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COKE OVEN CHARGING EMISSION CONTROL TEST PROGRAM--VOLUME I

by

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ABSTRACT

This report summarizes the results of the Coke Oven Charging Emission Control Test Program conducted at the P4 Battery of the Jones and Laughlin Pittsburgh Works. The duration of the program was from April 1971 through May 1974, with actual field testing accomplished during the period May 1973 through August 1973. The overall objectives of the test program were; (1) to quantify the atmospheric pollutants resulting from the charging operation in the coking process, (2) to provide a comparative evaluation of a pollution abatement system (an improved design larry car versus an existing larry car), and (3) to determine the feasibility of a compliance monitoring system concept based upon optical measurement. All objectives of the program were successfully accomplished, and emission characteristics of the charging operation have been defined in terms of both gaseous emissions and particulates released to the atmosphere. Emissions were also defined from leaking seals on the pusher side doors of the oven. Several pertinent conclusions were also developed relating to the technology of coke oven emissions measurement.

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This project spanned a period of nearly three years, and accordingly, a number of MITRE personnel were assigned to the project as it developed through various phases. K. Yeager and G. Erskine shared the Group Leader responsibilities, while J. Hoffman and R. B. Shaller each in turn acted as Task Leader. R. W. Bee conducted the Optics portion of the program, while A. Wallo III was responsible for sensors and gas/particulate samples with assistance from R. W. Spewak. W. L. Wheaton was responsible for the continuous monitoring instrumentation with assistance from J. Findley, J. Miller, R. Reale, and W. R. Robinson. R. C. Kuehnel assumed the data processing responsibility, and support was provided in this area by J. Morris. Additional assistance and advice was provided by A. F. Epstein, E. Jamgochian, B. A. Stokes and J. B. Truett.

SECTION I
CONCLUSIONS

Measurements were successfully made defining the emission characteristics of the coke oven charging operations for the P4 battery of The Jones and Laughlin Pittsburgh works. Both the old Wilputte and the production prototype AISI/EPA larry car charging operations at this battery were characterized in terms of gaseous emissions and particulates released to the atmosphere. Both continuous monitoring and manual sampling techniques were used in a specially designed test program to obtain the required information. Additionally, optical measurements were made to determine the technical feasibility of a compliance monitoring system based on optical measurements.

IDENTIFICATION OF COKE OVEN CHARGING EMISSIONS

Particulate mass emissions from the Wilputte Larry Car were defined from 10 charging operations. These mass emissions are reported in terms of particulates released from combinations of six major emission points. From the data on these emission points, a composite total mass emission of 815 grams per charge was derived for the Wilputte car. Mass emissions were also defined for the production prototype AISI/EPA larry car from three major emission points from four separate charging operations. A composite total mass emission figure of 120 grams per charge was derived from the data from the four charging operations.

The major gaseous pollutants emitted during charging that were measured are: total hydrocarbons, carbon dioxide, carbon monoxide, nitrogen oxides, sulfur dioxide, hydrogen sulfide, methane, ammonia, phenol, cyanide.

Based on analysis of particulate samples collected from the charging emissions, there is a possibility that carcinogenic materials may be generally present in emissions released during coke oven charging. This conclusion is based on the detectable presence of benzpyrene in the tar portion of a large number of particulate samples. Although not all chemical forms of benzpyrene have been identified as carcinogens,

benz(α)pyrene has been so labeled. In at least one large composite sample of collected particulate material, analytical techniques have established the presence of benz(α)pyrene and/or benz(e)pyrene and other known or potential carcinogens. Based on the representative nature of the sample involved, it is reasonable to assume that the same constituents will be generally found in the tar fractions of other coke oven emissions. To further characterize the quantities of materials involved, tar concentrations in particulate samples were found to range from approximately 30% to 90%, with an average of 57%. Additionally, benzpyrene analysis of the tar fractions showed concentrations ranging from 260 ppm to 18,000 ppm (1 ppm is equivalent to 1 μ gram benzpyrene/gram of tar).

An elemental analysis was undertaken to identify the trace constituents of the coal charged and the resulting emissions. The intended emphasis was the identification and quantification of hazardous elements, particularly heavy metals. The emissions analysis was performed on particulate sizing equipment catches, and was limited by the sample size, as well as available analytic techniques. These limitations resulted in a large number of instances where constituent concentrations, if they did exist, were below detectable limits. The emission constituent concentrations which were successfully measured and reported are consistent with the constituents identified in the elemental analysis of the charging coal. Some of the more important elements identified in detectable concentrations in the emitted particulate material were Cu, Fe, Pb, and Zn. Due to the variances in particulate sample sizes, it is not possible to make a generalized statement concerning constituent concentrations in the emissions. It should be pointed out, however, that no constituent concentrations in excess of what can be reasonably explained by coal constituents was identified in the particulate material. In order to obtain more definitive information on particulate constituents, much larger samples distributed as a function of particle size must be obtained and analyzed. The particle size information is important in assessing the results, since this property will determine whether the particles fall or settle out quickly (i.e., particles $>200\ \mu$), or behave similar to a gas in the atmosphere (i.e., $<3\ \mu$).

A particle size distribution was derived based upon a composite of samples taken from emissions released by both the Wilputte and the AISI/EPA cars. The size distribution found was characterized as a bi-populate lognormal distribution; with a distinct grouping of the finer particles containing 47% of the sample weight and a distinct grouping of the larger particles containing 53% of the sample weight. The finer particle size grouping was found to have a mass mean diameter of 8.5 μ and a standard deviation of 2.5 μ; whereas the larger particle size grouping was found to have a mass mean diameter of 235 μ and a standard deviation of 3.9 μ. It was also concluded that the tar portion of the particulate sampling was derived primarily from the small diameter portion of the particle size distribution.

As an additional baseline measurement, gaseous concentrations were determined for the longer term emissions from leaking seals on the pusher side doors of the oven. Data was collected from four separate measurements of leaking door emissions. The primary gaseous constituent found in these emissions was total hydrocarbons, for which an average emission value of .35 ACFM was found. This measured emission value for hydrocarbons translated to an average value of 1.2 pounds of hydrocarbon released over a 19 hour coking cycle per ton of coal charged to the oven. This figure of 1.2 pounds of hydrocarbon per ton of coal coked is obviously for an oven with doors leaking at a constant maximum rate. Since the majority of the doors do not leak at this rate, this emission rate should not be construed as a normal level of emissions from all oven doors.

COMPARISON OF EMISSIONS FROM WILPUTTE AND AISI/EPA CHARGING SYSTEMS

It was determined that the average total particulate mass emission from the Wilputte car was 815 grams per charge. The AISI/EPA car averaged 120 grams per charge, a reduction of approximately 85% from the average particulate emission level measured from the Wilputte Larry car.

The major gases emitted during charging with the Wilputte Larry car consisted of; total hydrocarbons (33.77 scf/charge), CO_2 (29.4 scf/charge), CO (17.49 scf/charge) and NO_x (.11 scf/charge). Other gaseous constituents

that were found in the emissions included; SO_2 (maximum concentration of 232 ppm), H_2S (maximum concentration of 42 ppm), methane (maximum concentration of 4 ppm), ammonia (maximum concentration of 130 ppm), phenol (maximum concentration of 31 ppm) and cyanide (maximum concentration of 16 ppm).

The gaseous emissions from the AISI/EPA larry car were measured for 10 separate charging operations and are compared to similar Wilputte measurements below. The major gases emitted during charging with the AISI/EPA larry car consisted of; total hydrocarbons (20.43 scf/charge), an improvement of 40% over the Wilputte emissions, CO (6.28 scf/charge), an improvement of 64%, CO_2 (3.82 scf/charge), an improvement of 87%, and NO_x (.021 scf/charge), an improvement of 82% over Wilputte emissions. Other gases found in these emissions included; SO_2 (maximum concentration of 25 ppm), and methane (maximum concentration of 1.8 ppm).

The percentage reductions of the various particulate and gaseous emission constituents are not uniform primarily because of the variations in emission reactions which occur during charging operations. Examples might be the presence or absence of flame, variations in dilution prior to sampling, and changes in volume flow causing similar changes in reaction rates. It is felt, however, that a comparison based on total mass emitted is reasonable and justified.

The elemental analysis of various particulate samples showed some degree of uniformity in constituent concentrations. This would indicate that the volume of trace elements emitted during a particular charge would be directly related to total particulates emitted. Based on this premise, it is reasonable to assume that reductions in particulate emissions from the Wilputte to the AISI/EPA car connote like reductions in total volume of trace elements (particularly heavy metals) emitted.

The primary carcinogenic materials, various types of benzpyrene, display reasonably uniform concentrations in the tar fraction of particulate samples. Therefore, it is reasonable to assume that an argument similar to the above would be valid for the appraisal of reductions in total

volume of carcinogens emitted (i.e., reductions in carcinogens could be considered equivalent to reductions in total tars).

TECHNOLOGY OF COKE OVEN EMISSIONS MEASUREMENT

Although a number of technical problems were encountered during coke oven testing, an extensive effort was made to minimize these problems and obtain valid data.

Sixteen separate gaseous constituents were measured by either manual sampling methods or the continuous measurement instrumentation system or both. Of these sixteen gases, eight gases were analyzed by both manual methods and the continuous measurement system, and good agreement was found between the methods for four of the major gases (CO, CO_2, total hydrocarbon, and O_2). Comparisons between the measurement methods for two of the gases (SO_2 and H_2S) showed significant discrepancies which were identified as being due to chemical interferents giving a "false high" reading from the continuous measurement systems. These interferents (polycyclic organic materials were suspected) preclude accurate measurement of SO_2 and H_2S with the best current method for continuous monitoring of these constituents - ultraviolet absorption. Additional testing must be performed to identify the nature of the chemical species which interfere with this instrumentation technique before the technique can be applied to the task of monitoring coke oven emissions.

Manual sampling was used for certain components (particulates, CH_4, NH_3, HCN, pyridine, and phenols) because the manual sampling method was the best and/or only technique which could be applied. In other cases (CO, CO_2, SO_2, H_2S, total hydrocarbon, H_2 and O_2), manual sampling was used as a supplementary method for comparison with the results of the continuous measurement instrumentation. For this latter group, good agreement was found between results from manual sampling and the continuous data, except for SO_2 and H_2S as noted above. The manual sampling data for these two constituents was judged to be the most valid obtained during the tests and is used in the comparison of emissions. Two

conclusions were developed concerning the suitability of manual sampling techniques applied to the measurement of coke oven emissions. First, the manpower required to perform the sampling was substantial when compared with that required for operation of the continuous measurement instrumentation system. Second, the time required to obtain analytical results on the samples was considerable, and therefore, the results could not be utilized for test-by-test modification of procedures (as continuous measurement results were used).

Several problems were encountered in the implementation of an emission measurement system. The first problem relates to the concept of isokinetic sampling and the difficulty of applying this concept to a highly variable emission source such as a larry car. The approach followed was to sample at a constant controlled rate close to the predicted average stack velocity and to correct the collected mass based on the actual measured velocities to a value that would have been obtained if isokinetic sampling had been followed. To do this, it was necessary to gather continuous data on the velocity and/or volume flow at the sampling point. It was concluded that this was the best approach when considered against the alternatives of continuously and manually adjusted sampling rates (to match stack velocities), and systems which automatically adjust sampling rates. Based on a review of the results obtained this appears to be a valid and successful approach.

In the measurement of the emissions released in coke oven charging, all emission points could not be measured during one charging sequence. The approach followed was to sample at several of the emission points on separate charges, and to combine these results into a composite mass representative of the total mass emissions of the charging operation. This approach to the measurement of mass emission was the best method within the time and economic constraints of the test program. After review of the data, it was concluded that there was sufficient variability in emissions from point-to-point and charge-to-charge, so as to preclude single point testing as a means of determining the total mass released during a single charge with any degree of accuracy.

The initial test objectives called for the performance of three tests per day. However, a number of factors encountered after the start of scheduled testing made the accomplishment of this goal impossible. These factors included unscheduled equipment maintenance and repair, problems in production "non-interference" scheduling of ovens within instrumentation accessibility limits, post-test instrumentation and data acquisition system turn around delays, and unexpected severe worker fatigue.

The high temperatures and open flame prevalent in the coke oven environment often caused extensive damage to various system components necessitating unscheduled repair or replacement. The unpredictable nature of these occurrences also caused problems in replacement component availability.

The instrument lines to the battery top were capable of reaching a block of 20 consecutive ovens. However, during an eight hour shift, only one pass would normally be made through the block, exclusively charging either the odd or the even numbered ovens. This reduced by a factor of 1/2 the number of available ovens in the accessible block and spaced the charges of interest approximately 45 minutes apart. It was often found necessary to delay the scheduled charging of an oven within the accessible block to allow the completion of test preparation. Such scheduled disruptions could only be tolerated on a limited basis without affecting normal production.

Assuming no obvious damage to oven top instrumentation, the necessity remained to check the continuous monitoring instrumentation and data acquisition system components for proper operation. In addition, considerable time was required when manual sampling was scheduled to turn around manual sampling equipment between consecutive tests.

Lastly, workers experienced an unusually high level of fatigue after a test period, primarily attributed to the rapid work pace necessary to limit production interference (tests were generally completed in less than 20 minutes), high ambient temperatures (100°+), and poor air quality.

The data which forms the basis for conclusions contained in this report are judged to be consistent and repeatable in the context of test requirements and the operational environment. This assessment is founded on a careful examination of basic data element test averages for volume flow, temperature, and measured constituent concentrations including particle size distribution. For example, the average volume flow values for a Wilputte stack emissions point show an average flow rate of approximately 200 cubic feet per minute over 15 individual tests, while the maximum and minimum average values for this same group of tests are approximately 290 and 130 scfm, respectively. The temperatures in the gas streams during these tests showed similar consistency with an approximate average of 600° Rankine. The corresponding maximum and minimum temperature averages were approximately 550° and 2000° Rankine (in the presence of flame). Although almost constant fluctuations were observed in volume flow, the data obtained appears consistent with all observations of the charging process.

Good agreement between the continuous monitoring system and data obtained through manual sampling is evident with the exception of H_2S/SO_2 data. The discrepancies noted here were several orders of magnitude and were traced to chemical interferents. In addition, the concentrations measured were consistent with similar data reported by other investigators.

A number of various techniques and equipments were used to obtain particulate size information. When the various sources of data are compared using particle statistics criteria, good agreement is shown in support of the composite particle size distribution reported here. It is felt, however, that valuable information might be obtained through the additional refinement of particulate sampling techniques and devices, and thorough analysis of the resulting data.

FEASIBILITY OF A COKE OVEN COMPLIANCE MONITORING SYSTEM

During the conduct of this test program, consideration was given to the applicability of this measurement approach to compliance monitoring. One factor which appears to transcend most other considerations is the

unique design efforts required to implement this measurement approach. Much of the time spent in preparing for the test operation was devoted to tasks of fitting the measurement system to the particular battery and larry car being tested (i.e., installation of sampling lines, signal cable, facility modifications, field fitting of emission guides, etc.). From this it was concluded that the measurement system and the concept of using this system could not easily be applied to the task of emission measurement of a larger population of coke ovens. Rather, the concept is tailored for specific application to the particular battery and larry car being tested.

The technical feasibility of a compliance monitoring system based upon optical measurements was established, with qualifications. The optical measurement system consisted of a fluorescent light bar source and a 35 mm sequence camera. Micro-densitometer readings of the film images of the light bar were then used to give a measure of the emissions of the charging operation based on the light transmission characteristics of the emission volume.

Light transmission or its inverse, opacity, can be mathematically related to particulate material contained in the emission plume based on the portion of source light an individual particle removes from the light reaching the detector or camera. Determination of total mass emitted using this approach depends on several assumptions. It is necessary to assume that the majority of the particles are larger than 3 μ in diameter so as to avoid problems caused by Mie scattering. It must be assumed that the particle size distribution is constant over time and that the distribution can be described accurately by its geometric mass mean radius value. In order to make the final total mass calculation, the emission plume remains constant over short periods (5 seconds in this calculation) such that total mass emitted can be related to vertical plume rise.

Technical and economic constraints precluded a charge-by-charge comparison of the particulates measured by direct means, with estimates of mass emission as determined by the optical measurement system.

Instead, a comparison was made for six separate charging operations (four Wilputte and two AISI/EPA), between the measured flow of gaseous emissions (scf/second at one second intervals) and the particulate mass rate across the length of the light bar as calculated from micro-densitometer readings using the appropriate algorithms (measured as grams particulate/meter vertical distance at five second intervals). In such a comparison, evidence of a correlation between optical measurements and the mass loading in the emission plume would appear as similarities in the trends of each measurement (i.e., comparison of peaks, and increasing and decreasing trends of the curves). In general, these trends and relationships were found, and are reviewed in detail in the body of the report.

Although reasonable correlation was found, problems encountered in accurately characterizing the particulate characteristics and the variability of the size distribution caused serious doubt concerning the ability of the system to accurately and consistently measure total mass emitted for compliance purposes. An alternative approach was developed and discussed in the body of this report. This approach involves the use of the basic system elements to implement a refinement of Ringelmann technique accounting for duration and volume of an emissions plume.

SECTION II
INTRODUCTION

The atmospheric environmental problems associated with coke manufacturing are a serious concern to the industry and to anyone in the near vicinity of a coke plant. The American Iron and Steel Institute (AISI) has made studies over a number of years addressing the environmental health problems associated with coke oven emissions. The results of these early studies led most steel companies to initiate programs related to control of coke oven emissions. One particular aspect of the emissions control program was improved charging techniques - a subject receiving increasing attention from AISI and the industry. As a result of this common interest, AISI and Jones & Laughlin Steel Corporation signed an agreement in March 1969 whereby J & L would manage the AISI coke oven charging program. In June 1970, AISI signed an agreement with the Air Pollution Control Office (later designated Office of Research and Development) of the Environmental Protection Agency under which half the cost of the program would be born by EPA.

The AISI coke oven charging program was to culminate in a prototype of a new larry car that would result in smokeless charges and have an environmentally controlled cab for the safety and comfort of the operator. In order to determine the improvement in atmospheric emissions due to the new prototype larry, EPA engaged the services of The MITRE Corporation in April 1971 to conduct a test and evaluation program. The overall objectives of the test program as agreed to by EPA and The MITRE Corporation were as follows:

- quantify the atmospheric pollutants resulting from the charging operation in the coking process,
- provide a comparative evaluation of the pollution abatement system (AISI/EPA larry car versus existing Wilputte Larry Car),
- determine the feasibility of a compliance monitoring system concept based upon optical measurements.

By July 1971, construction of the new car was started on the south end of the P4 battery at the J & L Pittsburgh Works. In December 1971, the new car first operated under power.

During this period, effort under the MITRE contract consisted of the design and fabrication of emission guides to fit around the drop sleeves of each larry car so as to channel emissions that would be normally vented to the atmosphere; the design and installation of a van mounted continuous monitoring instrumentation system for monitoring these emissions; the preparation of manual sampling and analytical specifications; and the design and fabrication of equipment for the optical measurement program.

In September 1972, MITRE performed two days of preliminary testing at J & L to determine the feasibility of using certain sensors and to determine gross flow parameters. Additional preliminary tests were performed in May 1973, and full tests on the oven began in June 1973 and concluded at the end of August. Data reduction and report production efforts were then initiated in September of 1973 and were completed with the submission of this final project report in March 1974.

As an adjunct to the test activities carried on at the J & L facility, observations of two new charging cars with features similar to the J & L car were scheduled at two other coking operations in March and April of 1974. The purpose of these observations was to collect data on the operation of these cars including production data, reliability data, and a qualitative assessment of emissions from the charge through visual observations. Observations were scheduled at the Weirton, West Virginia and Granite City, Illinois plants of The National Steel Corporation. However, due to operational problems and program schedules, observations at Granite City were indefinitely postponed.

Observations carried out at the Weirton Steel Division of The National Steel Corporation provided much additional information useful in any assessment of improvements and new technology currently in use at operating coke plants. The data obtained during these observations has been compiled and is published under separate cover.

SECTION III
APPROACH

GENERAL

In order to compare the improvement in atmospheric emissions resulting from the use of the new AISI larry car, the MITRE approach was to channel all emissions from around the drop sleeves and Wilputte stacks through ductwork of defined cross-sections for flow and particulate measurement and gas quantification. These data were then integrated to obtain a typical grain loading and gas mass flow during a charge by each type larry car and, in turn, a measurable change due to the new design. This section describes the Emissions Guides used for channeling emissions from around the drop sleeves, the sensors and probes used on the oven, and the instrument van where continuous gas analyses were performed and where data were recorded. Manual gas and particulate samples were obtained, and this sub-program is also described in this section.

A study was conducted to establish the feasibility of determining or inferring the mass loading of particulate matter during a charge by means of an optical (camera) system. This experiment is also described in this section.

Finally, the test program, schedule, and operating procedures used in the field measurement program are described.

CONTINUOUS MEASUREMENT SYSTEM

This system was designed to allow a continuous (one reading per second) measurement of flow and selected gases. The various components required to satisfy this requirement are described in this section.

