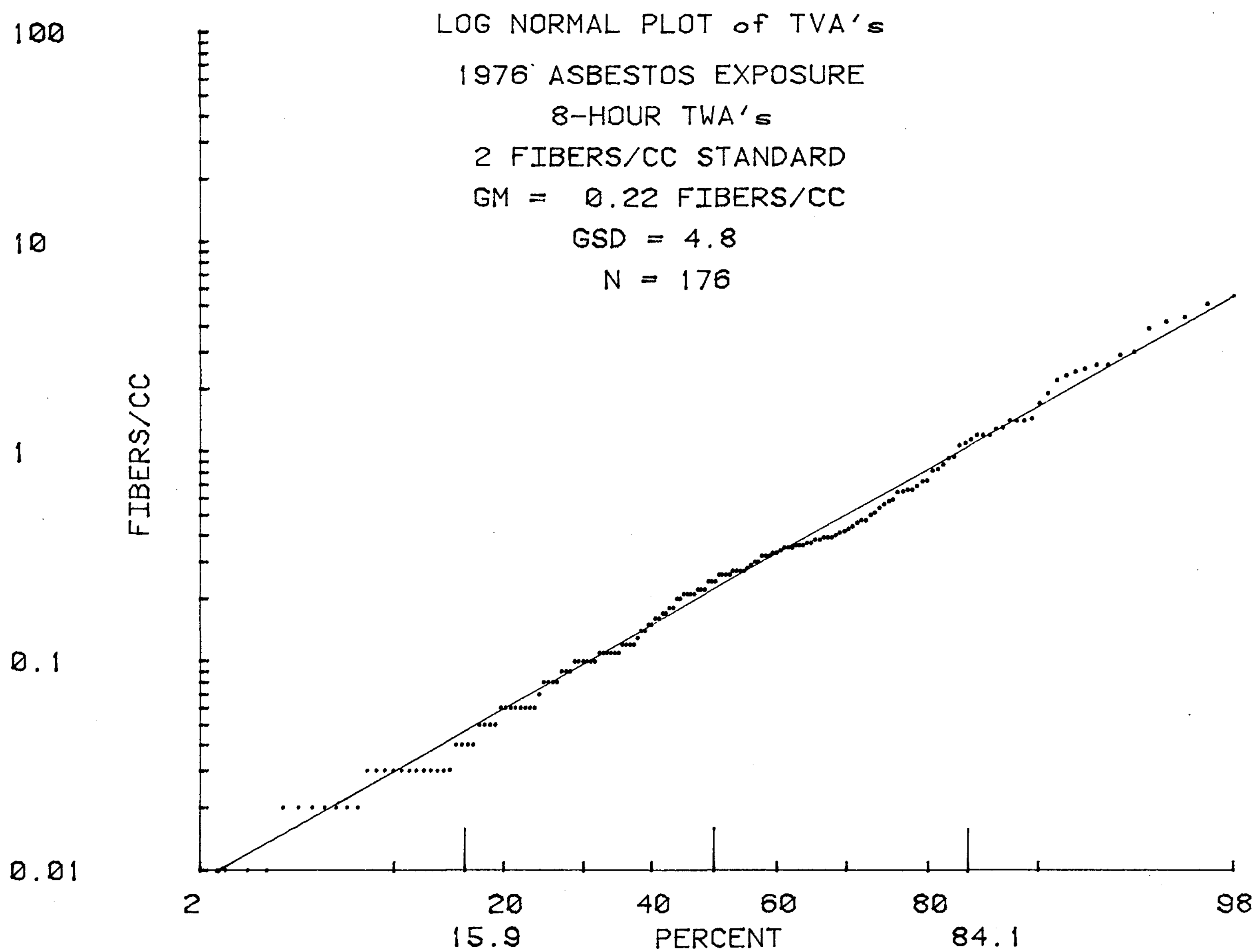

Figure 51. Log-probability plot of the 1976 exposures of TVA's asbestos workers in coal-fired power plants, GM = 0.2 f/cc and GSD = 4.8.