Emissions Guides

These are structures that were designed and fabricated to fit around the drop sleeves of the larry cars and channel the emissions that are usually vented to the atmosphere. The guides for each larry car are different because the configuration of the drop sleeves is different. In both cases, heavy emissions escape following normal charging when the drop

sleeve is raised up from the charging port on the oven floor. Consequently, the guides were designed so that moving parts would not leak emissions and still resist the heat of the gases and any local flames.

Wilputte Larry Car Emissions Guides - The duct which contained the emissions from the Wilputte car and provided a controlled measurement location was configured in the form of an annulus extending from the oven top upward around the drop sleeve assembly. The inner wall of the annulus was sealed to the bottom of the drop sleeve by means of a flexible fire retardant skirting. The outer wall of the annulus was located 7" outside the inner wall and extended from the top of the oven around the drop sleeve assembly. The outer sleeve was sealed to the top of the oven by the weight of the guide resting on its lower edge. As can be seen in Figure 1 and 2, the annulus is elliptical in shape and smaller at the bottom than at the top. This configuration provided an expanding volume in the vertical direction which allowed the hot emissions to rise and expand with minimal interference. Portions of the guide were blocked off by deflectors, allowing measurements to be made in one well-defined measurement duct. In order to provide a smooth emissions flow within the measurement area, vortex breakers were placed inside the duct at an appropriate distance from the sampling area. The breakers, in the form of wide mesh screens, appeared to improve the flow characteristics in the measurement ducts. The design of the guide was such that emission suppression or inducement was minimized.

In addition to emissions from the vicinity of the drop sleeves, emissions escaping from the three stacks on the Wilputte car were monitored. Guides for these emissions were merely cylindrical "stovepipe" extensions on the stacks.

AISI/EPA Larry Car Emissions Guide - This system consisted of two hoods connected by a flexible flameproof section for each of the three drop sleeve assemblies (Figures 3 and 4). The inner hood was designed to surround the drop sleeve and contain the emissions when the sleeve is in the lowered position. The hood was sealed at the top to the center

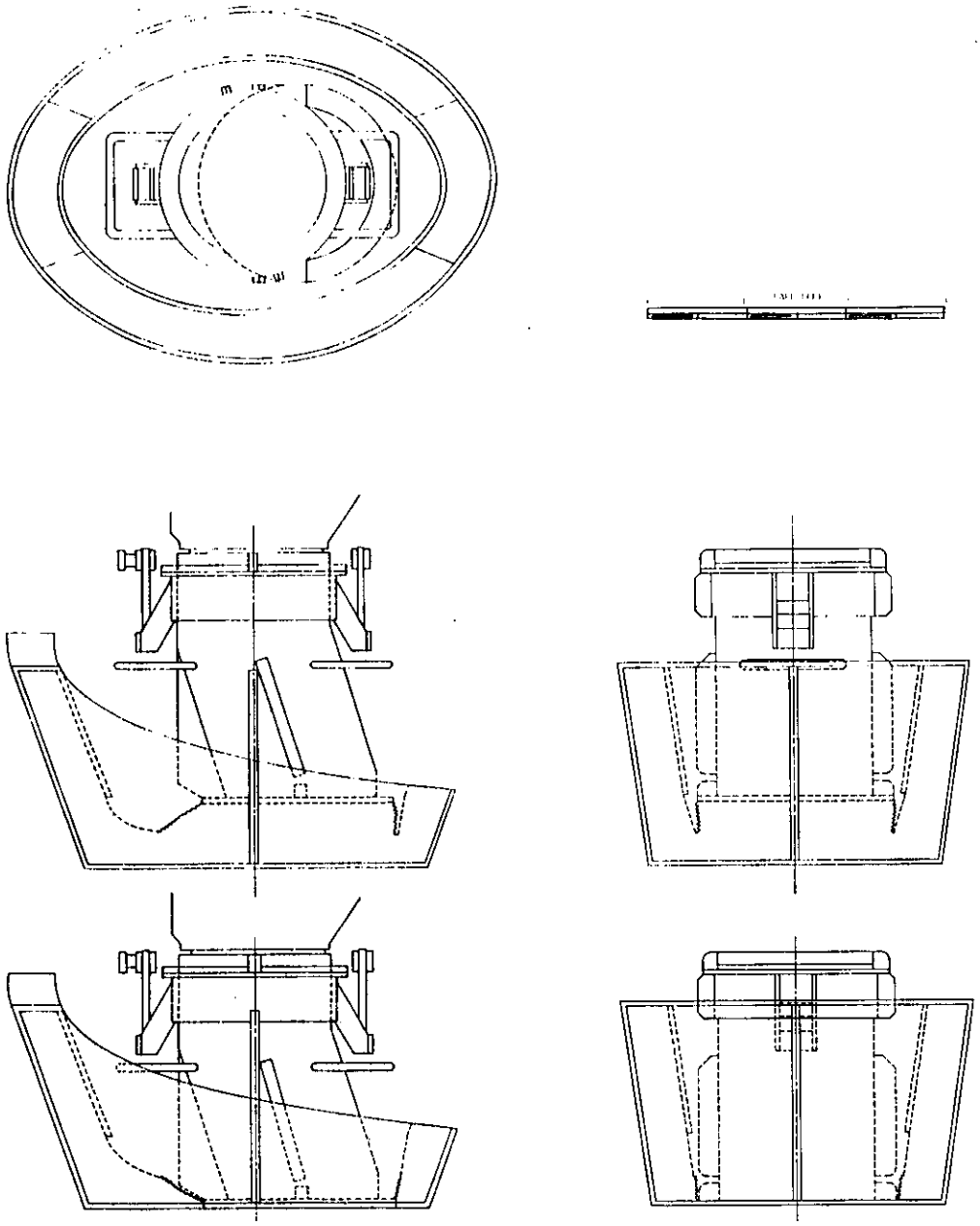

FIGURE 1
WILPUTTE LARRY CAR
EMISSIONS GUIDE

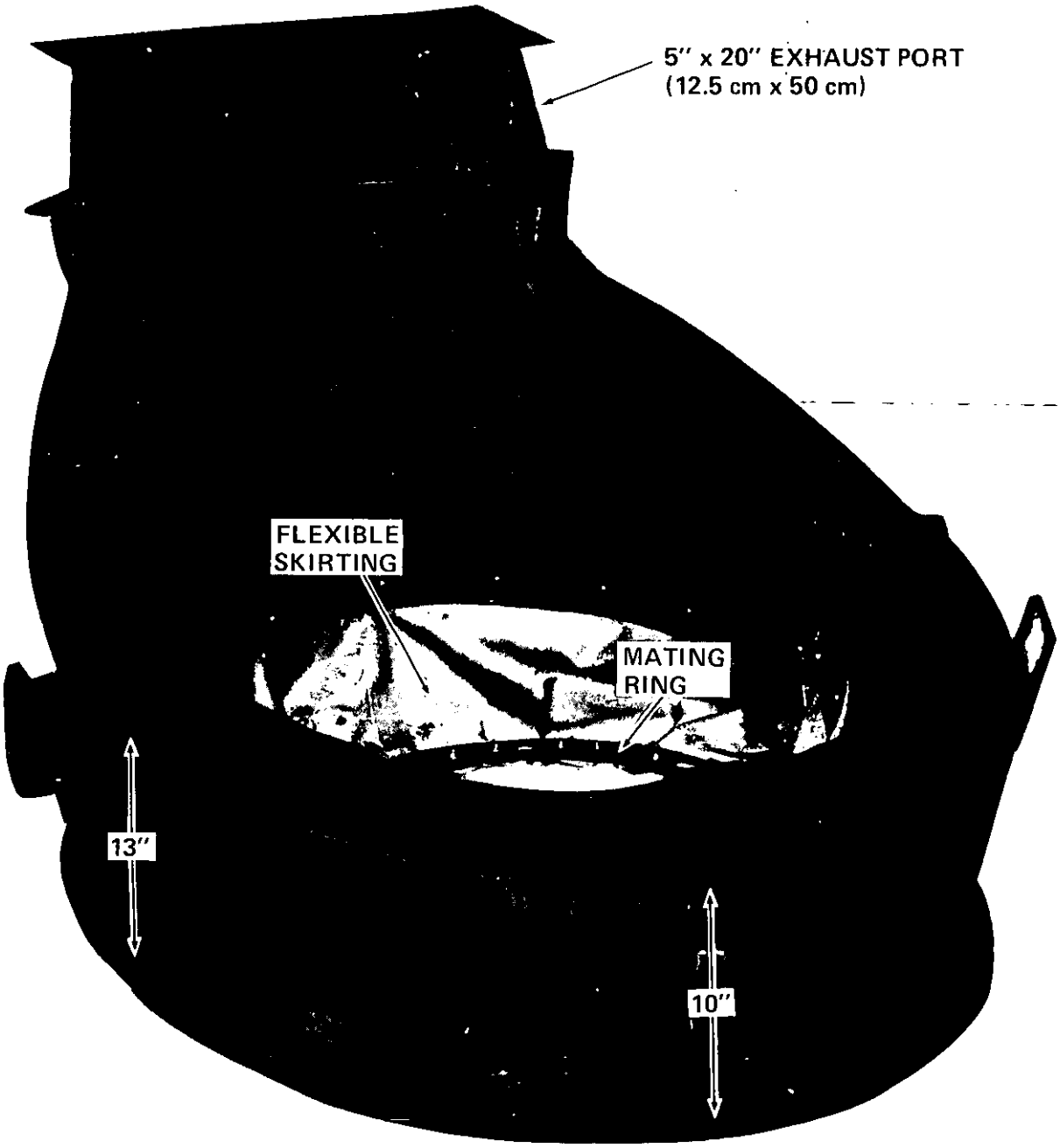

FIGURE 2
WILPUTTE LARRY CAR EMISSIONS GUIDE

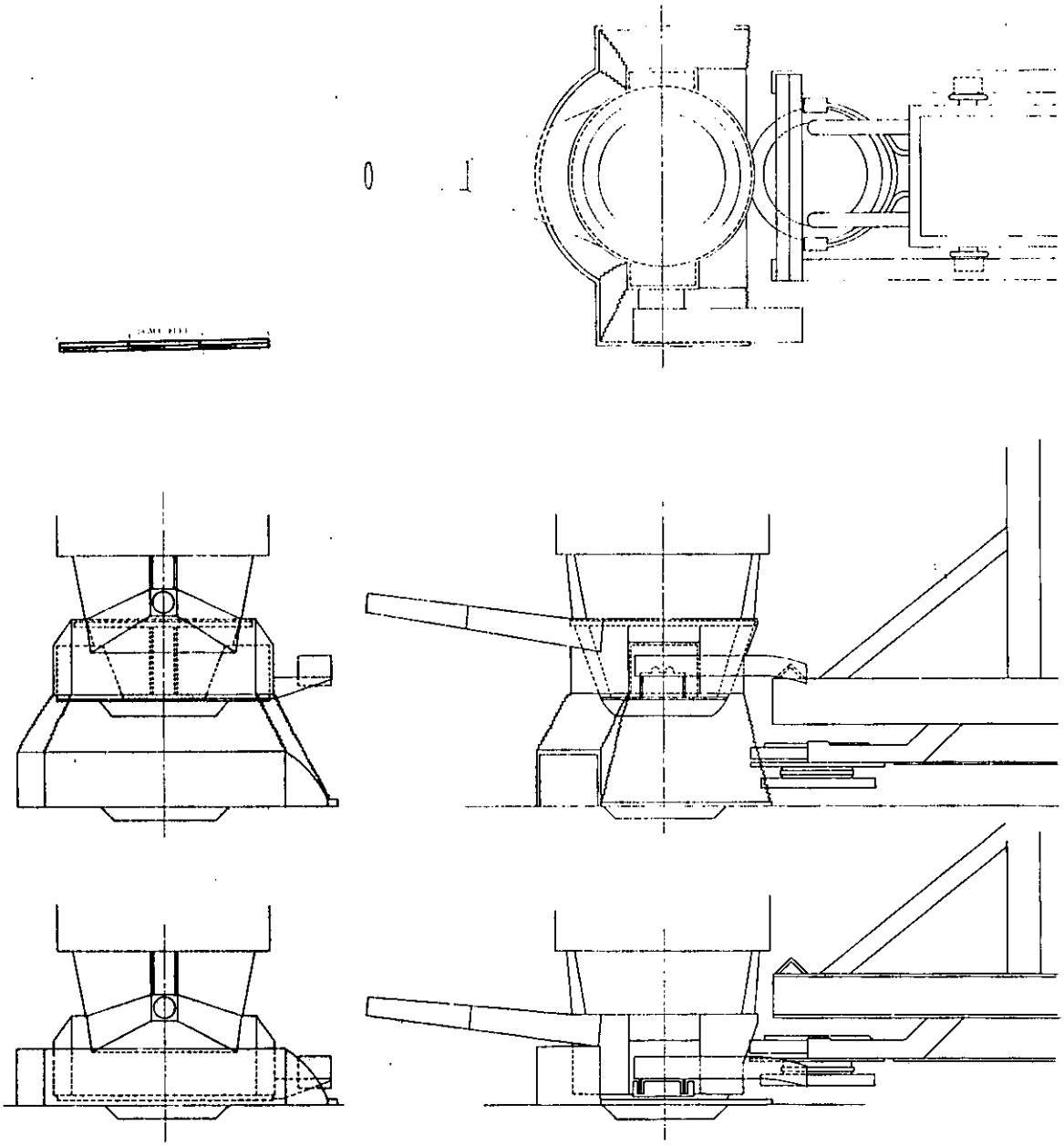

FIGURE 3
AISI/EPA LARRY CAR
EMISSIONS GUIDE

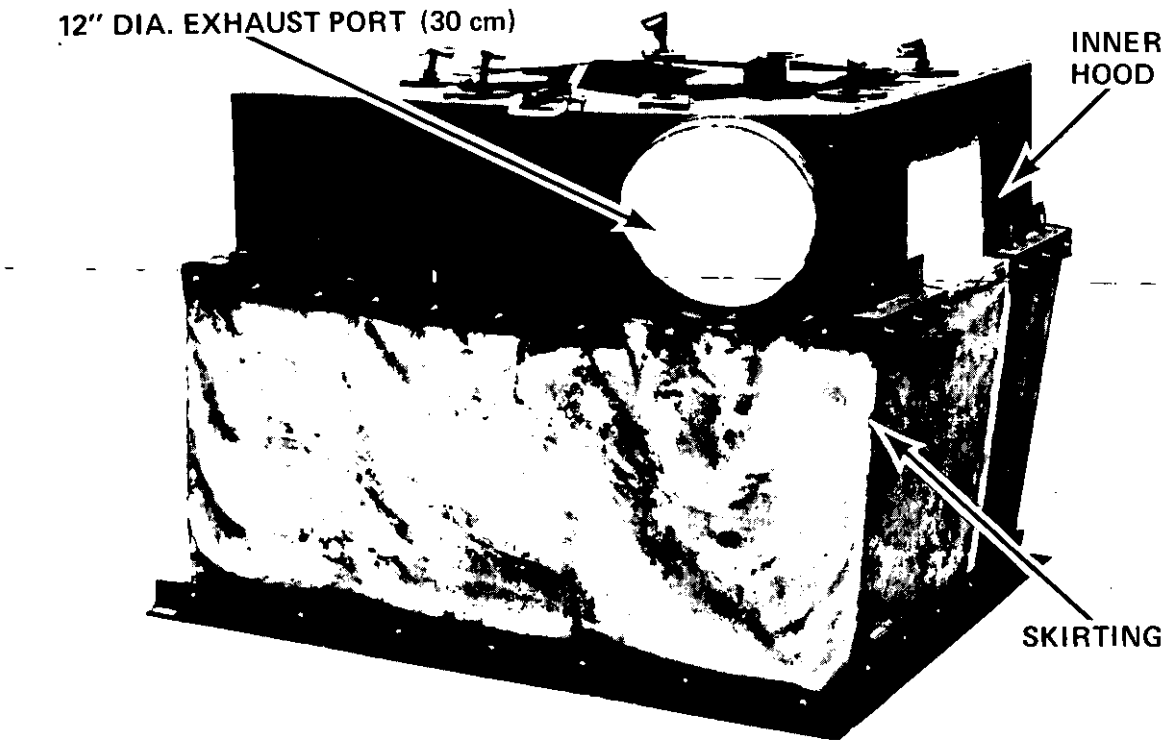

FIGURE 4
AISI/EPA LARRY CAR EMISSIONS GUIDE

flange on the drop sleeve assembly and extended downward and completely around the drop sleeve assembly to a point slightly above the oven surface.

A flexible woven fabric was attached to the lower edge of the inner hood and extended downward to contact the oven top along a line completely surrounding the lowered drop sleeve. The flexible wall was held in contact with the oven top by the weight of the angle iron fabric frame that rested on the oven floor. The hood was designed to minimize the internal empty volume while still allowing the movement of contained emissions to a single measurement duct located at the top and forward side (away from the lid lifting mechanism) of the inner hood. The measurement duct extended some distance to obtain a smooth flow of emissions, thus providing a region in which accurate measurements could be made. The small hood volume optimized the entrapment of emissions experienced during the portion of the charging cycle when the drop sleeve is lowered. Vortex breakers were placed at the beginning of the measurement duct.

At the completion of the charging cycle, the drop sleeves were raised and the lid mechanisms replaced the charging port covers. During this period, the outer hood, sitting on the oven surface and connected to the inner hood by the lower end of the fabric wall, confined the emissions and guided them upward to the measurement duct on the inner hood. In order to allow normal operation of the lid lifter mechanism, the rear portion of the outer hood was left open from the lower edge of the inner sleeve to the oven surface. The lid lifter mechanism then passed through this opening and replaced the charging port cover in the normal manner. A partial seal of this opening was achieved by a flexible fabric skirt attached to the back of the inner hood above the lid lifting mechanism and directly behind the lid lifter magnet assembly. The inner portion of the hood was balanced so as to allow the drop sleeve to be raised or lowered while the hood was in place.

SENSORS AND PROBES

Flow measurements and sampling require sensors and equipment located at the emissions guides and stacks. Other hardware was required on the oven to obtain the needed data. The mechanical, electrical, and electronic equipment located on the oven is described below.

Metal plates were fabricated and permanently attached to the sides of the ducts of the emissions guides, and the sensor heads were mounted on these plates in such a fashion that they extended into the flow of emissions from the ducts. This design allowed for all delicate sensors and circuitry to be handled separately from the emissions guides for ease of cleaning and maintaining, as well as for protection against rough handling. Equipment that was mounted on the plates consisted of: pitot tubes for gas velocity determination, thermocouples for temperature determination, probes for collecting gaseous emissions, filter bases for collecting particulates, and heaters for maintaining the temperature of the gas and particulate probes. Photographs of the sensor ducts are shown in Figures 5 and 6.

Sensors and sampling probes were connected to additional equipment located off the oven floor in or near the small shed on the pipe bridge opposite Oven 3-5 (see Figure 7). These connections were made through wires and heated tubing that either transmitted electrical signals, differential pressure, or gas samples. These wires and tubing were made up into bundles, termed cables, and run from the emissions guides and stacks via overhead booms and towers to the pipe bridge area.

Two booms were used in the testing area and were attached to the pipe bridge shed: one closest to the coal bin supported cables for testing the emissions guides of the Wilputte car and the one farthest from the coal bin supported cables for testing either the Wilputte stacks or the AISI/EPA emissions guides.