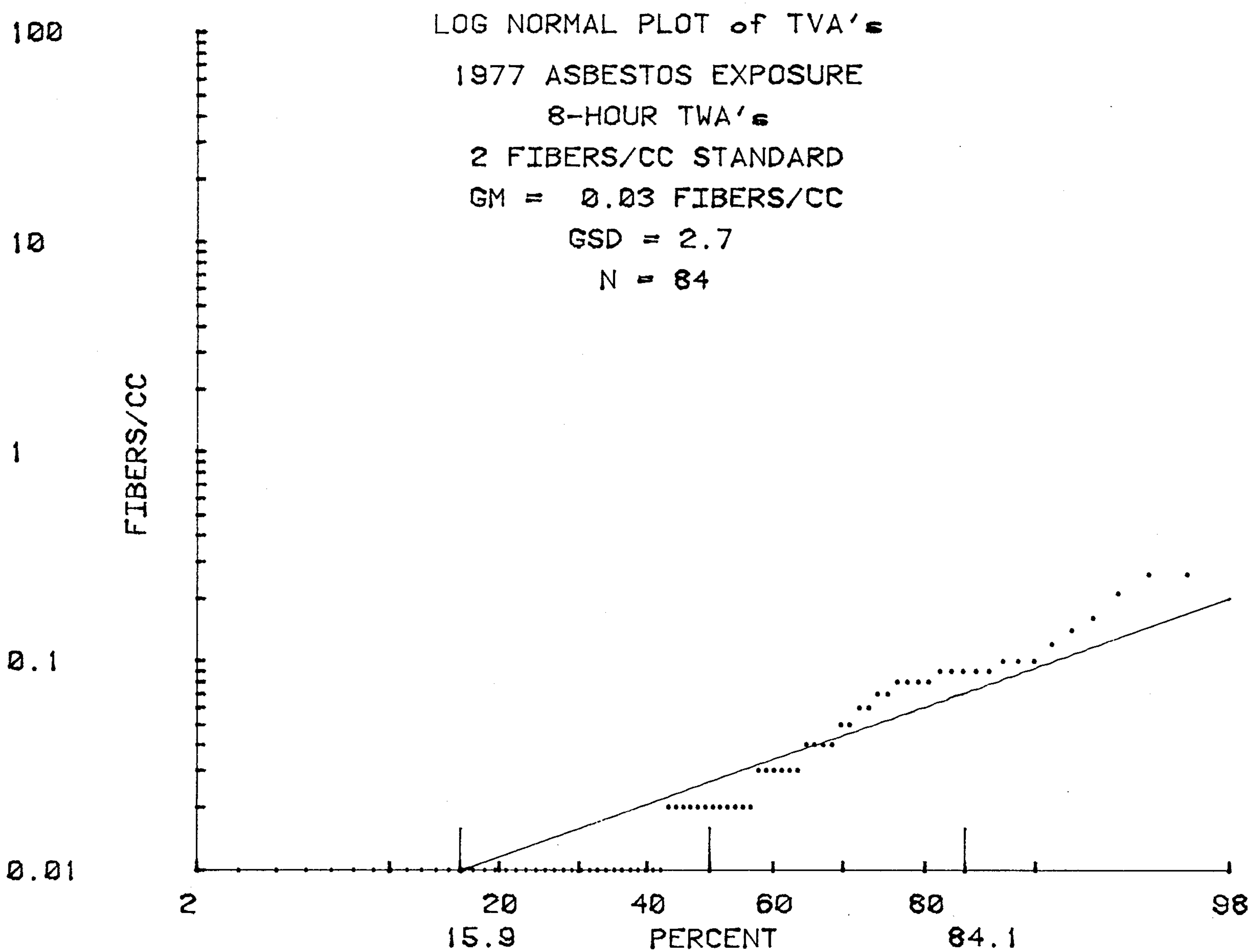

Figure 52. Log-probability plot of the 1977 exposures of TVA's asbestos workers in coal-fired power plants, GM = 0.03 f/cc and GSD = 2.7.