The small shed at the end of the pipe bridge cross-over main opposite Oven 3-5 housed equipment required to convert temperature and pressure probe outputs into electronic signals, and also served as the location

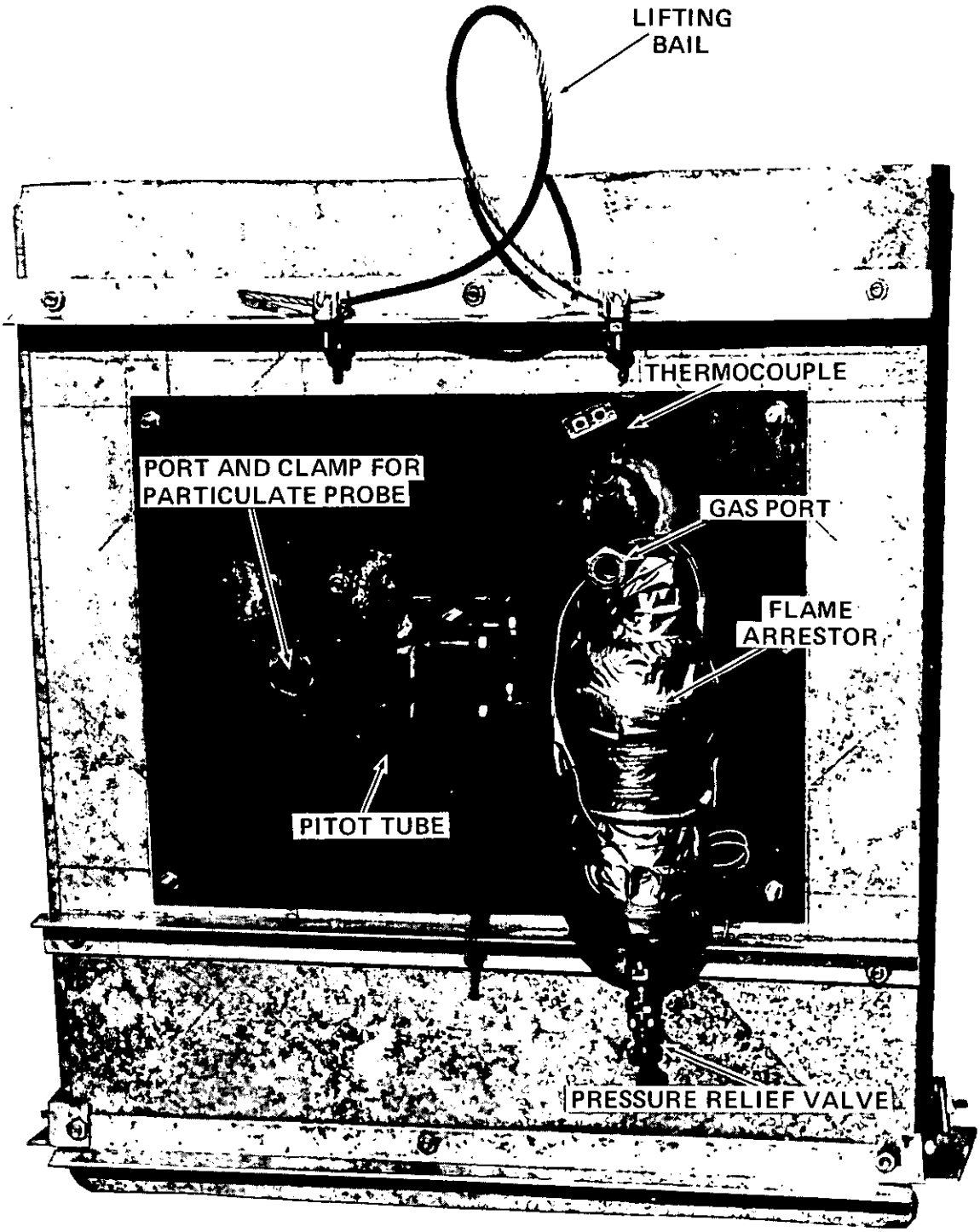

FIGURE 5
WILPUTTE EMISSION GUIDE
SENSOR DUCT

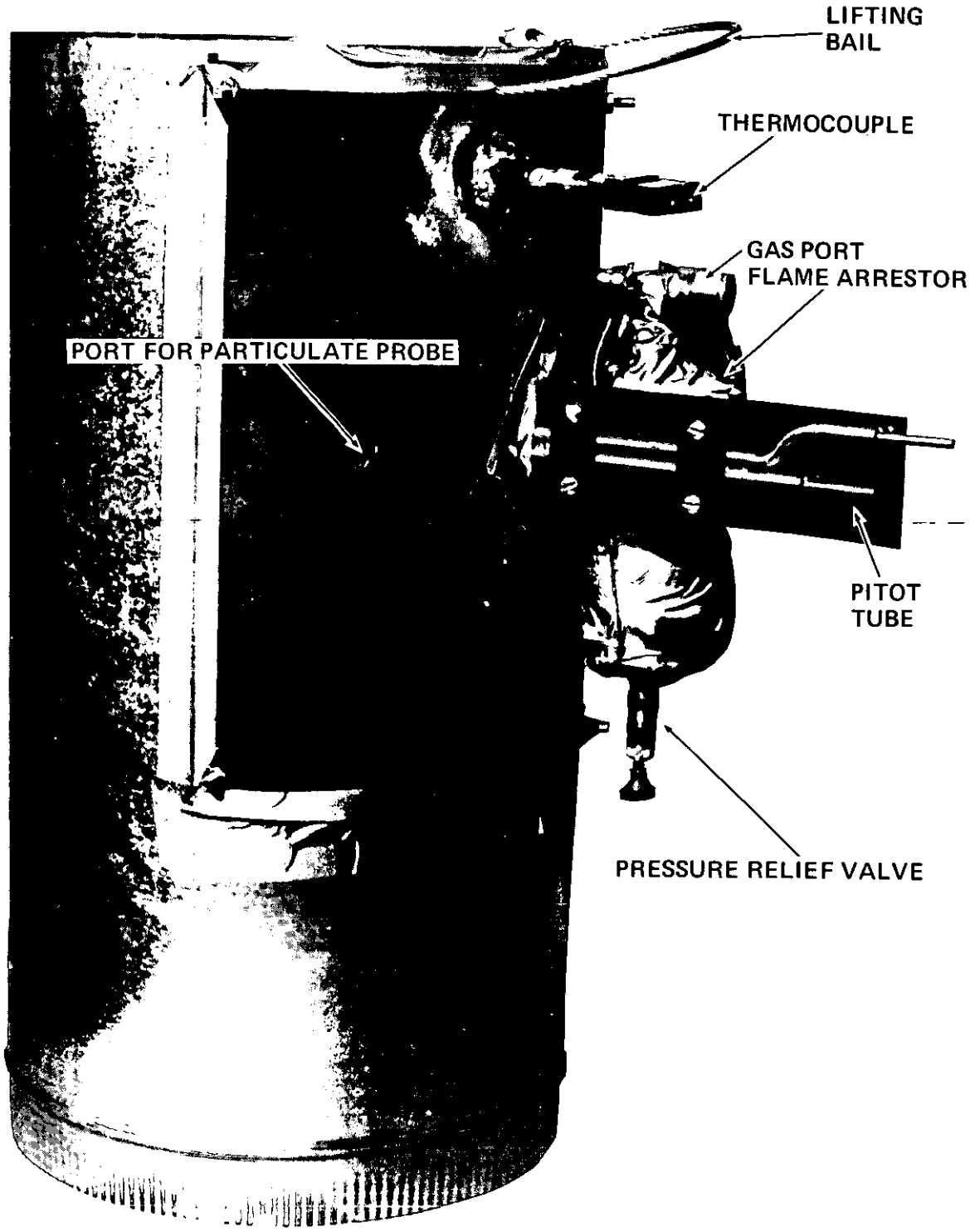

FIGURE 6
WILPUTTE STACK AND AISI/EPA EMISSION GUIDE SENSOR DUCT

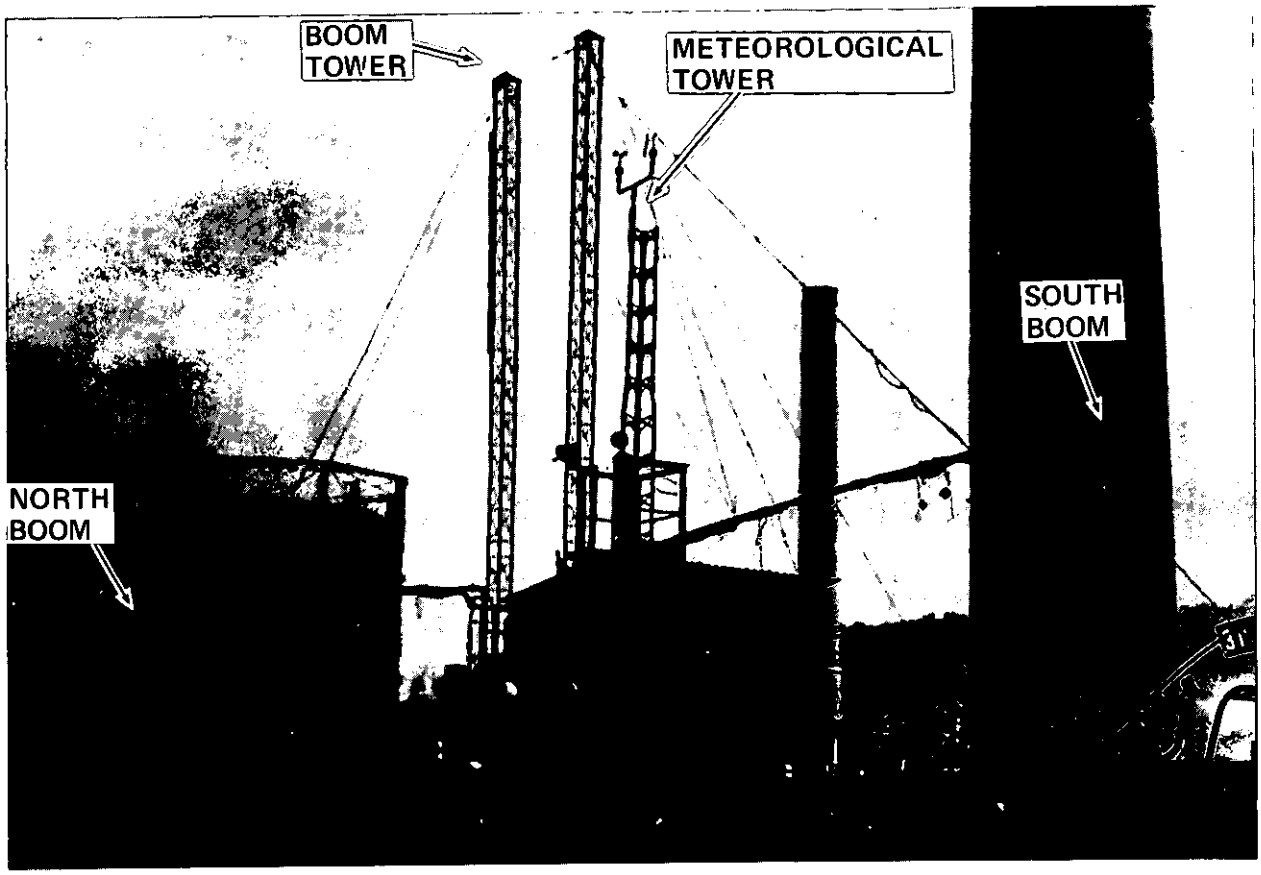

FIGURE 7
CROSS-OVER BRIDGE SHED AREA

for combining gas samples from all measuring points into a "common duct" for manual sampling and further transmission to the instrument van. The shed also served as a central location for communications via citizen band radio between the test director, instrument van, and the optics balcony, and was also the power distribution point for the heated probes and gas lines. The porch-like platform in front of the shed was the location from which the booms were manipulated.

Pressure transmitters were housed in a 24" w x 30" h x 18" metal box, located adjacent to the shed. Control switches for activating the gas and particulate control valves were also in this box. Temperature transmitters were secured to a 19" wide instrument rack inside the shed. The "common duct" manifold that combined gas flows was housed in a 12" x 12" x 36" heated box, located in the shed.

A meteorology station located on the top of the shed had associated electronic boxes in the instrumentation van.

Cables, wires, and heated tubing were placed in a cable trough located across the top of the pipe bridge where they dropped down to ground level to the instrumentation van at the base of the bridge tower.

Instrument Van

Gas collected at the sensor ducts and the output of the temperature and pressure sensors was processed by electro-chemical-mechanical instrumentation and the results recorded for subsequent analysis. The processing center was a 36' van filled with seven racks of electronic equipment to perform these functions and was located at the base of the pipe bridge tower as shown in Figure 7. Three specific functions were performed in the van: gas analysis, determining physical properties in the vicinity of the measurement points, and data recording. Instrumentation used is briefly described here, and a more detailed description can be found in the Test Plan, MITRE WP-10434 and in MTR 6566, "A Continuous Monitoring System for Coke Oven Emissions Due to Charging."

Gas Analysis System

The continuous gas measurement system consists of a number of specific gas analyzers of two basic types: raw gas analyzers which accept a gas sample as it comes from the emissions guides, and conditioned gas analyzers which require preconditioning in the form of gas drying and cooling.

The gas sampling system draws a representative sample of emitted gas from the emissions guide and the Wilputte stack (when testing the Wilputte Larry Car). The gases from the emissions guide probes and the Wilputte stack probes are combined at the common duct in the pipe bridge shed. All components in contact with the sample gas are held at elevated temperature to prevent condensation.

The common duct consists of a plenum containing a mixed representative sample of emission from the selected sources. The gas sample for the wet chemical analysis (manual sampling) equipment is extracted from this plenum. The remaining gas flowing through the common duct is fed through heated sample lines to the analyzers located in the instrumentation van.

Upon entering the instrumentation van, the gas flows through a heated manifold, from which a sample is extracted for the raw gas analyzers. The remaining gas flows through a refrigerated condenser where it is cooled and condensables are removed. The dried, cooled gas is then pumped under slightly positive pressure to the conditioned gas analyzers. A pressure regulator and bypass was provided to minimize the gas transit time. A schematic diagram of this system is shown in Figure 8.

Raw Gas Analyzers

A number of the gas analyzers operate on the gas sample under stack conditions. The gaseous constituents monitored in this manner include: SO_2, H_2S, THC, NO, NO_x and H_2O vapor. Each instrument incorporated an independently heated sample handling system for controlling the flow through each analyzer.

The H_2S analyzer is a dual gas instrument, manufactured by Peerless Instrument Company and operated on the principal of ultraviolet absorption.

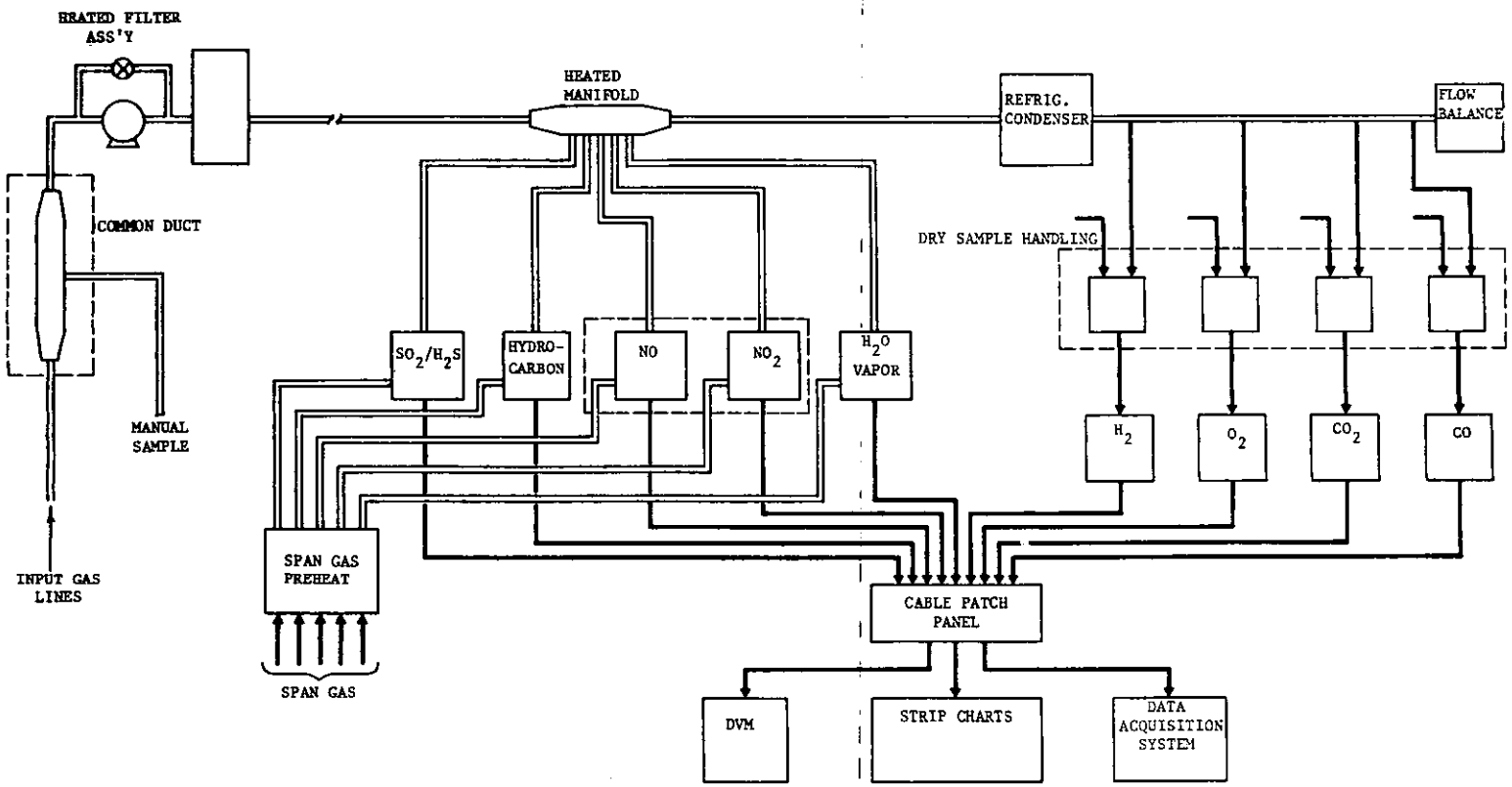

FIGURE 8
GAS HANDLING SYSTEM

The band selected for H_2S has an SO_2 interference factor, but since the analyzer was also measuring SO_2 on a continuous basis, a correction circuit was employed which subtracted out the SO_2 interference, providing a true output of H_2S. The analyzer incorporates three ranges providing 3,000, 300, and 100 ppm by volume full-scale.

The THC (Total Hydrocarbons) analyzer operates on the flame ionization principle whereby the gas sample is burned in an ionization chamber using a mixture of zero air and pure H_2 as fuel. The combustion process produces free ions, which are detected by an ion detector. The detector produces a current whose magnitude is a function of the number of ions reaching the collector; therefore, the detector current is a function of the total hydrocarbon content of the gas sample. The analyzer utilizes an input gas dilution system to eliminate interference caused by the H_2 present in the sample gas.

The analyzer for Nitrous Oxide is a chemiluminescent device. In the reaction

$$NO + O_3 \rightarrow NO_2 + h\nu \ , \qquad (1)$$

light ($\lambda \simeq .6\text{-}3\mu$) is emitted when electronically excited NO_2 molecules revert to their ground state, and the intensity is proportional to the NO concentration.

The analyzer for Nitric Oxide is similar to that for NO, but includes a hot catalyst for the reduction of NO_2 to NO. The resulting measurement is NO_x ($NO + NO_2$). The quantity of NO is subtracted electronically, from the NO_x value, producing an output in terms of NO_2 concentration.

The Water Vapor analyzer is a MSA Lira 200 HR Non-Dispersive Infra Red (NDIR) instrument. It has a dual range configuration with 10% and 50% moisture full-scale ranges.

Conditioned Gas Analyzers

These gas analyzers are supplied with a cooled, dried sample gas stream. A refrigerated condenser with a stainless steel condensation chamber is employed to pump the dried gas through the analyzers. A dry gas sample

handling system was employed for each analyzer, providing flow monitoring, throttling control, and calibration gas insertion. Those gases monitored are: H_2, O_2, CO, and CO_2.

The analyzer for Hydrogen is a Beckman 7C Thermal Conductivity Analyzer.

The analyzer for Oxygen is a Beckman Model 742, utilizing a polarographic oxygen sensor.

The analyzer for Carbon Monoxide is a MSA d11A 202, non-dispersive infrared instrument. The instrument is a three-range device, operating at 3%, .3%, and .03% by volume full scale.

The analyzer for Carbon Dioxide is a MSA LIRA 202 non-dispersive infrared instrument. The instrument is a four range device, operating at 10%, 3%, 1%, and .3% by volume full scale.

Physical Properties Measurement System

The physical properties of the gas effluent emitted at each source were monitored. These properties include temperature, static pressure, and differential pressure, and are used to compute the volume flow of the emission and in processing the data to convert the gas measurements to STP.

Temperature measurements were monitored by using Type K (Chromel-Alumel) thermocouples in conjunction with Leeds and Northrup Model 1992 temperature transmitters in a temperature range of 0-2,200°F. The temperature transmitter has a response of 1 millivolt/2°F.

The differential pressure measurements were made using a series of "S" Type pitot tubes, connected to CGS Datametrics Model 536 Barocel pressure transducers. The range of differential pressure is 0-10.0" W. C. with resolution of .0005" W. C.

Meterological parameters were monitored on a continuous basis. These parameters include ambient temperature, humidity, barometric pressure, wind speed, and wind direction.

Data Recording

The data produced by the gas analyzers and the physical property measurement instruments were recorded, in IBM-360 compatible format, on magnetic tape. Selected parameters were recorded in analog form on a series of strip chart recorders. In addition, each parameter could be monitored, independently, by a digital volt meter.

The data acquisition system was manufactured by Data Graphics Corporation, to MITRE specifications. The system provides 70 analog input channel capability, time of day clock, and manual data input. The analog-to-digital converter provides an accuracy and resolution of .005% of full scale and is capable of operating at a data rate of 200 conversions/second.

Selected data parameters were graphically recorded on strip charts. The recorders, manufactured by the MFE Corporation, are multi-channel devices using rectilinear heat writing and providing 29 channels of recording capability.

MANUAL SAMPLING

The sampling of gas and particulate by manual methods was done to complement the continuous monitoring and optical portions of the program. Samples were obtained at the same measurement points on the emissions guides and Wilputte stacks as the emissions were channeled during normal charging and simultaneously with the continuous measurement tests. A brief summary of this part of the test program follows below, with a more detailed description found in MITRE WP-10179, "Manual Sampling and Analytical Requirements for the Coke Oven Charging Emissions Test Program," 16 February 1973, and MTR-6288, "Manual Sampling System for the Coke Oven Charging Emissions Test Program," December 1972.