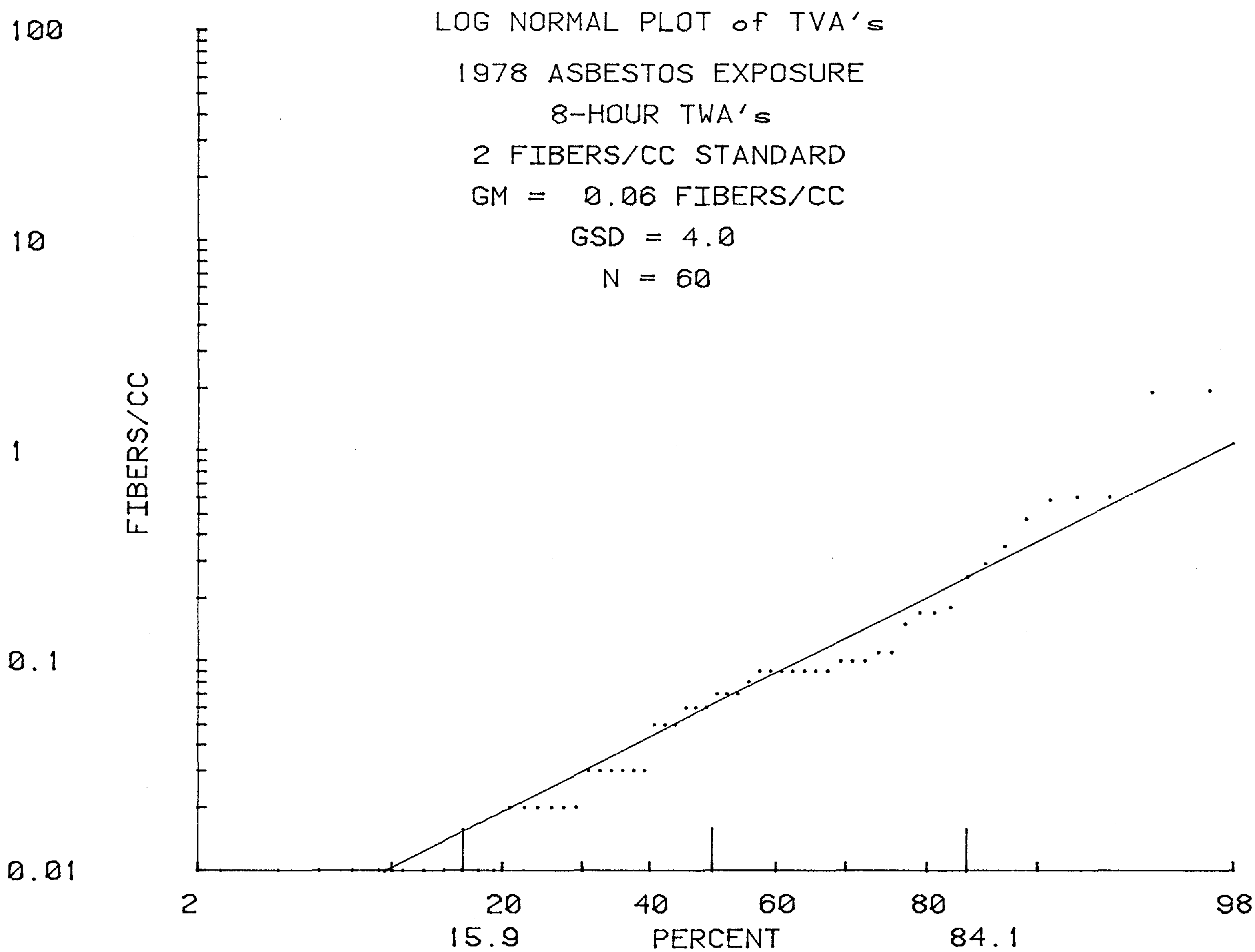

Figure 53. Log-probability plot of the 1978 exposures of TVA's asbestos workers in coal-fired power plants, GM = 0.06 f/cc and GSD = 4.0.

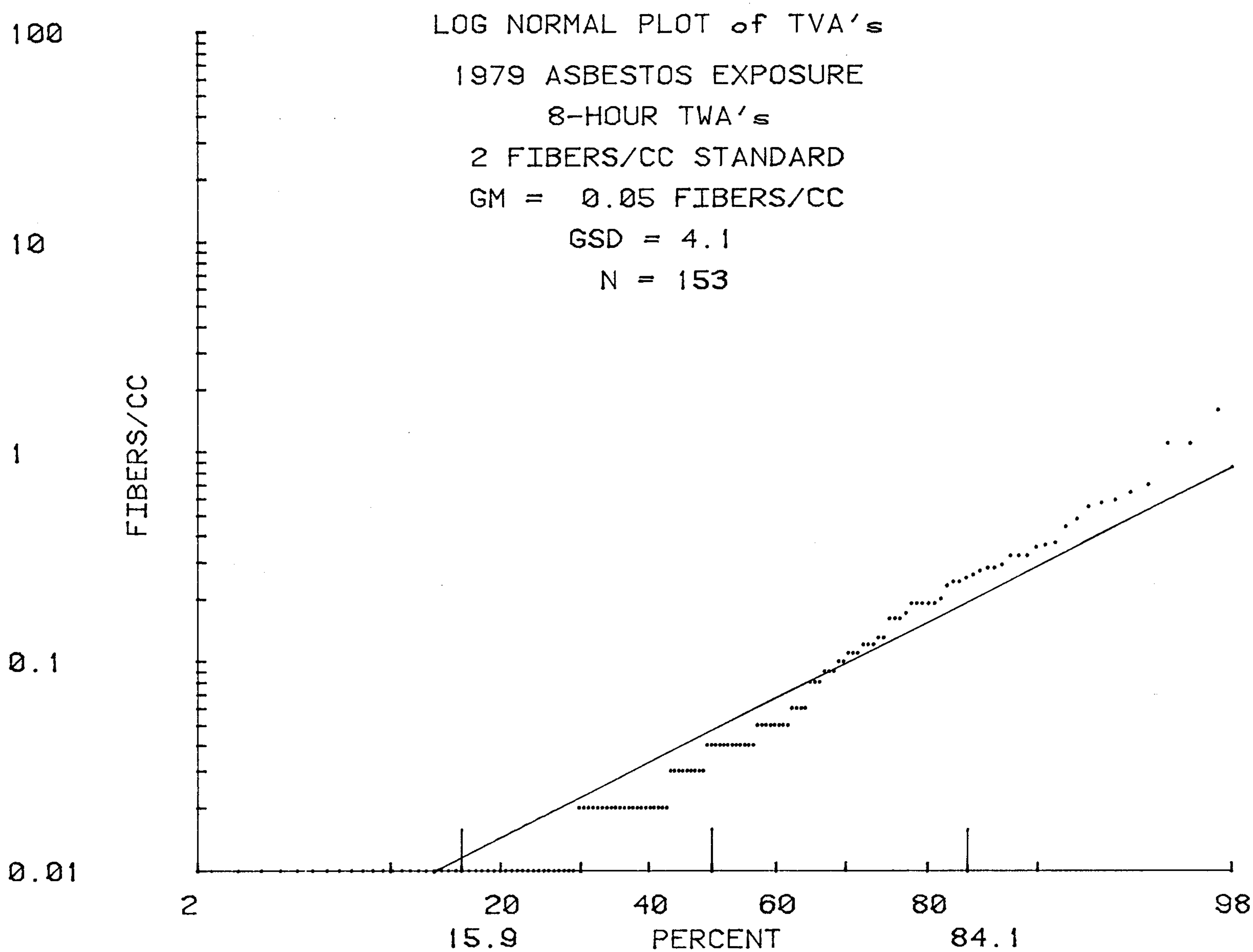

Figure 54. Log-probability plot of the 1979 exposures of TVA's asbestos workers in coal-fired power plants, GM = 0.05 f/cc and GSD = 4.1.