Gas Sampling System

Gases drawn through the probes of the sensor duct and into the overhead boom cables to the pipe bridge were mixed in the "Common Duct" manifold. The probes, cables, and common duct were maintained at elevated temperatures to prevent condensation of hydrocarbons and other tars. The

heated common duct manifold was used as the source for the manual gas samples, and a heated tube extended from this common duct to a heated box containing four Teflon bags. During the test of a normal charge, the four bags were sequentially filled with the gases from the common duct. The heated box containing the four bagged samples was removed to the portable lab where each sample was preprocessed and partially analyzed on site to minimize the possibility of degradation of any constituents. The preprocessing was as follows:

- Samples containing N_2, H_2, O_2, CO, CO_2, and CH_4 were transferred to glass containers for later analysis.
- SO_2 was absorbed using an impinger and held for later analysis.
- NO_x was analyzed on site.
- THC was analyzed on site.
- NH_3 was absorbed by an impinger for later analysis.
- HCN was absorbed by an impinger train for later analysis.
- H_2S was absorbed by an impinger train for later analysis.
- Specific hydrocarbons (pyridine and phenols) were placed in trains for later analysis.

Later analysis of the samples was performed in the Kansas City Laboratories of Midwest Research Institute by prescribed techniques.

Analytical Methods

In this section, the analytical methods are described for the determination of gaseous concentrations in the manual sampling program.

CO, THC, Methane - A Varian Aerograph Gas Chromatograph, Model 1420-10, equipped with a 5 ml. gas sample loop and a high sensitive thermal conductivity detector, was used throughout for this work. These gas determinations were made in the field lab due to the unstable nature of the gases. The sample loop system was evacuated to as low a pressure possible with a Welch Duo-Seal vacuum pump. For calculation purposes, this pressure drop was considered to be atmospheric pressure. The sample was

passed into the sample loop and the sample pressure measured. Using a molecular sieve 5A column, the gases were separated under the instrument conditions listed in Table 1.

O_2, N_2, CO_2 and H_2 - These gas concentrations were determined in the identical method as just described, except that the analyses were performed at the MRI laboratory in Kansas City at the completion of the field work.

H_2S - ASTM D 2725-70, "Methylene Blue Method;" exceptions to method - Neutral $CdSO_4$ solution (140 g/liter) used in place of zinc acetate absorbing solution.

NO_x - Federal Register Method 7 (Volume 37, Number 247), "Determination of Nitrogen Oxide Emissions from Stationary Sources."

NH_3 - Analytical Chemistry 39, 971 (1967), "Catalyzed Berthelot Reaction."

CN - ASTM D 2036-72, Method C. Colorimetric (chloramine-T/Pyridine-Barbituric Acid).

Phenol - ASTM D 1783-70. Aminoantipyrine-Ferricyanide Method.

SO_2 - Federal Register Method 6 (Volume 36, Number 247), "Determination of Sulfur Dioxide Emissions from Stationary Sources."

Pyridine - Gas Chromatographic Analysis. Instrument - MicroTek Gas Chromatograph, Model 220, equipped with a flame ionization detector. Column - 5% Theed on Chromasorb G, 80/100 Mesh, 9' x 1/4" Cu. Column Temperature - Isothermal at 85°C. Carrier Gas - N_2. Carrier Gas Flow Rate - 20 ml/min.

Particulate Sampling System

Particulate sampling was done at each emissions guide and Wilputte stack. The sampling nozzles were located in the measurement ducts parallel to the expected flow directions. Each nozzle was connected directly to a heated cyclone and filter or an Andersen Sampler. This sampling system further consisted of a modified EPA particulate sampling train employing quasi-isokinetic sampling.

TABLE 1

GAS CHROMATOGRAPH PARAMETERS FOR MITRE GAS ANALYSES

Gas	O_2	N_2	CO_2	H_2
Column	(a)	(a)	(a)	(b)
Column Temperature, ^oC	60	60	250	25
Detector Temperature, ^oC	195	195	195	140
Carrier Gas	He	He	He	N_2
Carrier Gas Flow Rate, ml/min	100	100	100	60
Bridge Current, ma	200	200	200	150

(a) Molecular Sieve 5A, 5 ft x 1/8 in., s.s.

(b) Molecular Sieve 5A, 15 ft x 1/8 in. s.s.

The samples were analyzed for mass loading, size distribution, and elemental analysis. The weight of each sample was correlated with the volume of the gas sampled from the stream to determine the anisokinetic particulate concentration to which theoretical corrections were applied to produce a calculated isokinetic concentration. Samples, obtained from the Andersen impactor and captured on the MITRE designed carrousel sampler (see MITRE WP-10480), as well as those collected by the Brink impactor, were used for size analysis. Methods used were aerodynamic classification and optical microscopy. The particulate samples obtained were analyzed for the following elements:

Al	Cu	Mo	Se
As	Fe	Na	Sn
Ba	Ga	Ni	Sr
Be	Ge	P	Ti
Ca	Hg	Pb	Tl
Cd	K	S	V
Co	Mg	Si	Zn
Cr	Mn	Sb	U

Coal Sampling System

Coal Samples were obtained while testing both larry cars. Analyses performed on these samples were size distribution, elemental, proximate, and ultimate.

OPTICAL PROGRAM

One objective of the MITRE test program was to investigate the feasibility of developing simple monitoring systems and techniques and to define an inexpensive compliance monitoring system for evaluating emission sources with similar characteristics.

The proposed system of monitoring was to cause minimal interference with the normal operation of this coke plant and was to be adaptable to various plant configurations and conditions. Optical techniques have been successfully applied in numerous situations involving a requirement to monitor emissions to determine pollution and air quality. Because of this previous use, because it did not interfere with coke production and

would be adaptable, and because it could be operated in parallel with the continuous monitoring system, an optical monitoring system was designed to satisfy this requirement.

The three essential elements in any optical measuring system are:

- a source of radiant energy (the sun, light bulbs, lasers, etc.) or a target which reflects radiant energy,
- energy collection and focusing devices (lenses, mirrors),
- energy detectors (the eye, photoelectric cells, photographic film, etc.) plus amplification, display, and recording devices.

The basic type of light source which best satisfied the system requirements is the flourescent tube. In order to achieve the desired vertical width for the light source, a parabolic reflector was placed behind two standard 1500 MA 96" parallel flourescent tubes which achieved desired intensity as well. The tubes and reflector were housed in a "light bar" which had a diffuser lens mounted in front of the unit to provide a more uniform light output. The bar was mounted 25 feet above the oven floor on the south end of the battery (see Figure 9). The main section extended across the entire width of the oven, and "wing sections" extended outward and downward.

The collecting, focusing, and detecting device selected is a modified 35 mm sequence camera capable of providing a frame rate of one frame per second. The camera was mounted on the first balcony of the coal in on the oven and was equipped with a 200 mm lens such that the light bin completely filled the field of view. The camera was also equipped with a time-of-day clock which recorded time on each frame. Additionally, a near-field light (18" flourescent lamp) was positioned in front of the camera balcony for orienting the camera after each setup.

During operation of the optical system, sequential photographs were taken of the light bar as the emissions plume from the larry car crossed the path between the camera and the bar. Each frame of the film contains an image of the large linear light source (light bar). In recording the

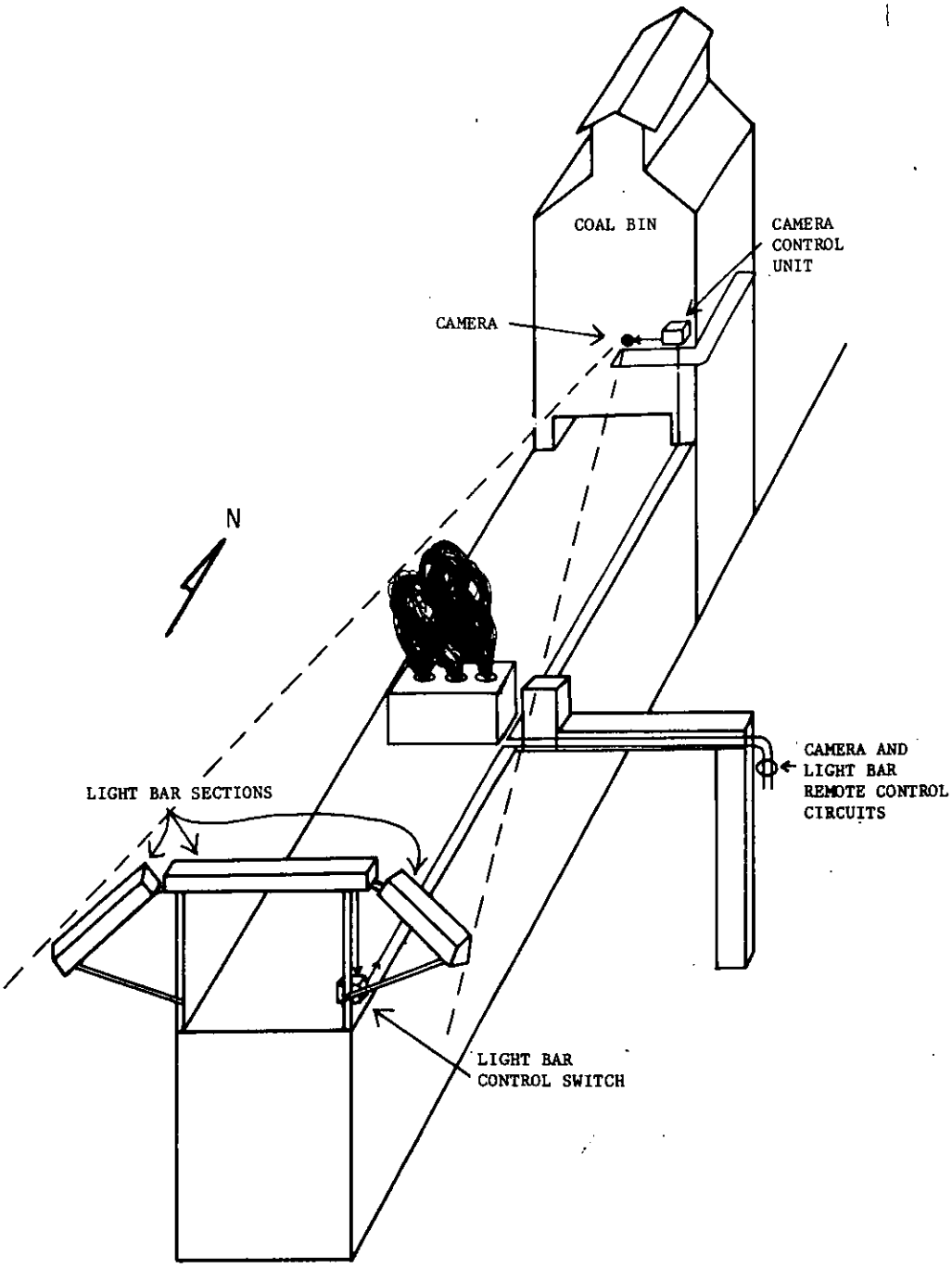

FIGURE 9
SIMPLIFIED SYSTEM COMPONENT CONFIGURATION

image of the light bar, the film detected any diminishment of light bar brightness caused by particulate or aerosol material in the light path. This diminishment was recorded as a decrease in density of the light bar image on the film. By properly choosing the exposure values for the film and accurately processing the exposed film, the amount of light diminishment was determined using a micro-densitometer to analyze image density changes of the individual frames.

Each frame contains three light bar segments as shown in Figure 10. Each segment has two distinct areas. The bottom or black (this drawing represents a negative film frame) area represents the surface of the light source. The top or white area is a flat surface of the light bar that was painted flat black to reduce any reflected light coming from this area. All three segments are identical in construction. The light source image appears ∿350μ high on the film frame. The flat black area appears ∿400μ high and adjoins the lighted area directly above or to the outside of it. Micro-densitometer analysis of both light and dark areas of each of the three segments of the light source image can be accomplished in the following manner.

The micro-densitometer was adjusted so as to have a 50 x 195μ aperture. A single scan was made across each area (lighted and black individually) of each of the three light bar segments. During the scan, a specified number of data points were recorded. A total of 539 data points evenly spaced were taken across the lighted and the black areas of the longer or horizontal bar section. The data obtained on each scan was placed on magnetic tape in the form of a binary density scale reading for each data point. Each scan sequence was further annotated on the magnetic tape with header information including sequence number, test number, type of frame and frame number information.

This brief summary of the optical program has been condensed from MITRE WP-10149, "Design of an Optical Emissions Measurement System for Coke Oven Monitoring," by R. W. Bee, December 14, 1972, and MTR 6596, "Optical Emissions Measurement Program Development."

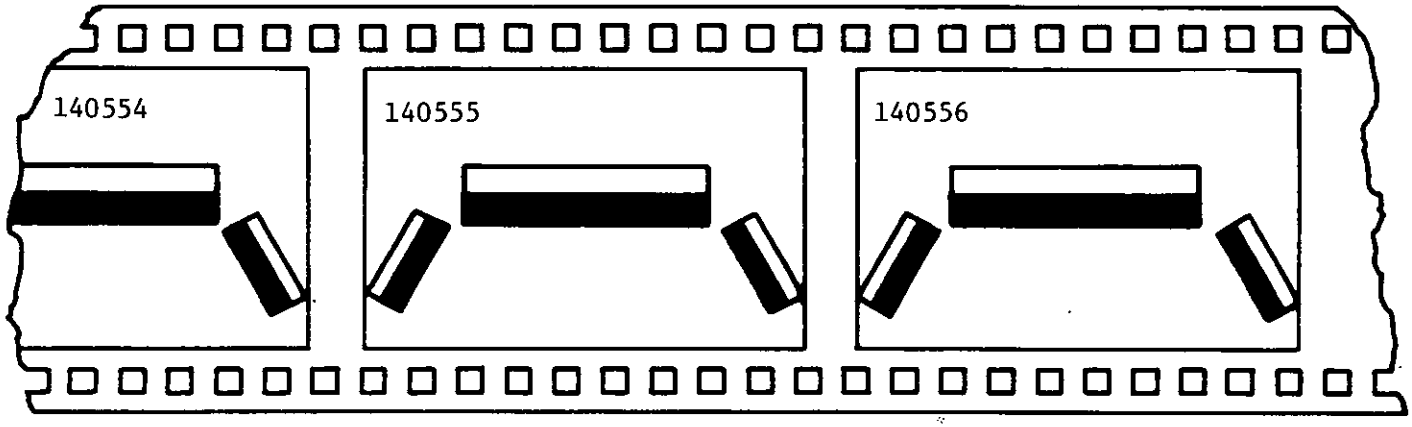

FIGURE 10
FILM FORMAT

FIELD TEST PROGRAM

Scheduling the tests on the battery in a reasonable sequence required coordination of many activities. First, the installation and site modifications to the new AISI/EPA larry car had to be completed; second, the procurement of critical equipment by EPA was required; third, the development and verification of the instrumentation by MITRE was necessary; and, finally, the EPA/AISI commitment to be completed at an early date was to be honored. A further requirement, to avoid interfering with J & L coke production, was also incorporated into the schedule. The system to measure the number of required parameters at the number of required measurement points, verify the measurement, convert the data to electrical signal and record these data for later processing required a large amount of equipment and an extensive amount of time for installation and checkout. Preliminary testing and data verification were also required and field tests, preliminary analysis, and dismantling had to be considered. These activities covered a five-to-six month period, during which five to six weeks of field system tests were conducted. The overall program schedule is shown graphically in Figure 11, and the final summary of the tests actually performed is provided in Table 2.

Only those ovens in the immediate vicinity of the pipe bridge and within reach of the overhead cable booms were monitored during the tests. Since an average time of approximately 15 minutes per oven was required between chargings, 11 ovens in the vicinity of the pipe bridge were normally charged during a four-hour period in any one daylight shift. MITRE avoided interfering with the charging schedule, and advantage was taken of the standard charging sequence and the normal shutdown at shift changes and noon to establish a tentative test routing. Based on this information, and experience on the battery, a Test Plan Outline for one day's activities was followed as shown in Figure 12.

Test Procedure

Various sampling techniques were employed during the time period when the larry car charged coal into the oven. These techniques and systems,

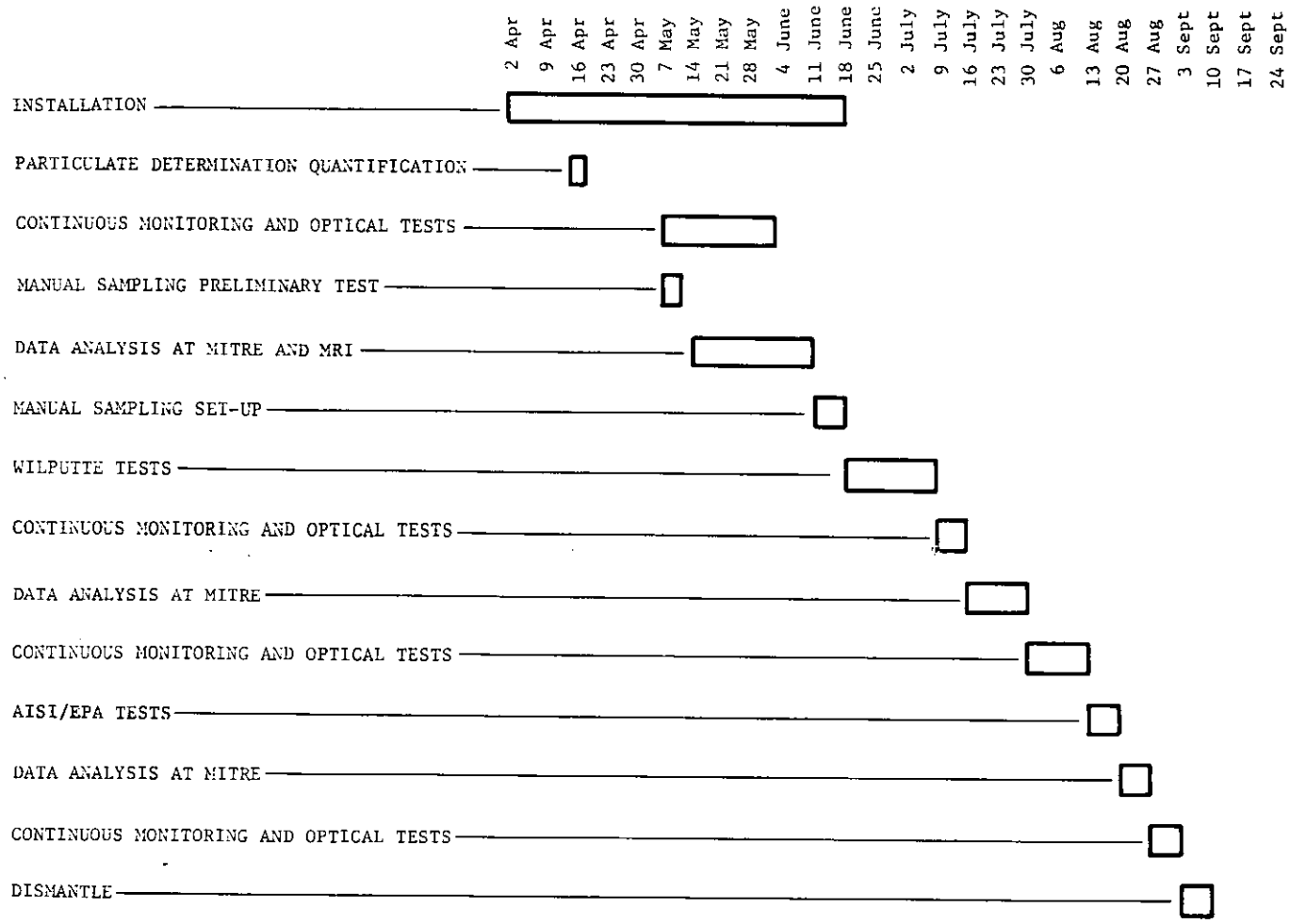

FIGURE 11
TEST PROGRAM SCHEDULE

TABLE 2
SUMMARY OF COKE OVEN TESTS

Date	MITRE Number	MRI Number	Oven	Time	Points Monitored	Remarks
May 7	0A		3-12		#2 Wilputte Guide	Flow data only - no mag. tape
9	0B		3-13		#2 Wilputte Guide	Flow data only - no mag. tape
10	1		3-7	7:30	#2 Wilputte Guide	Preliminary test for MRI - bad flame out
30	1A		3-5	4:45	#2 Wilputte Stack	Flow data only - no mag. tape
31	1B		3-7	10:30	#2 Wilputte Guide & Stack	Flow data only - no mag. tape
June 18			3-6	4:00		No test - boom cables shorted
19	2	W1	3-3	5:30	3 Wilputte Guides	MRI activated manually - bent boom
20						Larry car breakdown - no test
21	3	W2	3-8	1:00	#2 Wilputte Guide & Stack	Diff. press. pitot plugged
22	4	W3	3-3	11:15	#1 Wilputte Guide & Stack	Diff. press. pitot plugged
25	5	W4	3-6	5:00	#2 Wilputte Guide & Stack	
26	6	W5	3-10	12:00	#3 Wilputte Guide & Stack	
27			3-11	2:00		J & L cancelled test
28	7	W6	3-8	4:00	3 Wilputte Stacks	
29	8	W7	3-8	12:00	3 Wilputte Stacks	
July 2	8A	W8	3-6	5:20	3 Wilputte Stacks	No mag. tape - no gas sampled
3	9	W9	3-10	12:00	3 Wilputte Stacks	
4	10	W10	3-11	4:00	3 Wilputte Guides	
5	11	W11	3-8	4:00	3 Wilputte Guides	Gas leaks
11	12		3-9	3:00	3 Wilputte Guides	
12	13		3-15	10:00	#2 Wilputte Stack & Guide	
12	14		3-6	4:20	#1 Wilputte Stack & Guide	Guide gas probe plugged
Aug. 6	15		3-6	1:30	#1 & #2 AISI/EPA Guide	
7	16		3-4	12:00	3 AISI/EPA Guides	#2 probe & thermocouple data N.G.
8	17		3-4	12:00	3 AISI/EPA Guides	Early part of test not recorded
8	DL-1		2-27	2:30	Leaking Door	
9	DL-2		2-27	11:00	Leaking Door	
9	18		3-3	4:00	3 AISI/EPA Guides	#3 sensor burned out
13	19	K1	3-5	11:30	3 AISI/EPA Guides	
13	DL-3		2-26	1:00	Leaking Door	
14	20	K2	3-4	11:30	3 AISI/EPA Guides	
15	21	K3	3-3	12:00	3 AISI/EPA Guides	Bad seal on #3 drop sleeve
15	22		3-11	4:00	#2 Wilputte Stack	
16	DL-4	DL-1	2-23	2:00	Leaking Door	
16	DL-4A	DK-2	2-23	3:30	Leaking Door	
16	23	W12	3-12	4:00	#2 Wilputte Stack	
17	24	K4	3-3	2:00	3 AISI/EPA Guides	Low flow - fans burned out
17	24A		3-11	5:00	#2 Wilputte Stack	MITRE Carrousel Particulate Sampler
22	25		3-1	12:00	3 AISI/EPA Guides	Bad fire on #3
22	26		3-9	3:00	#2 Wilputte Stack	Poor gas data
22	26A		3-13	5:00	#2 Wilputte Stack	No gas data obtained
23	27		2-23	12:30	#2 AISI/EPA Guide	
23	28		3-4	3:00	#2 Wilputte Stack	
23	28A		3-10	5:00	Coke Side Door	Particulate sample during push
24	28B		3-10	9:00	Ascension Pipe	Particulate filter

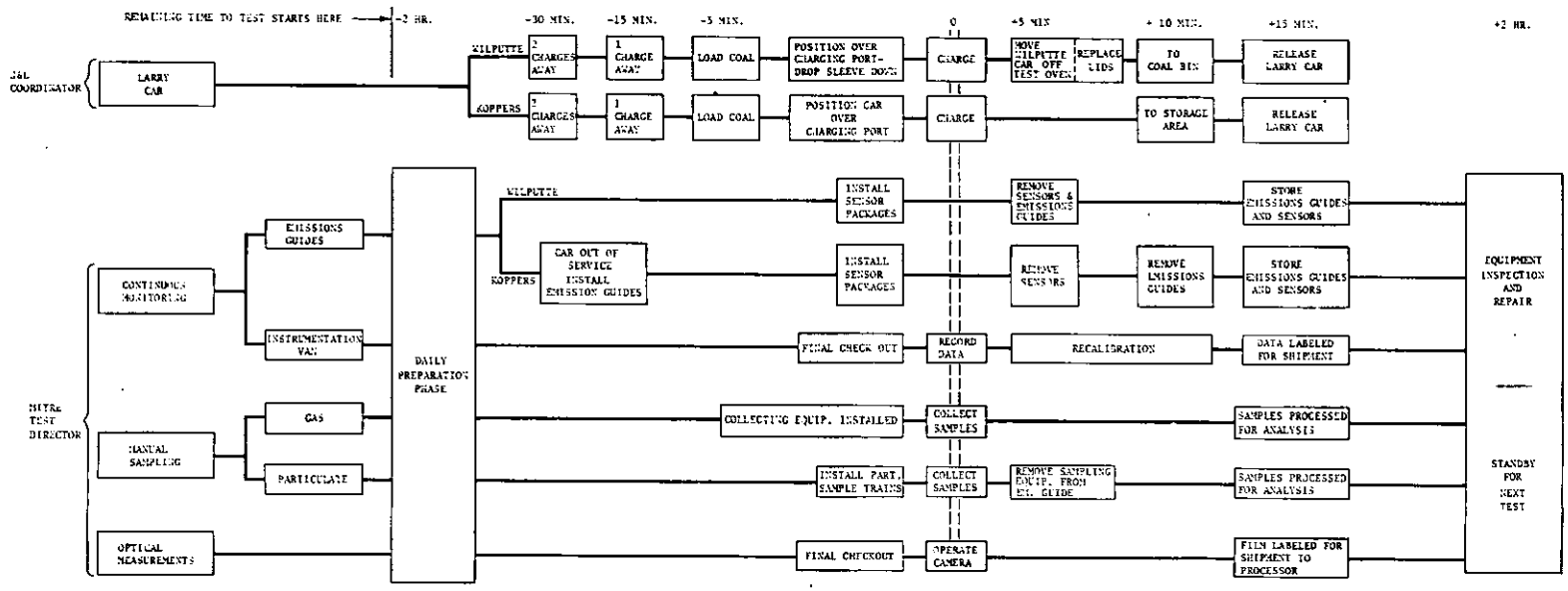

FIGURE 12
DAILY TEST SCHEDULE OUTLINE

the continuous gas sampling system, the manual gas sampling system, the particulate sampling system, and the optical system are described in this section.

Continuous Sampling

The MITRE Test Director obtained from J & L a list of ovens to be charged during the test day. Based on this data, a schedule was prepared which showed tentative times that the "MITRE dedicated" ovens were to be charged. Based on this schedule, the step-by-step actions for the tests were scheduled.

Two hours prior to the test, all heaters and gas samplers were turned on. One hour prior to the test, all other equipment was turned on.

Gas sample analyzers were calibrated per manufacturer's instructions and placed in a "standby" mode. Temperature and pressure sensors were tested for response, and all flow lines were checked for pressure leaks.

Emissions guides for the Wilputte car were temporarily stored beside the railing along the coke side of the battery near the oven to be tested. The sensor ducts were made ready for the test and hung on the boom. An aluminimum ladder was stored in a convenient location.

During installation of test equipment on the battery, the Wilputte larry car was modified by installing the following equipment:

- Stack sensor modification rings
- Drop sleeve modification rings.

The AISI/EPA car required no modification.

Initial plans to test all stacks and emissions guides of the Wilputte larry car at one time were reduced in scope due to the time required to install equipment prior to charging, the time allowed by J & L for testing the car, and the excess exposure of personnel to heat and smoke during a prolonged period. This plan reduced to testing either the three emissions guides, the three stacks, or one emissions guide and

its corresponding stack. Testing the AISI/EPA car was done by monitoring all three emissions guides at one time. The step-by-step procedure for each of these three test situation is given below.

In testing with the Wilputte Emissions Guides, the larry car proceeded to the coal bin in the usual fashion, was loaded with coal, and was then disengaged, moved to the charging port and the drop sleeve was lowered to the top of the oven. At this point, the charging cycle was halted, and two men installed the emissions guide on the pusher side drop sleeve and then proceeded to install the center emissions guide and the coke side emissions guide. A third man then detached the sensor ducts from the boom and attached them to the emissions guides. After coordinating the quenching sequence of the coke car, to assure that excess steam was not emitted during the charging, the Test Director communicated via citizen band radio with the camera operator, the manual sampling crew chief, the boom operator, and the instrumentation van operator; and when all parties were in a state of readiness, he or the lead man on the oven floor commenced a ten point countdown to instruct the larry man to start the charge. This countdown was broadcast to all parties associated with the test so that the exact starting time for the charge was known. The charging cycle was resumed at this point, and the oven was charged in the usual fashion. The larry man reported to the lead MITRE man on the oven floor when this charge was complete. This completion time was relayed via radio to all test personnel. After all coal had been deposited in the oven, the drop sleeve was raised for approximately one minute, after which time personnel removed all instrument housings from the emissions guides, and the guide handlers removed the guides so that the larry could move far enough for the lid man to replace the oven lids. The larry car was then released to continue its normal charging duties. Emissions guides, sensor ducts, booms, and cables were removed from the oven floor near the test area, so that they would not interfere with the normal operation of the J & L personnel. Instrument probes, wires, and tubes were visually inspected, and emissions guides were examined. Any clogging, burning, or warping was repaired by the boom man and guide handlers prior to the next test.

Wilputte Stack Tests

For these tests, the larry car was again positioned over the charging ports, and the drop sleeve was lowered to the oven top. The charging cycle was halted, and a ladder was raised against the pusher side hopper. The sensor duct was then removed from the boom, carried up the ladder, and installed in the stack cap. The ladder was then moved to the center hopper and the sensor duct installed in the stack cap. In a similar fashion, the sensor duct was installed on the coke side stack cap. After all the sensors were in place, the countdown was initiated and charging proceeded as for the emissions guide tests. At the conclusion of the charge, the larry car was backed off the oven enough to allow replacing the lids. After the lids were replaced, the ladder was used to climb up on the larry to remove the sensor housings. After the larry had been released, all equipment was inspected and repaired in preparation for the next test.

The emissions guides for the AISI/EPA larry car consists of two parts: the rigid inner hood and flexible outer skirting. The inner hood was installed while the car was stored at the south end of the battery and the drop sleeve lowered to the floor. The outer hood was placed around the charging ports of the oven to be tested while the larry was off the floor. The larry car proceeded to the coal bin for coal after the inner hood had been attached and the drop sleeve raised. The car then proceeded to the oven to be tested, was positioned over the ports, and was then placed in a standby mode while testing equipment was attached. The outer flexible skirting was then attached to the inner rigid hood. The sensor ducts were then inserted into the openings in the inner hood and firmly attached so that raising and lowering the drop sleeves would not cause them to disengage. The countdown and charging then proceeded as for the previously described tests. At the completion of the charge, the larry car operator signaled the Test Director, who broadcasted this information to all parties involved. The emissions guides were constructed so as to remain in place while the lids were automatically replaced. After replacement of the lids, the outer skirt

was then removed, the larry car was returned to storage at the south end of the battery, and the inner hoods were removed.

After the last test of the day, the emissions guides were stored at the south end of the battery, well out of the way of normal activities, and the booms were securely tied back.

Optical Measurements

At the beginning of each test day, initial setup of optical equipment was necessary. This involved the transport of the camera and camera control unit from its storage place in the office van to the balcony of the coal bin. During inclement weather, installation of a protective hood or shelter on the balcony was accomplished prior to movement of the equipment. Also, prior to transport of the camera, film was placed in the camera and camera mechanical operation was checked. The first step in initial assembly of the system was to attach the camera body to the camera mount on the balcony rail. Next, the lens was mounted on the camera and preliminary alignment of the camera was accomplished. Next, the camera control unit was set up and connecting cables were installed. The A.C. power supply for the camera and control was connected and power applied to the system. The camera was then checked on manual pulse operation and the presence of automatic exposure pulses was confirmed. Next, the correlation data display was synchronized with the data acquisition system by using the manual set button of the display and the intercommunications circuit to the van. After synchronization, the display was allowed to run continuously during the test day. Next, fine alignment and focusing of the camera was accomplished. This step required the illumination of the light bar which normally remained on night and day during a test week. The lens opening was set and the camera frame rate switch and shutter speed adjustment checked for proper settings.

The camera was then ready for the first test. The procedure described above required 30 minutes and was started at least 45 minutes prior to the expected test time to allow proper coordination and temperature stabilization of all equipments involved. At this point, a written

record of equipment configurations and settings was made for the test record. When all equipment had been checked and configuration data recorded, a cloth cover was placed over the camera and lens to protect it from particulates and moisture in the air.

While the larry car was moving into position for the charge, the camera cover was removed, and a final visual check of the equipment was made. Ten to twelve exposures would be taken during this time to obtain a clear background base reference for the test.

Camera operation was initiated at the conclusion of the countdown by the Test Director. Exposure continued for five minutes or until only four feet of film remained on the supply roll. At this point, the camera was stopped to provide a section of unexposed film on which exposure calibration could be performed.

After the test, the connecting wires to the camera were disconnected, and the lens was removed and stored in its carrying case. The camera was next removed from its mount and placed in its carrying case and transported to the van dark room where the film was removed and placed in a storage container along with one copy of the test configuration data sheet. The container was then placed under refrigeration to await shipment to the processor.

Next, the camera was inspected and cleaned, if necessary, in preparation for the next test. When another test was contemplated for the day, a fresh roll of film was threaded into the camera and the proper mechanical operation checked. If it was the last test of the day, the camera was placed in its storage container and left in the van until the next test day. After the camera had been checked, cleaned, and stored in the van after the last test, the camera control unit and associated components were removed from the balcony and stored in the van.

Manual Gas Sampling

Prior to the test-charging operation, manual sampling personnel set up the gaseous sampling system on the pipe bridge. The heated lines from the sampling trains and common duct to the heated manifold were connected

and preheated to operating temperature. All components of the system (pumps, lines, connectors, solenoid valves, and heaters) were tested to see that they were in operating condition.

Once pre-test activity was completed, the manifold line was connected to the common duct. The sequential sampling system was then manually turned on at the conclusion of the start countdown for charging.

Once turned on, the sequential sampling system was manually controlled by predetermined time intervals. The sequential sampling trains then collected grab samples at selected intervals. When the charge was complete, the manual sampling personnel stopped the sequential cycle as the last grab sample bag was filled.

Particulate Sampling

Prior to the test, sampling nozzles and filter assemblies were mounted on the sensor ducts. The impinger trains, pumps, and regulators were mounted on the instrument carts and prepared for operation, and were set up along the coke side of the battery near the oven to be charged. The lines from the filter to the impingers were connected. All quick disconnect connectors were checked to see if they were in operating order. The lines were checked for leaks and/or breaks, as well as preheating to proper temperature.

As each emissions guide was brought into place and the sensor duct connected, the manual sampling team brought the assigned instrument cart up to the guide and connected the input heated lines of the impingers to the filter assembly. This procedure was followed for each emissions guide and was performed consecutively as the guides were set up.

After the test was completed, the lines between the impingers and the valves were disconnected. At the same time the line between the filter and impinger was disconnected from the sensor ducts. The instrument carts were then moved to the coke side of the oven. Once the emissions guides or stack sensors were removed, the filter, lines, and nozzles were cleaned.

SECTION IV
DATA HANDLING PROCEDURES

Data obtained during the field portion of the program were consolidated at MITRE headquarters, where it was subjected to critical quality control, corrected for travel time delays, and analyzed by computer methods. The results of the analyses were then presented in terms of pollutants emitted from the two larry cars being tested. This section describes the steps taken to develop these larry car emissions characteristics.

INPUT DATA

Test data were obtained from the Continuous Monitoring, Manual Sampling and Optics Programs. With minor exceptions, all data required extensive analysis at a location other than the test site before meaningful information could be derived. The original data, in its various forms, is discussed here.

Continuous Monitoring Data

The continuous monitoring data were obtained every second from the sensors during the tests and were recorded on magnetic tape and strip charts. The data consisted of gas analysis, flow sensor output, meteorological parameters and certain control and status information. To utilize the magnetic taped data, a program was prepared for reading the tape and printing the data in a form that could be read and evaluated. In the output of this program, the units defining the data are in voltage form. The print-out from this program was inspected to prove that the basic data, as produced by the sensors, was recorded on the tape accurately. The second-by-second variations in output voltages can be observed on the print-out, and the absence of data becomes readily apparent.

An example of one of these print-out sheets is shown in Figure 13, which shows data from Test 13, for the center Wilputte stack and guide. The first line on the print-out is a data-time group [year, month, day, hour (EST) and minute]. The second line consists of headings for the data

YEAR 73 MONTH JULY DAY 12 HOUR 09 MIN 15

SEC 1307	SEC 1407	SEC 1507	SEC 1607	SEC 1707	SEC 1807	SEC 1907	SEC 2007	SEC 2107	SEC 2207	SEC 2307	SEC 2407	SEC 2507
CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS	CH VOLTS
00-03738	00-03755	00-03790	00-03798	00-03836	00-03894	00-03949	00-04042	00-03840	00-03668	00-03518	00-03354	00-03220
01-04860	01-04863	01-04857	01-04857	01-04799	01-04733	01-04640	01-04434	01-04292	01-04204	01-04140	01-04020	01-04040
02-16380	02-16343	02-16380	02-16383	02-16360	02-15922	02-15439	02-15022	02-14650	02-14190	02-13819	02-13510	02-13013
03-00500	03-00448	03-00400	03-00340	03-00250	03-00250	03-00220	03-00172	03-00158	03-00116	03-00084	03-00060	03-00040
04-01513	04-01492	04-01492	04-01260	04-01449	04-01372	04-01442	04-01433	04-01476	04-01469	04-01457	04-01490	04-01530
05-00733	05-00720	05-00732	05-00733	05-00793	05-00843	05-00774	05-00137	05-01790	05-01570	05-01394	05-01248	05-01090
06-00472	06-00496	06-00500	06-00463	06-00422	06-00513	06-00513	06-00548	06-00005	06-00004	06-00009	06-00000	06+00003
07-07130	07-07078	07-07153	07-07042	07-07100	07-07166	07-07254	07-07330	07-07440	07-07470	07-07516	07-07540	07-07592
08-01140	08-02880	08-02894	08-02263	08-02052	08-01780	08-01580	08-01399	08-01278	08-01100	08-01048	08-00820	08-00700
09-00173	09+00001	09+00001	09+00015	09-00210	09+00071	09+00002	09+00021	09+00001	09+00021	09-00100	09+00157	09+00001
10-01473	10+00042	10+00014	10-01060	10-01920	10-01673	10-01277	10-01063	10-00962	10-00996	10-01474	10-01530	10-01610
11-07423	11-07378	11-07174	11-07172	11-06451	11-06443	11-06954	11-09160	11-08476	11-08284	11-08092	11-07869	11-07770
12-01213	12-01257	12-01277	12-01246	12-01250	12-01233	12-01257	12-01234	12-01250	12-01238	12-01270	12-01260	12-01260
13-07060	13-07060	13-07100	13-07100	13-07100	13-07100	13-07100	13-07100	13-07112	13-07100	13-07100	13-07112	13-07110
14-03554	14-03557	14-03557	14-03587	14-03573	14-03553	14-03562	14-03559	14-03518	14-03518	14-03520	14-03530	14-03518
15-00518	15-00513	15-00529	15-00556	15-00528	15-00520	15-00540	15-00520	15-00526	15-00514	15-00518	15-00518	15-00540
16-06753	16-06730	16-06729	16-06723	16-06753	16-06723	16-06752	16-06726	16-06730	16-06722	16-06729	16-06729	16-06730
17-01343	17-01353	17-01340	17-01344	17-01368	17-01553	17-01570	17-01564	17-01362	17-01360	17-01372	17-01358	17-01352
18-01243	18-01253	18-01243	18-01243	18-01240	18-01520	18-01314	18-01213	18-01240	18-01314	18-01330	18-01278	18-01278
19-00579	19-00572	19-00569	19-00570	19-00570	19-00553	19-00576	19-00608	19-00592	19-00570	19-00590	19-00570	19-00570
20-00763	20-00763	20-00763	20-00756	20-00754	20-00764	20-00768	20-00760	20-00760	20-00756	20-00768	20-00759	20-00760
21-01183	21-01180	21-01183	21-01180	21-01160	21-01131	21-01180	21-01151	21-01180	21-01190	21-01180	21-01212	21-01208
22-01278	22-01243	22-01278	22-01240	22-01275	22-01273	22-01265	22-01278	22-01220	22-01230	22-01230	22-01278	22-01278
23-16152	23-16140	23-16152	23-16140	23-16152	23-16152	23-16143	23-16159	23-16152	23-16152	23-16152	23-16150	23-16154
24-01053	24-01074	24-01053	24-01053	24-01059	24-01048	24-01059	24-01034	24-01088	24-01080	24-01080	24-01092	24-01080
25+16381	25+16381	25+16381	25+16381	25+16381	25+16381	25+16381	25+16381	25+16381	25+16381	25+16381	25+16381	25+16381
26+16381	26+16381	26+16381	26+16381	26+16381	26+16381	26+16381	26+16381	26+16381	26+16381	26+16381	26+16381	26+16381
27+00001	27+00001	27+00001	27+00001	27+00001	27+00001	27+00001	27+00001	27+00001	27+00001	27+00001	27+00001	27+00001
28+16381	28+16381	28+16381	28+16381	28+16381	28+16381	28+16381	28+16381	28+16381	28+16381	28+16381	28+16381	28+16381
29-00190	29-00190	29-00190	29-00190	29-00192	29-00180	29-00190	29-00190	29-00190	29-00190	29-00190	29-00190	29-00190
30+00001	30+00001	30+00001	30+00001	30+00001	30+00001	30+00001	30+00001	30+00001	30+00001	30+00001	30+00001	30+00001
31+00463	31+00491	31+00491	31+00501	31+00501	31+00513	31+00513	31+00515	31+00515	31+00521	31+00571	31+00591	31+00569
32+09241	32+10241	32+09721	32+09681	32+09731	32+09541	32+09981	32+10243	32+10241	32+10405	32+10533	32+10861	32+10733
33-00100	33-00210	33-00240	33-00234	33-00274	33+00001	33-00050	33-00070	33+00001	33+00001	33-00060	33-00202	33-00020
34-00443	34-00452	34-00440	34-00442	34-00443	34-00444	34-00443	34-00444	34-00442	34-00444	34-00444	34-00442	34-00444
35+16381	35+16381	35+16381	35+16381	35+16381	35+16381	35+16381	35+16381	35+16381	35+16381	35+16381	35+16381	35+16381
36+00011	36+00011	36+00009	36+00009	36+00007	36+00003	36+00003	36+00005	36+00007	36+00003	36+00001	36+00003	36+00001
37-00554	37-00550	37-00550	37-00552	37-00543	37-00552	37-00554	37-00552	37-00550	37-00554	37-00550	37-00550	37-00552
38+00001	38+00001	38+00001	38+00001	38+00001	38+00001	38+00001	38+00001	38+00001	38+00001	38+00001	38+00001	38+00001
39-00410	39-00410	39-00410	39-00412	39-00410	39-00410	39-00410	39-00410	39-00410	39-00412	39-00410	39-00410	39-00412
40+00021	40+00021	40+00021	40+00021	40+00021	40+00021	40+00021	40+00021	40+00021	40+00021	40+00021	40+00021	40+00021
41+00001	41+00001	41+00001	41+00001	41+00001	41+00001	41+00001	41+00001	41+00001	41+00001	41+00001	41+00001	41+00001
42-00760	42-00760	42-00760	42-00762	42-00763	42-00762	42-00760	42-00770	42-00792	42-00790	42-00770	42-00772	42-00760
43+16381	43+16381	43+16381	43+16381	43+16381	43+16381	43+16381	43+16381	43+16381	43+16381	43+16381	43+16381	43+16381
44+00009	44+00009	44+00013	44+00013	44+00011	44+00013	44+00013	44+00013	44+00013	44+00013	44+00013	44+00013	44+00011
45-00635	45-00714	45+00001	45+00001	45-00580	45-00645	45-00576	45-00720	45-00770	45-00760	45-00754	45-00570	45-00570
46+16381	46+16381	46+16381	46+16381	46+16381	46+16381	46+16381	46+16381	46+16381	46+16381	46+16381	46+16381	46+16381
47+16381	47+16381	47+16381	47+16381	47+16381	47+16381	47+16381	47+16381	47+16381	47+16381	47+16381	47+16381	47+16381
48-15571	48-15570	48-15571	48-15572	48-15569	48-15571	48-15570	48-15569	48-15570	48-15568	48-15569	48-15570	48-15580
49+16381	49+16381	49+16381	49+16381	49+16381	49+16381	49+16381	49+16381	49+16381	49+16381	49+16381	49+16381	49+16381
53-00700	53-00700	53-00700	53-00700	53-00700	53-00700	53-00700	53-00700	53-00700	53-00700	53-00700	53-00700	53-00700
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	00000000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	00000000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	00000000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	00000000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	00000000
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columns further down the page. The time is in seconds to the second decimal place, therefore, the first two digits are the only significant ones for this analysis. The third line is also a heading line for the columns, indicating channel number and voltage levels. The remaining lines are data channel numbers and their respective voltage levels, ranging from 0-1.638/volts, with the channel assignments as given in Table 3.