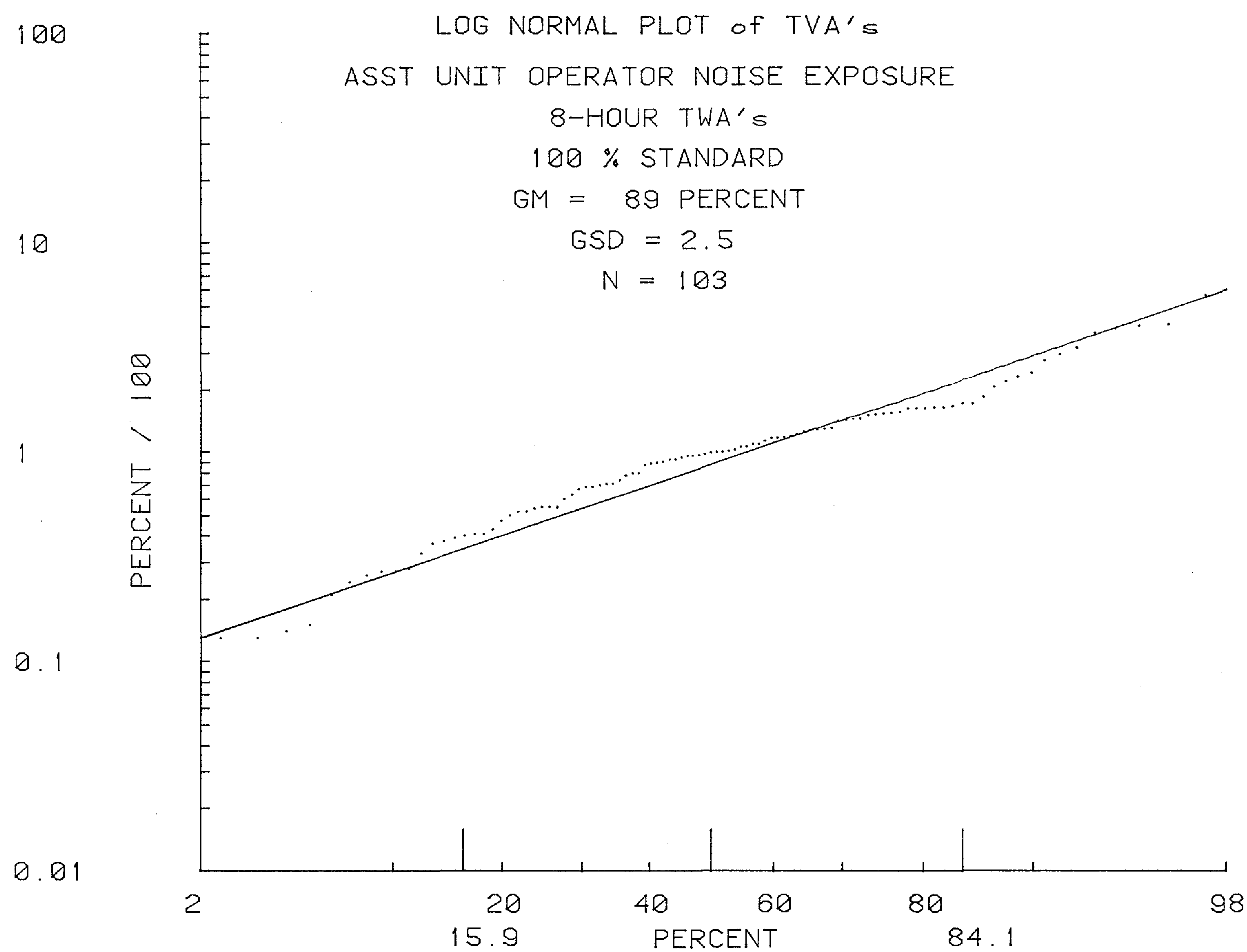

Figure 55. Log-probability plot of cumulative (1975-1979) noise exposures of TVA's assistant unit operators, GM = 89% of standard and GSD = 2.5.