The channel assignments given in Table 3 were made before experience was gained on the oven and several significant field modifications were performed. Of most signficance is the fact that a maximum of only three measurement points were monitored at one time as opposed to the nine as originally planned. Many temperature and pressure channels were, therefore, not used. A threshold system to start and stop gas flow was found to be impractical and, therefore, those channels were also not used. These channels continued to record on the data acquisition system, but the values shown on the print-outs are noise recorded on the unused channels, and were ignored in later work with the data.

Another source of continuous monitoring data was the strip charts. All gas analyzer data and all flow related data (pitot pressure and temperature) were recorded on strip charts as well as on magnetic tape. Examples of this data are given in Figures 14 and 15, which show outputs from four gas analyzers and four channels of output data for AP and T for Test 13. The print-outs described above were compared on a channel-by-channel basis with the strip charts and corrections made to reconcile any differences. In those cases where the data acquisition channel was determined to be faulty, the data were then taken from the strip charts and punched on IBM cards for insertion in the analyses program.

As a next step, the output of gas analyzers (located in the instrument van) was correlated with the thermocouple and pitot tube output (located on the oven floor). The time difference between these two readings is due to the travel time of the gas to pass through the tubing to the analyzers and the process time in the analyzers. (During the Field Test Program, sample gases were inserted in the lines on the oven and the time

TABLE 3

DATA ACQUISITION SYSTEM - CHANNEL ASSIGNMENT

Channel No.	Constituent	Channel No.	Constituent
00	H_2O	26	St.P
01	SO_2	27	∠P
02	H_2S	28	T
03	NO	29	St.P
04	NO_X	30	ΔP2
05	THC	31	T.2
06	H_2	32	St.P
07	O_2	33	ΔP3
08	CO	34	T3
09	CO_2	35	St.P
10	Wind Speed	36	ΔP
11	Wind Direction	37	T
12	Relative Humidity	38	ΔP
13	Ambient Air Temp.	39	T
14	Barometric Pressure	40	ΔP
15	Volume Flow	41	ΔP
16	Threshold Sum	42	T6
17	" #1	43	T
18	" #2	44	ΔP
19	" #3	45	ΔP9
20	" #4	46	T
21	" #5	47	T
22	" #6	48	Manual Sampling Control
23	" #7	49	Threshold Status
24	" #8	53	Gas Temp. Input in Van
25	" #9		

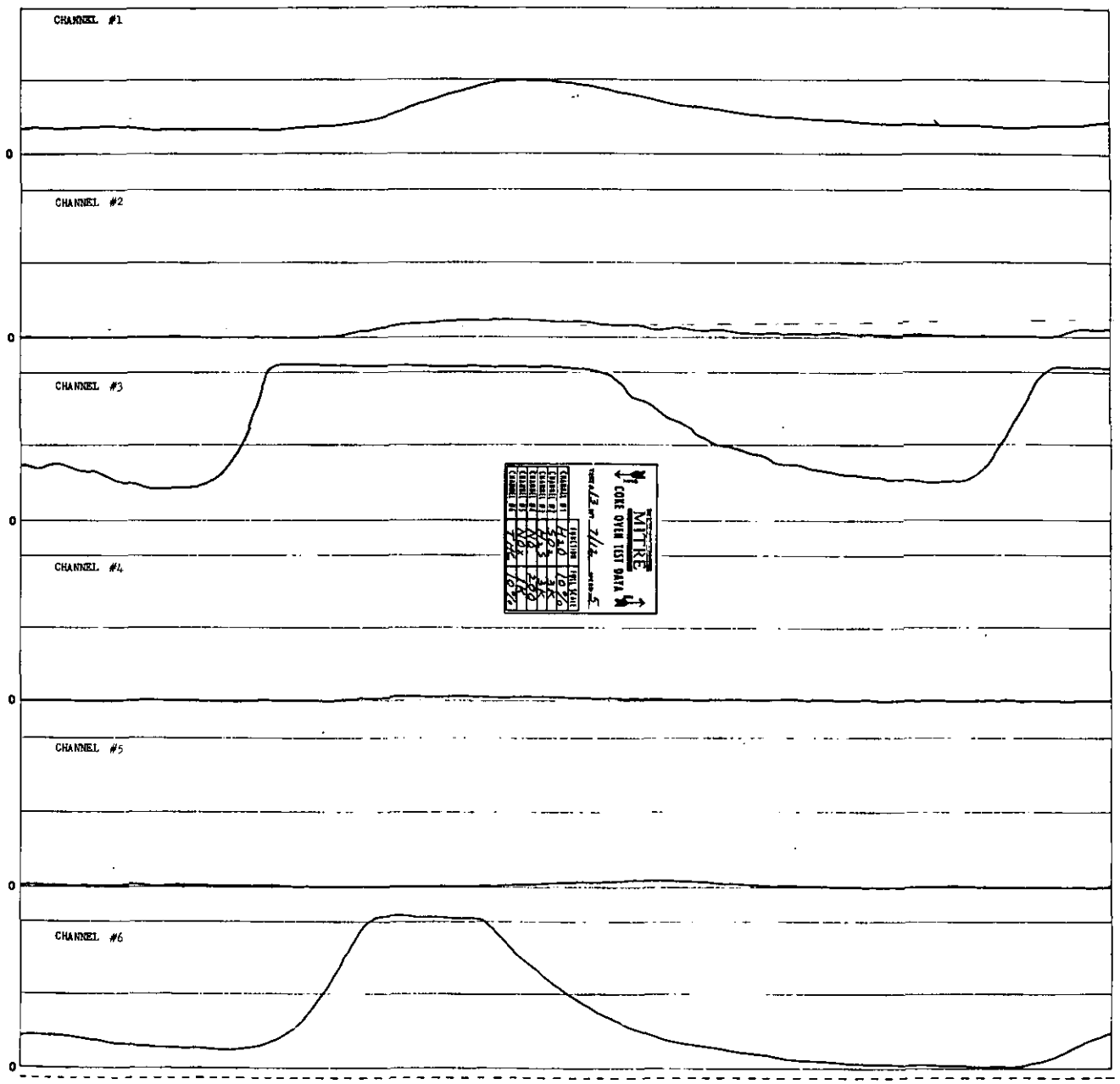

FIGURE 14
GAS ANALYZER STRIP CHART DATA

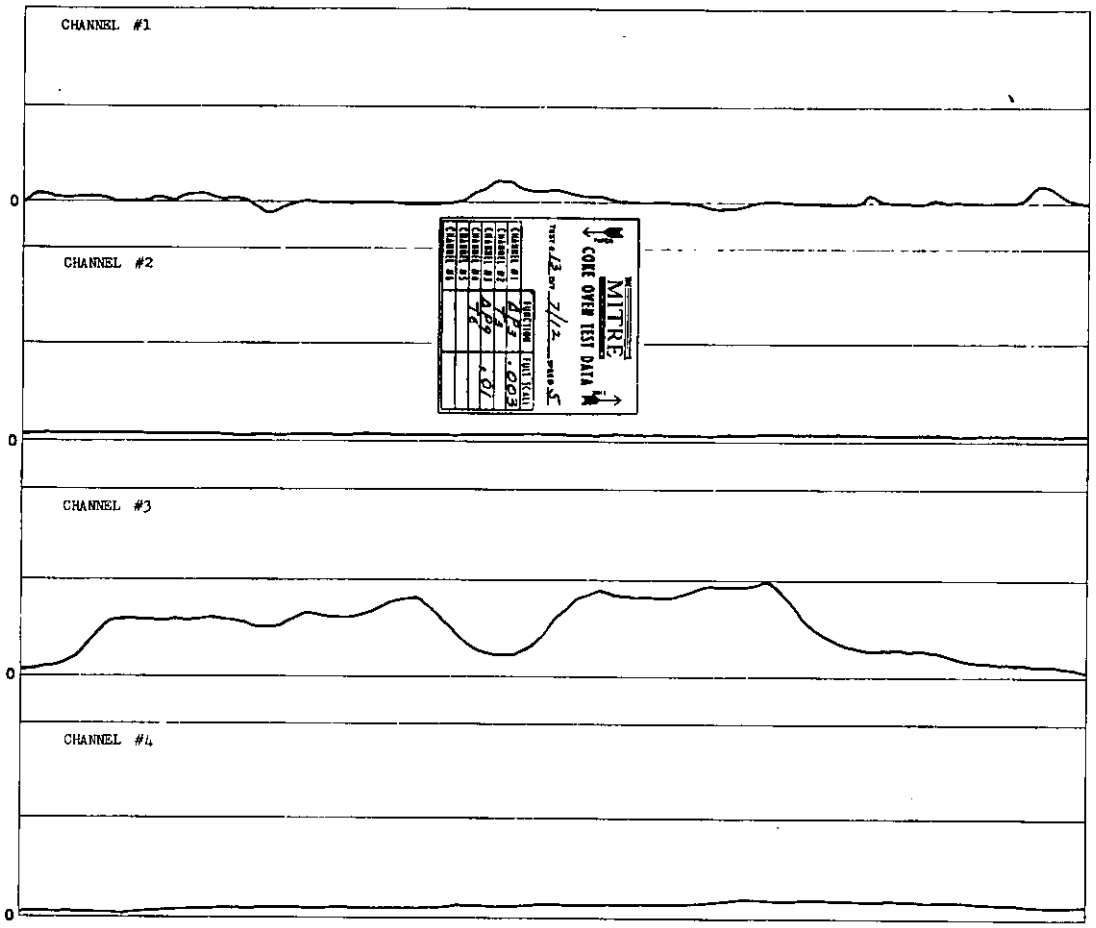

FIGURE 15
GAS TEMPERATURE AND PRESSURE STRIP CHART DATA

at which the analyzer responded was noted. This was done for all gases analyzed, and the delay varied from 16 to 30 seconds.)

After the specific "gas channels" had been time-shifted, the data were then ready to be converted from voltages to engineering units. This was done by applying the manufacturers calibration data (which was periodically checked at the site) and observed effects, adding the proper units and reformatting the print-out page into groups of rows and printing increments of 15 seconds on a page. The actual corrections and calibration factors applied are not included in this report, but have been published separately as MITRE Working Paper WP-10445, "Conversion and Correction Factors for Coke Oven Emissions Data."

The resulting print-out for part of Test 13 is shown in Figure 16. Here the columns are better separated and identified for the 15 seconds of data. The first two columns along the left hand side are channel identifying number and identifying constituent. The first ten rows are either percent or parts per million of the indicated gas. The next twelve rows (four used in Figure 16) are allocated for pitot tube pressure and associated measurement duct temperatures in inches of water and degrees Fahrenheit; actual channel assignment for each measurement point is also given in MITRE WP-10445, "Conversion and Correction Factors for Coke Oven Emissions Data." The next four lines (Ch. 10 through 14) are meterological data: wind speed in miles per hour, wind direction in degrees from true north, ambient temperature in Fahrenheit and barometric pressure in inches of mercury. Thresholds 1 and 2 (Ch. 17 and 18) were not used. Channels 19 through 24 indicate points on the larry car that were being monitored; Emissions Guide (EG) on the Pusher Side (P), Middle (M) and Coke Side (C), and Stacks (ST) on the Pusher, Middle and Coke Sides (P, M, C). Channel 48 indicates when manual gas samples were being drawn.

The magnetic tape that produced this final print-out was then used as the starting point for the final data analysis. A complete listing of the data was sent to the Environmental Protection Agency, Office of Research and Development, National Environmental Research Center, Control Systems Laboratory.

DATE JULY 12, 1973
MITRE TEST NUMBER 13
MRI TEST NUMBER
TIME: 09:15

OVEN 3-15
POINTS MONITORED #2 WILPUTTE STACK & CLICK
REMARKS

		SEC 15	SEC 16	SEC 17	SEC 18	SEC 19	SEC 20	SEC 21	SEC 22	SEC 23	SEC 24	SEC 25	SEC 26	SEC 27	SEC 28	SEC 29
00	% H2O	2.6	2.5	2.5	2.4	2.4	2.3	2.4	2.3	2.3	2.3	2.3	2.3	2.3	2.2	2.2
01	PPM SO2	1075.0	1076.6	1088.6	1017.2	1016.4	986.0	941.0	926.0	859.0	850.0	935.0	906.2	887.0	855.4	875.0
02	PPM H2S	3651.0	3622.8	3535.4	3576.0	3534.0	3519.0	3552.0	3494.4	3450.0	3408.6	3285.0	3252.0	3195.0	3087.0	3055.4
03	PPM NO	0.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
04	PPM NOX	73.4	75.2	78.2	77.4	78.0	103.2	61.2	74.2	73.6	71.2	70.2	68.2	66.2	63.2	60.6
05	% THC	0.60	0.60	0.60	0.70	0.70	0.70	0.60	0.60	0.60	0.50	0.50	0.50	0.40	0.40	0.40
06	% H2 *	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
07	% O2	19.5	19.5	19.2	19.3	19.2	19.3	19.6	0.0	19.6	19.6	19.6	19.6	19.7	19.6	19.7
08	% CO	0.16	0.17	0.16	0.17	0.18	0.18	0.17	0.15	0.17	0.16	0.18	0.17	0.18	0.15	0.12
09	% CO2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	.01" WC	0.140	0.135	0.085	0.065	0.081	0.066	0.065	0.065	0.084	0.129	0.072	0.046	-0.275	-0.330	-0.025
34	DEG F	99	98	100	99	98	99	98	99	99	98	99	99	99	98	99
45	.01" WC	0.700	0.700	0.700	0.700	0.670	0.670	0.670	0.670	0.560	0.560	0.560	0.560	0.450	0.450	0.450
42	DEG F	168	166	164	166	162	160	158	158	154	154	152	152	152	151	148
10	WS MPH	1.5	3.1	3.5	3.1	2.3	1.9	1.7	1.8	2.7	2.8	2.9	3.2	2.9	2.3	2.2
11	WD DEG	081	081	096	098	125	134	097	087	076	065	059	037	022	351	037
13	DEG F	81.8	81.8	81.8	81.8	81.8	81.8	81.8	81.8	81.8	81.8	81.8	81.8	81.8	81.8	81.8
14	IN. HG	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00	29.00
17	TH 1															
18	TH 2															
19	EG-P															
20	EG-M	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON***
21	EG-C															
22	ST-P															
23	ST-M	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON***
24	ST-C															
48	MRI	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON	***ON***

FIGURE 16
FINAL DATA PRINTOUT IN ENGINEERING UNITS

Manual Sampling Data

The manual samples of gas and particulate were obtained by Midwest Research Institute (MRI) under separate contract to the Environmental Protection Agency. The samples were transported to MRI's laboratory in Kansas City for final analysis, and the results were transmitted to MITRE for incorporation in the overall data study of the coke oven emissions. Particulate samples were also collected as part of the manual sampling effort, and the analyses of these samples are also incorporated in the overall study.

Gas Samples

Results of the gas analysis were in the form of tables. Analytical results for pyridine, SO_2, cyanide, phenol, NH_3, NO_x, and H_2S are listed on computer print-out charts. The results of the analysis for O_2, N_2, CO, CO_2, CH_4, H_2 and total hydrocarbons are listed on a hand-printed table. These print-outs and tables are provided in Appendix C of this report.

Particulate Samples

Samples obtained at the Emissions Guides and the Stacks by MRI were analyzed at their laboratory. The data were reported in the form of computer print-outs, copies of laboratory notebook sheets and hand written mass loading tables. This data is included in Appendix B.

Particulate samples obtained by the MITRE carrousel sampler were analyzed at the MITRE Washington operations facility. This sampler, analytical procedures and a complete presentation of data has been published as MITRE Working Paper WP-10480, "Direct Impaction Particulate Collecting Carrousel." The form of these results is a series of tables and size distribution curves, which are provided in Appendix E.

Coal Samples

Proximate analyses were performed on the four coal samples obtained. This work was done by Industrial Testing Laboratory of Kansas City under subcontract to MRI. Their findings are reported as "Certificate of Coal

Analysis", tables listing the constituents measured, and are enclosed in Appendix B.

The ultimate analysis, elemental analysis and size determination were presented as tables and are also enclosed in this appendix.

Optical Data

The record of light transmission from the light bar passing through the emission plume to the detector (camera) was recorded on the photographic film in the form of varying light bar image densities. The exposed film was sent to a photographic processing laboratory where a sensitometric exposure was placed on an unexposed portion of the film, and the film was developed. The sensitometric exposure provides a basis for associating an observed light bar image optical density with a value of light intensity producing the image exposure. Using the values thus obtained, it is possible to determine the value of light obscuration. This information was then used to estimate the mass loading values of the observed emission plume.

The data on optical densities of the light bar images was provided in two forms by the film processing facility. The microdensitometer electronically digitized the measured optical density value for a specific point (area of 50 by 200 microns) and placed this value in a binary number format on a magnetic tape. The microdensitometer also simultaneously produced a continuous strip chart record of measured optical density.

As stated previously, the data on the tape was contained in the form of eight place binary numbers ranging from 0 to 255. One horizontal scan across the light bar image produced 539 individual binary density records corresponding to 539 points on the scanned image. A second pass across the black surface area produced 539 more density records which correspond directly with the light bar records for purposes of comparison and mass loading calculations. A third scan containing 539 records was made for some frames as a part of an experiment to investigate the Mie scattering effect. This scan was across a short section of light source having color filters placed on the diffusion lens to approximate

monochromatic light. This unit was located on top of and at one end of the primary light bar structure.

The data tape, generated on a manually controlled data logger, was read as a binary number by a standard nine-track computer tape drive, but was not directly compatible with computational or display portions of the data processing program. Because of the format of the tape, records to be processed were combined with header information obtained from the hand-written tape log supplied with each raw data tape. The header information for each individual scan of 539 points consisted of a sequence number, test number, clock time for frame, and type of frame. This information was combined on a separate program data input tape for further processing.

A second data input consisted of two place tables in punch-card form. These tables provided necessary correlation for conversion from density values to relative exposure values (light intensity values, assuming a constant exposure time) for a particulate processing run. The table was generated by the processing laboratory using 21 density values obtained from the sensitometric exposure wedge. A computer program fitted a curve to these 21 points and produced the 300 evenly spaced (in light intensity) values of optical density in the range of the sensitometric exposure. A second table of 300 corresponding exposure values was calculated by the program from the density information. The program used to generate the exposure values is described in detail in MITRE Working Paper 1045, "Correction and Conversion Factors from Coke Oven Emissions Data."

MATHEMATICAL TREATMENT OF DATA

The processes of converting the data that was described above into meaningful terms such as pounds of pollutant emitted, mass loading, etc., are generally straightforward. An effort was made to perform these functions with automatic data processing hardware, although this project was a one-time effort and programming requirements are out of proportion to the amount of data processed. This was intentional so that the analytical routines developed for this project could be made available to anyone with a future similar requirement.

Concentration and Volume Flow Variability

The pattern of emissions produced by a coke oven charging operation differs radically from a source which could be monitored by standard manual sampling techniques. As a result, real time information is required for data reduction procedures. For the brief period of time during which the charging operation lasts, differential pressure (ΔP), temperature (T), and constituent concentration vary erratically. Values can change from 0 to .1" H_2O ΔP, 100° to 1000°F temperature, or zero to full scale concentration in a matter of seconds. Figures 14 and 15 are strip charts showing some typical fluctuations in ΔP and concentrations. Figure 17 shows flow with respect to time and charging procedures for a typical test.

These figures demonstrate the importance of a continuous monitoring system for measuring the type of emission fluctuation that results from a charging operation. It is obvious from Figure 17 that a manual measurement would be too insensitive for the emission guide flows and too slow for the rapid variations in the stack emissions to produce an accurate volume of emissions. An example of the effects of using real time concentration values as opposed to an average concentration value for calculating emission volume can be shown in Test 21 (see Appendix C for data). A volume of THC from Test 21 was 33 scf as calculated using real time values while the use of average concentrations and flow produced 19.2 scf (∿40% error).

Volume Flow Parameters

A program to determine volume flow and velocity of coke oven emissions was the first of the data reduction programs implemented. Both the gaseous and particulate systems depend on velocity and volume flow for final calculations of mass and/or volume.

The volume flow program uses the equation:

$$F_i(t) = (174)\ \chi_p A_i \sqrt{\frac{\Delta P_i(t)\ [T_i(t) + 460]\ (29.92)}{P_i(t) \cdot G_k}} \qquad (2)$$

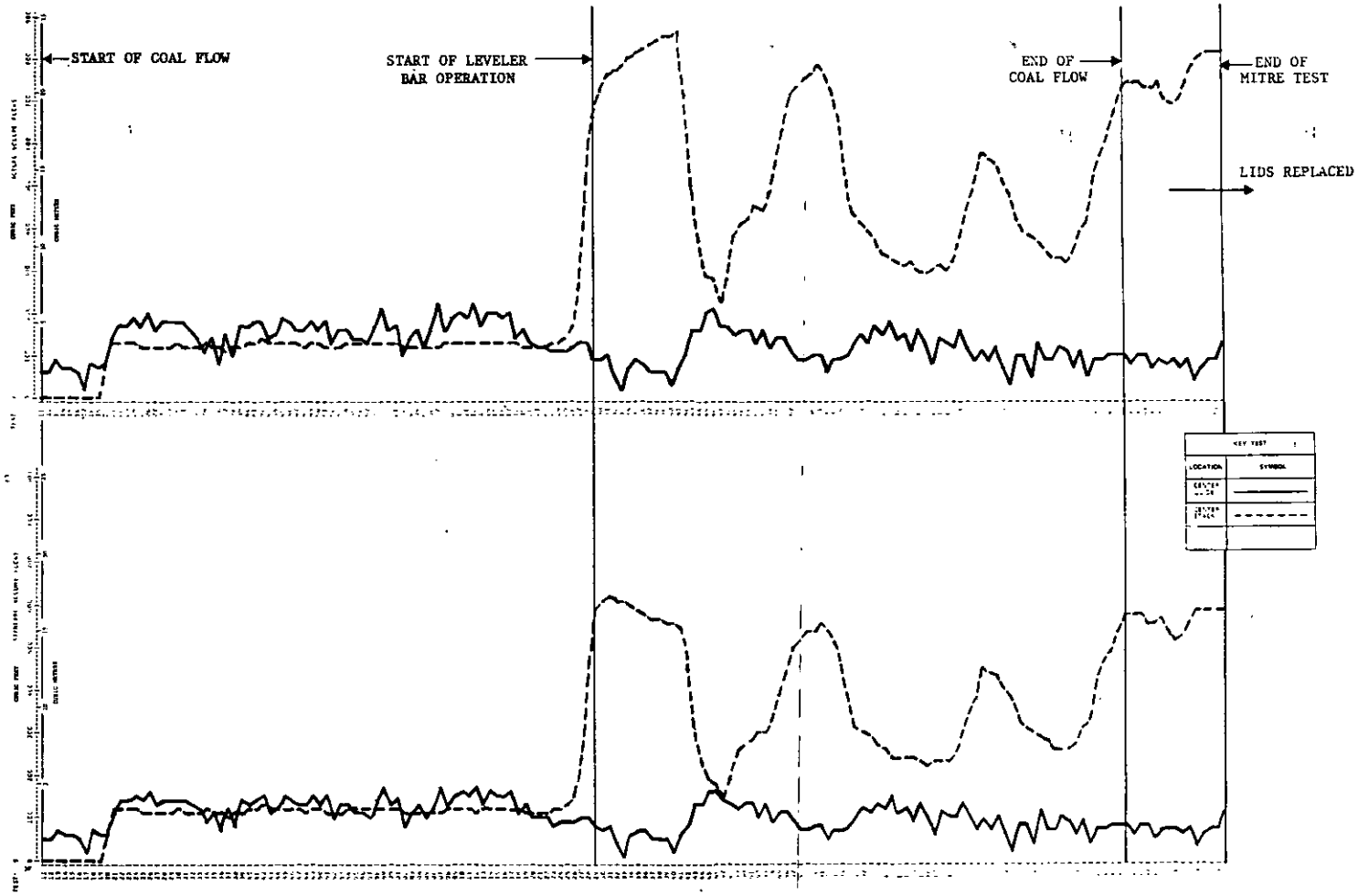

FIGURE 17
TYPICAL VOLUME FLOW GRAPH VERSUS CHARGING PROCEDURES

to determine the volume flow, $F_i(t)$, at location i for a given test. Constants and variables required in this equation are listed in Table 4. Equation 2 was used to determine the in-stack real time volume flow (CFM) at each emission point and these values were then stored for use with the particulate sampling program.

A second real time volume flow adjusted to standard conditions (SCFM), $F_i'(t)$, (70°F @ 1 atm) was required for use with the continuous gas and manual gas calculations where:

$$F_i'(t) = \frac{F_i(t)\ P_i(t)}{[T_i(t) + 460]°R} \cdot \frac{530°R}{29.92'' \text{ Hg}} \quad . \tag{3}$$

Then the total volume (CF) emitted at location i, E_{Ti}, under stack conditions is given by:

$$E_{Ti} = \sum_{t=t_1}^{\tau} \Delta t[F_i(t)] \tag{4}$$

and under standard conditions (SCF):

$$E_{Ti}' = \sum_{t=t_1}^{\tau} \Delta t[F_i'(t)] \quad . \tag{5}$$

The real time volume flow in standard and stack conditions $F_i'(t)$ and $F_i(t)$ was stored on magnetic tape, but the output format was in graphic form only. The total volume values E_i and E_i', however, were both stored and output numerically. The average temperature (F°):

$$T_i = \sum_{t=t_1}^{\tau} T_i(t)/\tau \tag{6}$$

was also computed and printed during this operation, as well as the high and low temperatures.

TABLE 4

VARIABLES USED IN VOLUME FLOW

χ_p	≡	Pitot tube factor, a value from .95 to .7
A_i	≡	.69 ft^2 for Wilputte Emissions Guide .85 ft^2 for Stacks and AISI/EPA Guides
$P_i(t)$	≡	Static pressure - Channel 14 (inches Hg)
G_k	≡	Specific gravity of the gas relative to air
τ	≡	Total time of test, in most cases, will be described by Channel 48 (in seconds)
t_1	≡	Start of test, Channel 48 will read on (1 volt)
$\Delta P_i(t)$	≡	Differential pressure at time t and location i (inches H_2O)
$T_i(t)$	≡	Temperature at time t location i (F°)
Δt	≡	Time interval (seconds)

Continuous Gas Monitoring System Parameters

The gaseous concentrations are given for standard conditions and the concentrations, $C_j(t)$, of the gas constituents are assumed to include % H_2O in total volume. Gases measured after drying (H_2, O_2, CO, CO_2: channels 06 to 09, respectively) were corrected to wet gas concentrations by:

$$C_j(t) = C_{jdry}(t) \left\{ \frac{100 - C_1(t)}{100} \right\} \tag{7}$$

where, $C_{jdry}(t)$ = volume % in dry gas as measured by respective instruments.

To determine the volume flow (SCFM) of each gas constituent, j, that is measured in the stack under standard conditions (70°F, 1 atm) the equation:

$$\dot{E}_j(t) = C_j(t) \left\{ \sum_i^n F_i'(t) \right\} \tag{8}$$

was used for a preliminary calculation. A corrected constituent volume $E_j'(t)$ was calculated by:

$$\dot{E}_j'(t) = C_j'(t) \left\{ \sum_i^n F_i'(t) \right\} \quad . \tag{9}$$

$C_j'(t)$ is a corrected concentration (% volume) of j to account for the sampling of ambient air at points where $F_i'(t) < F_T$ and

$$C_j'(t) = \frac{C_j(t) - \gamma C_{Aj}}{1 - \gamma} \tag{10}$$

where

$$C_{Aj} \equiv \text{Concentration of } j \text{ at ambient}$$

$$\gamma \equiv \frac{\text{Number of Locations: } F_i(t) < F_T}{\text{Number of Locations}} .$$

F_T is a constant which was determined after the first run of the volume flow data was analyzed.

Equation 9 (correction for ambient dilution) was only used for channels:

SO_2 - 01	THC - 05
H_2S - 02	CO - 08
NO - 03	CO_2 - 09
NO_x - 04	

Then the total volume (SCF) of constituent j measured directly was:

$$E_j = \sum_{t=t_1}^{\tau} \Delta t[\dot{E}_j(t)] \tag{11}$$

and the total volume corrected for continuous sampling is

$$E_j' = \sum_{t=t_1}^{\tau} \Delta t[\dot{E}_j'(t)] \quad . \tag{12}$$

The real time volume per unit time $[\dot{E}_j(t)$ and $\dot{E}_j'(t)]$ for each constituent j was displayed in graphic form. The total volumes in correct and uncorrected form (E_j' and E_j) was listed numerically. The average concentrations $C_j(t)$ and $C_j'(t)$ were computed by

$$\bar{C}_j = \sum_{t=t_1}^{\tau} C_j(t)/\tau \tag{13}$$

and

$$\bar{C}_j' = \sum_{t=t_1}^{\tau} C_j(t)/\tau \qquad (14)$$

and output numerically. Table 5 indicates the channel-to-variable relation, and lists other variables necessary to complete the algorithm.

Data reduction of the manual gas data was similar to the continuous data. Equations 8 through 12 were used, although the gas data were input on IBM cards. The variable $C_j(t)$ is a concentration measured for a sample integrated over 30 to 60 seconds of test time.

Solutions to Equations 2 and 3 were output in a graphic form, and are displayed in Appendix B. The total volume under stack conditions, E_{Ti} (Equation 4), and the high, low, and average temperature for each location i of each test are displayed in the same appendices, along with the total volume emitted relative to standard conditions, E'_{Ti} (Equation 5).

Data produced by Equations 8 through 19 were used in the continuous gas analysis program. The resultant output of this program is provided in Appendix C.

Concentration Calculation - The calculations for quantification of the gas concentration are shown below. Briefly, the volume percent of each gas was calculated, as follows: the volume of the unknown gas was calculated from the instrument response in peak area or height and the response ratio of the instrument per volume of each standard gas. The volume of unknown gas was divided by the total volume of sample introduced into the chromatograph after both were corrected to atmospheric pressure. The response ratios were calculated from at least four different levels of each standard gas.

(1) Volume of standard gas calculated to atmospheric pressure =

$V_{sa} = (5)\ (P_s/P_a)\ (s)$, where

V_{sa} = Volume of standard gas at atm. pressure;

5 = Gas sample loop volume;

TABLE 5

VARIABLES FOR GAS ANALYSIS

$F_i'(t)$ - from volume flow program (SCFM)

	$C_1(t)$	-	% H_2O	-	00
	$C_2(t)$	-	ppm SO_2	-	01
	$C_3(t)$	-	ppm H_2S	-	02
	$C_4(t)$	-	ppm NO	-	03
$C_j(t) \equiv$	$C_5(t)$	-	ppm NO_x	-	04
	$C_6(t)$	-	% THC	-	05
	$C_7(t)$	-	% H_2	-	06
	$C_8(t)$	-	% O_2	-	07
	$C_9(t)$	-	% CO	-	08
	$C_{10}(t)$	-	% CO_2	-	09

$$\gamma \equiv \frac{\text{Number of } F_i'(t) < F_T}{\text{Number of Locations Monitored}}$$

$F_T \equiv$ A constant to be determined after volume flow data has been reduced

P_s = Standard pressure, mmHg;

P_a = Atmospheric pressure, mmHg;

S = Volume % of gas in standard.

(2) Ratio of standard gas at atmospheric pressure per instrument response unit =

$R = V_{sa}/IRU_s$, where

R = Ratio, volume of standard gas per instrument reponse unit;

IRU_s = Instrument response units (either peak area or height) for standard gas.

(3) Volume of unknown gas at atmospheric pressure =

$V_{ua} = (R)\ (IRU_u)$, where

V_{ua} = Volume of unknown gas at atmospheric pressure;

IRU_u = Instrument response units for unknown gas.

(4) Total sample volume at atmospheric pressure =

$V_{ts} = (5)\ (P_v/P_a)$, where

V_{ts} = Total sample volume;

P_u = Pressure of sample, mmHg.

(5) Concentration of unknown gas, volume percent =

Volume percent of unknown = $(V_{ua}/V_{ts})\ 100$.

Size Analyses - The primary methods used to determine a particle size distribution consisted of a combination of Andersen size distribution and optical sizing performed in samples taken from the MITRE Carrousel.

The Andersen samples were taken in the measurement ducts. At the completion of a test, the Andersen sampler was hand carried to the field laboratory and allowed to cool down to a stable temperature. The sampler was then disassembled. The plates and rings were then weighed on site. The sampler was cleaned and readied for the next test and the washings were stored and labeled for later reference.

The data from the field weighings were later analyzed at the MRI Kansas City facilities. Standard computer programs were used by MRI to produce size distribution information in ranges from about 20 μ to .5 μ and information on gross weight percent of the sample above and below these boundaries. The data are listed in Appendix C. They were then combined and reduced with MITRE data as described in another section. The original Andersen distribution was calculated assuming a 1 gm/cc density; however, the final distribution given was calculated assuming a 1.2 gm/cc density.

Samples collected by the MITRE Carrousel were analyzed by optical techniques. Representative slides were selected from each test and analyzed for particle size distribution and number density. The microscope reticle was calibrated with 39μm and 28μm pollen. Particles were grouped in one of seven size ranges using the calibrated reticle with the "Ferets diameter" method. The ranges are:

1 - 4.6 to 9.2 μm	5 - 73.6 to 147.2 μm
2 - 9.2 to 18.4 μm	6 - 147.2 to 230 μm
3 - 18.4 to 36.8 μm	7 - 230 μm .

The particles were sized optically with a B & L microscope at 300, and 150 powers. The magnified samples were displayed and counted on a closed circuit television system coupled optically to the microscope. Through the use of a polaroid camera attachment, pictures were periodically taken.

A particle count of about 500 (termed a "batch")* was required at each of the powers. Areas scanned (fields-of-view) were selected at random to produce a representative sample, until the batch was complete. Each

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* Lodge, J. P. Production of Controlled Test Atmospheres In: Air Production, Volume II, Stern, A. C. (ed.) New York and London, Academic Press, 1968. p. 465-481

slide to be analyzed was chosen such that a field-of-view had less than 200 particles** in the countable ranges for any given power. The areas of field-of-view at 150 power and 300 power are 965 μm^2 and 241 μm^2, respectively.

A batch counted in the 300 power range includes particles between 4.6 μm and 147.2 μm (excluding ranges 6 and 7). The 150 power batches include particles greater than 9.2 μm (excludes range 1). To combine the results for 300 power and 150 power batches sized for the same test, the number of particles in the omitted ranges were calculated from the ratios of the other batches. For example, the number of particles in range 1 of batch 2 would be calculated as the ratio:

$$N_{12} = \frac{N_{11} \cdot \sum_{i=2} N_{i2}}{\sum_{i=2}^{5} N_{i1}} \tag{15}$$

N_{12} ≡ the number of particles in (unmeasured) range 1 of batch 2,

N_{11} ≡ the number of particles in range 1 of batch 1,

N_{i2} ≡ the number of particles in range i of batch 2,

N_{i1} ≡ the number of particles in range i of batch 1.

The number of fields-of-view completing a batch were counted and recorded and the area calculated. The density of the slide was then calculated as a ratio between the number of particles counted to area scanned. The location of each field-of-view was recorded to the nearest tenth of a mm using the movable stage position scale. All slides were labeled and stored for later access.

** Silverman, L., Billings, C. E., First, M. W. Particle Size Analysis in Industrial Hygiene. New York and London, Academic Press, 1971. p. 106-107

The theoretical collection efficiency of the microscope slides was investigated to determine system biases relative to particle size and emission velocity.

The collection efficiency corrections were applied to the respective size ranges. Though the optical sizing of the coke oven particles included ranges from 4.6 μm and larger, the data analyzed will include the size ranges where the particles were larger than 18.4 μm. Ranges 1 and 2 were excluded from final computations because:

a) it was found that the collection efficiency drops off rapidly below 20 μm;
b) the Andersen sampler adequately sized particles up to 20 μm; and
c) it was difficult to confidently identify the smaller particles due to foreign materials and grease anomalies on the slides.

Each slide was also analyzed for particles larger than 1000 μ with a ten power magnifier. The number of particles larger than 1000 μ was counted on each slide and the density for particles >1000 μ was calculated and recorded.

All data obtained from optical sizing are presented in Appendix E which includes:

a) Particulate counts for each test,
b) Particle density for each slide for particles larger than 18 μ,
c) Particle density of particles larger than 1000 μ,
d) Calculated percentage of particles versus size range,
e) Cumulative number and weight percents versus size range.

Secondary methods of size analyses are described in Appendices B and E. The methods included:

Brink
Sieve and Sedegraph
Coulter counter
Optical of Andersen and cyclone cateles.

Mass Loading - Due to oven constraints and the unique features of emissions produced during a charging operation, particulate sampling was done anisokinetically, where the sampling velocity was held constant, independent of stack velocity. To bracket the error created by anisokinetic sampling and determine theoretical isokinetic values, modified procedures explained in detail in MTR-6288, "Manual Sampling System, Coke Oven Emissions Test Program," were used and are summarized here.

The theoretical isokinetic mass, EM_i, can be calculated by the algorithm:

$$EM_i = \frac{A_i}{a_i} M_i \sum_{l=1}^{n} Q_{il} \cdot (\%W_l) \qquad (16)$$

where

M_l = mass of sample collected at location i,

$\%W_l$ = the weight percent of total mass at a given range,

A_i = area of stack at duct i,

a_i = area of sampling nozzle at duct i,

Q_{il} = anisokinetic correction factor for particle size range l at location i from a given test.

The correction factor is found as a function of particle size, sampling velocity and stack velocity and is calculated from:

$$Q_{il} = \sum_{t=1}^{T} Q_{il}(t)/T \qquad (17)$$

and

$$Q_{il}(t) = \frac{1}{[1-\alpha_{il}(t)]\, V_{si}A_i/F_i(t) + \alpha_{il}(t)} \quad \text{for } F_i(t) \neq 0. \qquad (18)$$

The inertial parameter $\alpha_{i1}(t)$ can be determined from:

$$\alpha_{i1}(t) = \frac{1 - \exp[-4.5/\lambda_{i1}(t)]}{4.5} \left(\lambda_{i1}(t)\right) \tag{19}$$

where

$$\lambda_{i1}(t) = (.508)F_i(t)\gamma_1/(A_i g) \tag{20}$$

and

A_i = Area of location i .69 ft^2 for Wilputte Emissions Guide .85 ft^2 for stacks and AISI/EPA Guide

a_i = Area of sampling nozzle

$\%W_{i1}$ = Weight percent of mass in size range i at location i. The values and ranges were calculated beforehand from Andersen and Optical sizings and assumed constants for all tests. Volume flow data are needed to determine $\%W_{i1}$.