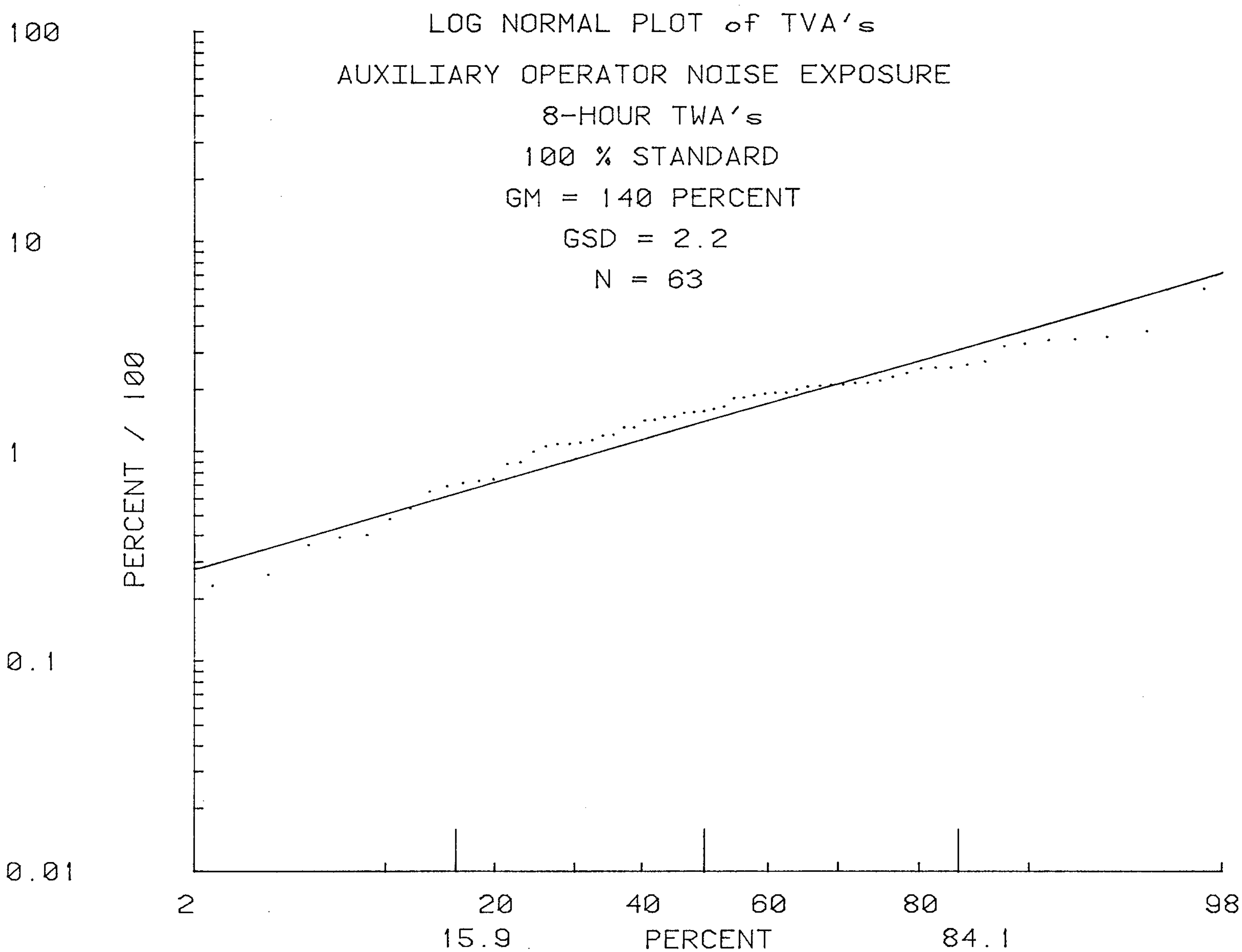

Figure 56. Log-probability plot of the cumulative (1975-1979) noise exposures of TVA's auxiliary operators, GM = 140% of standard and GSD = 2.2.

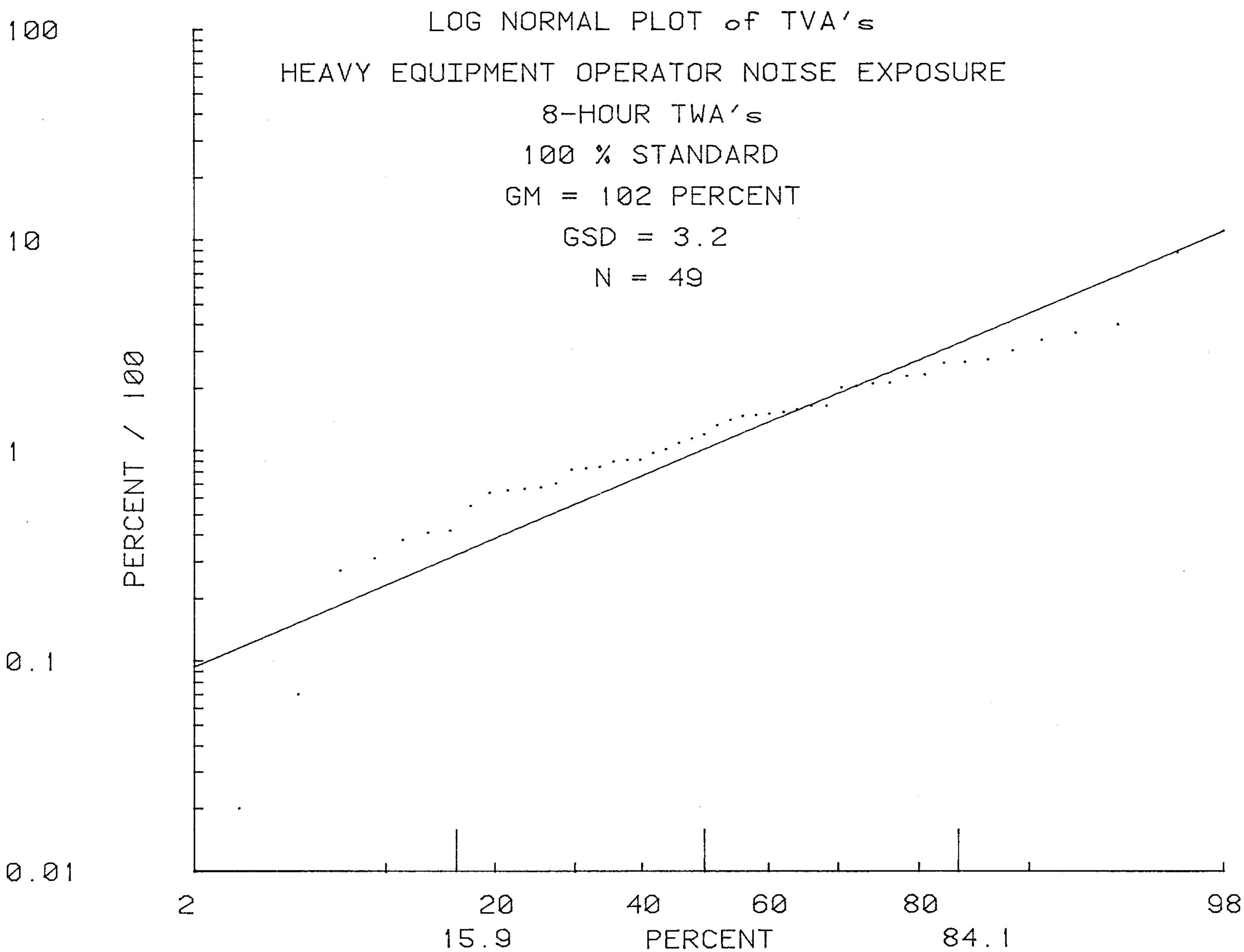

Figure 57. Log-probability plot of the cumulative (1975-1979) noise exposures of TVA's heavy equipment operators, GM = 102% of the standard and GSD = 3.2.

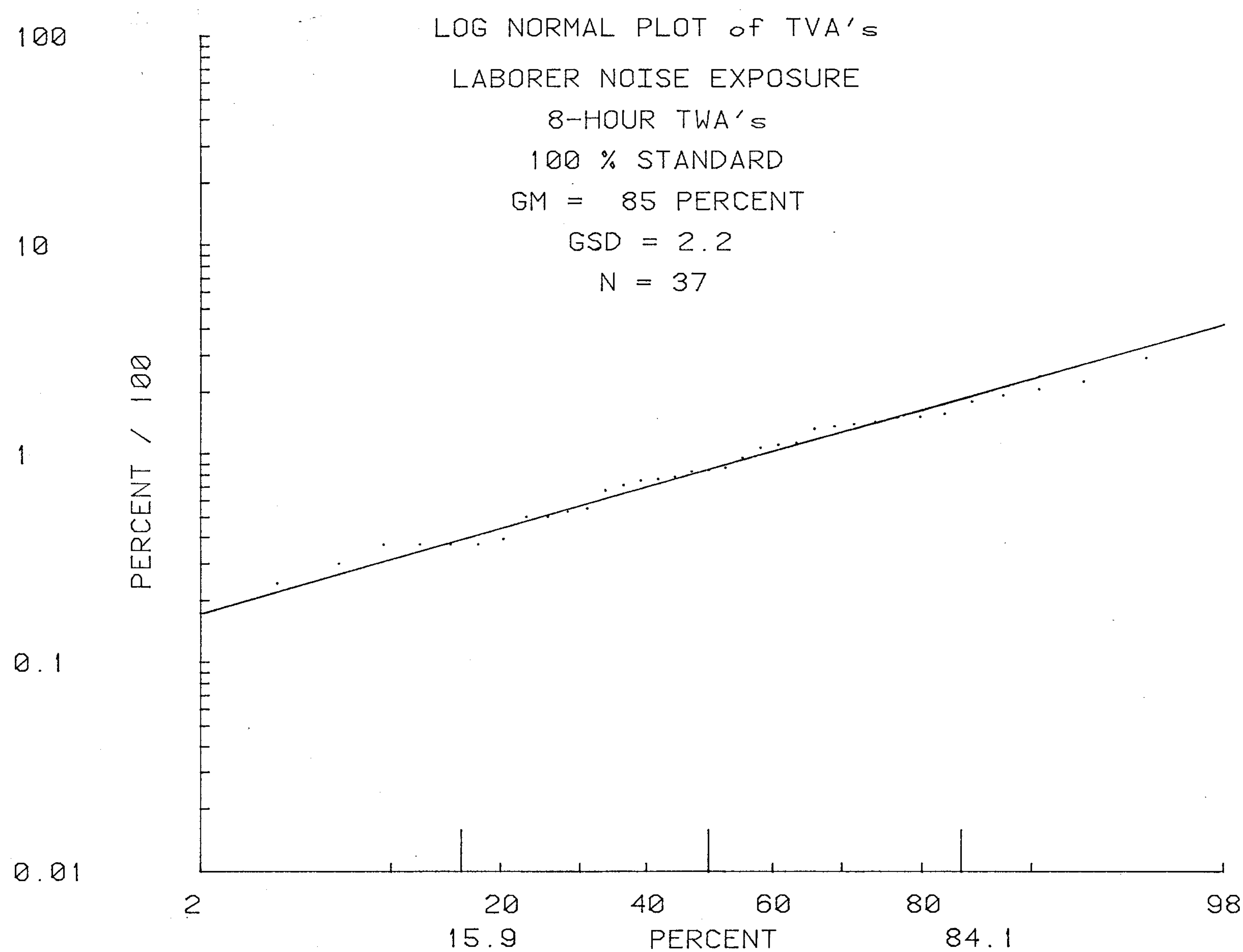

Figure 58. Log-probability plot of the cumulative (1975-1979) noise exposures of TVA's powerhouse laborers, GM = 85% of the standard and GSD = 2.2.