τ = Total time of test measured by Channel 48

V_{si} = Sampling velocity to be computed for each sampling location for each test

$F_i(t)$ = Volume flow at stack conditions computed and stored during volume flow calculations. ft^3/minute

g = Acceleration due to gravity. 980 cm/$second^2$

γ_1 = Average free fall velocity of particles in size range 1 (in cm/second)

Ideally, when employing this sampling method in the stack velocity or volume flow, $F_i(A)$ should never go to zero. Correction factors for $F_i(t) = 0$ are inadequate. However, the condition did exist on a number of tests and was handled by setting $Q_{i1} = 0$ for small particle ranges where $F_i(t) = 0$ and $Q_{i1} = 1$ for the larger particle ranges. The rationale behind this concept is simply small particles (those which act as gases) remain in the stack after the flow has gone to zero and are

sampled. Hence, they mistakenly add some amount of weight to the sample. The larger particles fell out rapidly and similarly are not sampled. The amount of mass produced by the large particles is correctly zero for $F_i(t) = 0$ implying $Q_{il}(t) = 1$.

The particle mass distribution is described by $\%W_l$ where $l = 1, 2, \ldots 13$ (number of size ranges). It is calculated as a function of anisokinetic weight percents found for each test duct i and is found by:

$$\%W_{il} = \frac{\%W_{il}\, Q_{il}}{\sum_{i=I}^{13} \%W_{il}\, Q_{il}} \tag{21}$$

and the average weight percent is ranged over all tests, n, for range l is:

$$\%W_l = \sum_{i=1}^{n} \%W_{il}/n \quad . \tag{22}$$

These values for weight percent were calculated and used for anisokinetic corrections, as well as to determine a representative mathematical frequency distribution model.

Optical Monitoring System Parameters

Data analysis for the optical monitoring system was divided into three phases. The first phase consisted of the necessary operations to convert data in the form of a photographic image to information about the source light transmission characteristics of discrete areas of the emission plume. The second phase included the calculation of mass loading estimations from the transmission values for discrete areas and the combination of these estimations to provide mass loading data across the entire light source image at some instant in time. The third phase involved the estimation of total mass emitted over time by multiplying the instantaneous mass loading estimations by the velocity at which the emission plume is passing upward across the light source. The calculations and quantities involved in each phase will be discussed below.

Quantitative data was obtained from the photographic record through the use of a microdensitometer having a digitized output. The machine measured the optical density of discrete areas on the source film image and produced a record on magnetic tape in the form of an eight-place binary number. The 256 integral values possible in an eight-place binary number are uniformly distributed between two bounding optical density values as part of the initial adjustment of the microdensitometer. The bounding values for the optical density range were selected so that the lower value fell below the observed optical density for the photographic image of the black portion of the light source in the absence of emissions. The upper bound of optical density was chosen so that it was above the maximum observed photographic image density of the lighted portion of the light source in the absence of emissions. Further, the photographic film was processed so that a close to linear relationship existed between light source image optical density values and the log exposure values which produced them.

The relationship between the exposure values was established for each film roll through a 21-step density versus exposure tablet placed on each roll prior to processing. Each step associated a relative exposure value with a resulting optical density. From the 21 tablet steps sequentially spaced at .15 log exposure units apart, a vendor-supplied computer program fitted a cubic curve of density versus exposure values. The program then continued to assign individual relative exposure values to each of the binary density values between 0 and 255 as represented on the magnetic tape.

The output values of this program were provided in the form of a punch card deck and the magnetic tape. The exposure values were positioned in the table matrix so that their sequential position number (address) corresponded to the binary number value associated with that particular density. Thus, using the binary value as an address in the matrix, the relative exposure value was found as the numerical contents of that address.

Transmittance "T" is defined as f/fo, where f and fo are the values for light intensity incident upon the system detector in the presence and absence of a plume, respectively. The relative exposure values are a product of light intensity and time:

$$EV = \text{Meter Candle Seconds.}$$

In this system, distance in meters, which determine apparent intensity and exposure time in seconds, was held constant. Thus, a change in EV can be considered to be a change in luminance (candles) caused by a change in plume transmission characteristics.

In order to facilitate the calculation of "T" from exposure values, a lower exposure value associated with zero source light was established. The density readings of the black area in the absence of emissions was taken to represent this value. This condition existed on the designated "base frame" of each test. There were, however, slight differences in individual density values in the scan record of this area. These could be caused by machine inconsistencies, anomalies in the photographic films, or small quantities of emission somewhere along the line of sight causing a plume-air light return. In order to obtain a representative zero value, all measured densities across the unobscured black portion of the bar were averaged as follows:

$$D^o = \frac{\sum^{P} D^o_{1i}}{P} \tag{23}$$

where D^o_{1i} was the binary density number for a point; and P was the total number of points scanned across the black area on the base frame.

This value was established for each roll of film or test run. This density value is assumed to be the image density value of the light source if transmission were to go to zero and there were no other scattered light, which appeared to come from the light source position on the frame.

This density value was then located in the density versus exposure table and a corresponding exposure value was determined. This exposure value was then substituted in the equation for determination of the reciprocal of transmittance:

$$\frac{1}{T} = \frac{f_{oa} - f_{ob}}{f_a - f_b} \tag{24}$$

where f_{ob} is always the exposure value corresponding to $\bar{D}_o$, f_{oa} is the exposure value corresponding to the unencumbered point density of the light source and f_a and f_b are equal to the exposure values corresponding to the point image density of adjacent light source and black areas respectively, in the presence of the emission plume.

The exposure values f_{o2}, f_a, and f_b were obtained by using the binary optical density value of each record on the magnetic tape as an address in the exposure value matrix table. The contents of that address is the corresponding relative exposure value for direct substitution in the formula above.

As the reciprocal of transmittance was found for each point in the scan, the natural log of that value was determined and added to an accumulation. When transmission calculations on all the 539 points in a frame scan were completed, the contents of the log 1/T accumulator was multiplied by the constants representing particulate characteristics.

The equation for the calculation of the mass emission rate for each film data frame is:

$$M = \frac{4}{3}\phi K \Delta L \sum_{i=k}^{P} \ln\left[\frac{f_{oA}(l_i) - f_{oB}(l_i)}{f_A(l_i) - f_B(l_i)}\right] \tag{25}$$

where ϕ represents the mass density of the particles, K is defined as the specific particulate volume divided by the light extinction coefficient ratio and ΔL is the lateral dimension of a small area of the light source (termed a point) which is represented by each of the measured

density values (539) across the light source. The values of 1/T were calculated for each of the measured density points across the light source and summed as ln(1/T) as described above.

The values of ϕ directly determines the calculated mass volume from particulate volume determined by the opacity,measurement. If the particles collected were made up of a single material or compound, the value of ϕ would be simply the mass density of that single material. The particle population collected on the coke oven was not, however, composed of a single material. An analysis of particulate samples collected in particle sizing equipment shows that several different materials were present in the population. There is, however, a predominance of two materials. They are carbon (as it occurs in coal) and heavy hydrocarbons or coal tars. A further analysis shows that the larger particles are composed mostly of carbon with some tar causing considerable particle agglomeration. The smaller particle size ranges, on the other hand, are composed primarily of tar globules which are probably condensed from the existing gas as it reaches the ambient air. The particulate size distribution from the particle sizing equipment further explains the apportionment of the material between the two ranges. The combined weight of the stages shows that 53.4% of the total average sample mass is contained between 9.4 μ and ∿1000 μ, while 46.6% is contained in the ranges 6.4 μ and below. Using this information, a representative particle mass density value was estimated. The value used in mass rate calculations for the optical system is 1.2 gm/cm^3. It is quite simple, however, to determine mass rates for other assumed values of density since this factor is purely multiplicative in the mass rate equation.

The determination of an appropriate value for the constant K is complicated by the complex particle material makeup and the distribution of particle size. The value of K is mathematically evaluated using the equation:

$$K = \frac{4}{3} \frac{\int_{r_1}^{r_2} \exp - \left[\frac{\ln^2 r/r_{gn}}{2\ln^2 \sigma_g} \right] dr}{\int_{r_1}^{r_2} rQ_E(d,m) \exp - \left[\frac{\ln^2 r/r_{gn}}{2\ln^2 \sigma_g} \right] dr} \tag{26}$$

in which r is the radius of a particle, r_{gn} is the simple geometric mass mean radius and σ_g the standard deviation of a lognormal particle size distribution, and Q_E is the extinction coefficient assigned or calculated for size distribution. It was shown by Conner and Hodkinson* and Pilat and Ensor** that Q_E can reasonably be set equal to 2 for large particles (larger than 2-4 μ) without serious error in calculations. This approach cannot, however, be used for small particles since their Q_E value is much more strongly influenced by their material makeup, their complex index of refraction, and the wavelength of the light source which they attenuate.

Measurements and analysis of the particle size distribution have shown that the size frequency curve is bi-populate in nature. It has also been demonstrated through graphic and chi-square tests that each half of the combined curve generally fits a lognormal distribution.

The upper portion of the combined curve representing the larger particles has a geometric mass mean radius of ∿100 μ. This portion of the particle population can be expected to have a value of Q_E approximately equal to two. The lower portion of the combined curve, however, has a geometric mass mean radius of .85 μ. With this mean radius, it is improper to assign a value of z for Q_E of these particles.

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* Conner, W. D., Hodkinson, J. R. Optical Properties and Visual Effects of Smoke Stack Plumes. U. S. Department of Health, Education, and Welfare, Cincinnati, Ohio. Publication #PB 174-705. 1967.

** Ensor, D. S., Pilat, M. J. Calculation of Smoke PlumeOpacity from Particulate Air Pollutant Properties. Journal of Air Pollutant Control Association. Volume 21, Number 8, August 1971.

In order to develop a K value for the total particle population, K was determined for each of the two particulate mean values and the observed variance about that mean. The upper portion around 100 μ was assumed to be made up primarily of carbon with an index of refraction of 1.96-0.66 i. The lower portion of the population was assumed to be primarily coal tar with an estimated value for the complex index of refraction of $1.54 - 1.9 \times 10^{-4}$ i. The values of K found for each half were combined using the particle number distribution as a weighing factor.

Particle number distribution showed 4% of the total particles to be in the upper distribution, while 46% was contained in the lower portion. The K value for the upper portion was found to be 28, while the lower K value was estimated to be .22. The combining of these two values using the associated population percent as a weighing factor yields a combined value of 1.33 for K. This value was used in the mass rate calculations. Since this factor is purely multiplicative, mass rate for other K values can be easily estimated.

The last constant, ΔL, is the lateral width of a single sample point. The microdensitometer was set up to take 539 equal width samples across the 48' light source. The equation for ΔL is therefore:

$$\Delta L = \frac{48' \times .3048 \text{ M/ft}}{539} = .027 \text{ M.} \qquad (27)$$

This is the value for ΔL used in the mass rate calculations across the horizontal bar. The same ΔL can be used for rate calculations involving the vertical "wing" light sources.

In order to calculate a total mass emitted over any period of time during a charge, the instantaneous value of mass emission rate is multiplied by the plume vertical velocity or plume rise velocity. In the original system concept, the value or values for plume velocity was to be determined using motion pictures of the actual plumes. This approach was modified slightly to utilize the system sequence camera instead of a motion picture camera.

In order to measure the vertical progress of the plume, an illustrated scale was constructed and placed on one of the equipment towers approximately 30 feet above the top of the oven. The bar consisted of ten small light bulbs spaced one foot apart. As viewed from the coal bin balcony, the scale started about one foot below the light bar and extended upward about nine feet above it. This scale was used to calibrate the visible vertical area included in each frame which extended about 30 feet above the image of the bar.

In order to prevent special distortion, emission plumes were chosen which were rising near vertically (not being blown by wind) in the vicinity of the illuminated scale (about the same distance from the camera). An additional consideration in the selection of emission periods was the visibility of the illuminated scale during at least some portion of the period recorded on film. It was not necessary that the bar be visible the entire period since only two or three frames per period were required to calibrate the viewing screen.

The technique used in photographing the plume involved observing the emissions until a vertically rising plume developed with a number of distinguishable features such as puffs. The sequence camera was then operated at either one or five frames per second for some period of time - usually from 30 seconds to one minute. The record of the vertical motion was thus made at known time intervals.

The resulting film was processed and viewed using a standard 35mm projector and a square grid as a viewing screen. The projector was adjusted with respect to the screen until the distance between two adjacent bulbs on the scale image correspond to some convenient number of viewing screen grid dimensions. This allowed a direct estimation of the vertical rise distance of some observed feature on the plume.

A total of 60 observations were made on five different charges. The arithmetic mean value was calculated for those observations. This value was 6.63 feet/second free rise velocity for the plume in the vicinity of the light source. A one σ value for the population was also calculated. These values were used for mass emission calculations in the optical program.

SECTION V
RESULTS

This portion of the document summarizes the final results of the data analyses. A comparison is provided of gaseous emissions released by the AISI/EPA car and Wilputte car along with a comparison of gaseous emissions that were measured by both the continuous and manual sampling systems.

The results of the particulate analyses are provided in two parts. First, particle size information is given for a number of sizing methods used during the program. An overall frequency size distribution is also determined. Following this, a comparison is given between the total particulate mass emitted during a charging operation of the AISI/EPA car to that emitted by the Wilputte car.

The optical monitoring results are also presented. The results are evaluated and compared to the in-stack measurement system results. The feasibility of this system for general use in source monitoring is also discussed.

COMPARISON OF CONTINUOUS MEASUREMENT AND MANUAL GAS SAMPLING METHODS

The continuous monitoring system was used to obtain gas measurements on 27 charging operations, 25 of which produced useful data. The manual sampling system was in operation on 16 of the 27 tests, and data from 10 of the tests were analyzed.

Table 6 lists the constituents measured by the continuous and manual sampling systems. The data from manual and continuous gas analyses is presented in Appendices B and C, respectively. Of the 16 gases, eight gases were analyzed by both the continuous and manual systems. In the presentation of results, either the continuous or manual values were used, based on the comparison of the systems as described below. The results for both manual and continuous analyses are shown in Tables 7 through 14. In these tables, the columns labeled "Interval Average" refer to average values calculated over the period during which manual gas sampling was taking place. Under the "MITRE Values" heading, the "Interval Average"

TABLE 6

CONSTITUENTS MEASURED BY THE CONTINUOUS AND MANUAL SAMPLING SYSTEMS

Constituent	Continuous	Manual
CO	X	X
CO_2	X	X
SO_2	X	X
H_2S	X	X
THC	X	X
CH_4		X
NO	X	
NO_x	X	X
N_2		X
NH_3		X
H_2O	X	
HCN		X
H_2	X	X
O_2	X	X
pyridine		X
phenols		X

TABLE 7, SO_2

MITRE # /MRI #	MITRE VALUES IN PPM				MRI VALUES IN PPM				
	TEST AVERAGE	INTERVAL AVERAGE	HIGH	LOW	INTERVAL AVERAGE	BAG A	BAG B	BAG C	BAG D
5/W4	427.9	<380 *	1088.1	0	7.033	<4.5 *	9.2	<7.4 *	
6/W5	76.1	< 69.35	293.6	0	159.99	87.51	232.47		
7/W6	496.9	450 **	857.5	256.2	28.69	< 4.5 *	< 19.16 *	69.1	< 22 *
10/W10	221.8	125 **	454.2	0		< 9.7 *			
11/W11	388	425 **	654.1	0	9.55	< 7.3 *	< 6.6 *	< 4.5 *	< 19.8 *
19/K1	120.1	19.22	381.6	4.7	22.33	25.4	24.75	21.32	17.84
21/K3	1453.4	450 **	3485.7	8.4	23.63	21.03	9.72	68.25	< 15.53*
23/W12	3.8	2.35	14.0	0	14.85	<23.2 *	< 6.5 *		
24/K4	188.9	250 **	833.3	18.8	28.34	< 6.3 *		<50.37 *	

* Detectable Limit - Minimum detectable quantity calculated for sample size

** Approximated Values - Data not completely reduced due to obvious instrument operational problems

TABLE 8, $\square_2$

MITRE # /MRI #	MITRE VALUES IN %				MRI VALUES IN %				
	TEST AVERAGE	INTERVAL AVERAGE	HIGH	LOW	INTERVAL AVERAGE	BAG A	BAG B	BAG C	BAG D
5/W4	.1	.0497	1.0	0	.0933	0	.28	0	
6/W5	0	0	0	0	.315	.17	.46		
7/W6	0	0	0	0	1.66	1.8	.01	.43	4.39
8/W7	0	.01	.2	.1	.54	.48	.13	1.23	.32
10/W10	0	0	0	0	.38	.21	.51	.42	
1/W11	0	0	0	0	.977	2.13	.3	.06	1.42
19/K1	0	0	0	0	.0175	.01	.03	.02	.01
21/K3	2.2	1.57	9.0	0	2.038	.41	.36	3.54	3.84
23/W12	.2	.175	2.3	0	.875	.19	1.56	1.56	
24/K4	.1	.081	.6	0	1.9	.48		3.32	

TABLE 9, CO

MITRE # /MRI #	MITRE VALUES IN %				MRI VALUES IN %				
	TEST AVERAGE	INTERVAL AVERAGE	HIGH	LOW	INTERVAL AVERAGE	BAG A	BAG B	BAG C	BAG D
5/W4	.68	.6	2.02	.02	.02	.01	.04	.01	
6/W5	1.08	1.0	2.15	.58	.99	.77	1.22		
7/W6	1.18	1.2	2.88	.13	1.15	1.53	.12	1.4	1.53
8/W7	1.22	1.2	3.34	.20	.63	.34	.17	1.34	.68
19/K1	.41	.1	2.36	.04	.02	.02	.02	.03	.01
21/K3	1.12	1.3	2.53	.08	.93	.5	.15	1.96	1.11
23/W12	.69	.7	2.95	.10	.27	.2	.33		
24/K4	.41	.6	1.63	.01	.26	.1	.43		

TABLE 10, CO_2

MITRE # /MRI #	MITRE VALUES IN %				MRI VALUES IN %				
	TEST AVERAGE	INTERVAL AVERAGE	HIGH	LOW	INTERVAL AVERAGE	BAG A	BAG B	BAG C	BAG D
5/W4	.0	.1	.4	.0	.21	.06	.28	.29	
6/W5	3.2	3.1	8.1	.6	2.7	2.33	3.06		
7/W6	2.1	2.1	6.3	.0	1.9	.96	2.14	2.77	1.84
8/W7	1.2	1.3	4.5	.0	.9	.74	.27	1.4	1.3
10/W10	.7	.3	2.0	.0	.7	.29	.56	1.2	
11/W11	.8	.9	1.9	.0	.6	.86	.07	.15	1.39
19/K1	.2	.0	.9	.0	.1	.07	.14	.12	.11
21/K3	.4	.5	1.1	.0	.7	.22	.16	1.24	1.14
23/W12	.0	.0	.0	.0	.4	.42	.4		
24/K4	.3	.6	1.8	.0	.6	.15	.95		
9/W9	.0	.0	.0	.0	.2				

TABLE 11, THC

MITRE # /MRI #	MITRE VALUES IN %				MRI VALUES IN %				
	TEST AVERAGE	INTERVAL AVERAGE	HIGH	LOW	INTERVAL AVERAGE	BAG A	BAG B	BAG C	BAG D
6/W5	.73	.69	1.84	.00	.93	.68	1.18		
7/W6	1.57	1.23	6.34	.00	1.44	.8	.15	2.08	2.72
19/K1	1.12	.14	7.00	.00	.09	.11	.09	.10	.06
21/K3	3.62	3.45	7.00	.00	5.77	7.41	.52	8.1	7.05
23/W12	3.00	2.50	13.96	.00	.87	.26	1.48		
24/K4	1.78	2.55	6.98	.00	1.51	.44	2.59		

TABLE 12, O_2

MITRE # /MRI #	MITRE VALUES IN %				MRI VALUES IN %				
	TEST AVERAGE	INTERVAL AVERAGE	HIGH	LOW	INTERVAL AVERAGE	BAG A	BAG B	BAG C	BAG D
5/W4	18.1	18.19	18.7	15.0	16.29	16.56	15.71	16.6	
6/W5	16.7	16.96	21.6	5.8	13.52	15.75	11.29		
7/W6	15.1	15.22	19.0	9.7	14.72	15.23	16.59	12.99	14.06
8/W7	14.7	15.14	18.7	7.5	15.87	15.58	16.33	15.96	15.6
10/W10	14.4	15.4	16.9	11.0	15.69	16.1	16.27	14.7	
11/W11	16.5	16.25	18.9	13.9	15.64	15.33	16.01	16.22	15.0
19/K1	18.9	19.46	19.6	15.8	16.13	16.03	16.42	15.96	16.11
21/K3	17.5	17.72	19.6	15.3	15.075	14.85	16.41	14.20	14.84
23/W12	18.0	17.98	19.3	13.9	16.195	16.05	16.34		
24/K4	19.6	16.37	20.3	18.3	15.39	15.76		15.02	

TABLE 13, NO_x PLUS NH_3

MITRE # /MRI #	MITRE VALUES IN PPM				MRI VALUES IN PPM				
	TEST AVERAGE	INTERVAL AVERAGE	HIGH	LOW	INTERVAL AVERAGE	BAG A	BAG B	BAG C	BAG D
5/W4	22.2	22	47.9	0.0	< 4.89 *				
6/W5	42.2	40.9	103.8	1.4	< 37.07 *				
7/W6	124.9	95.7	483.8	6.0	<140. *				
8/W7	68.8	65.2	144.3	0.0	<208.0 *				
10/W10	57.9	50.6	120.5	0.0	< 4.4 *				
11/W11	82.7	91.2	365.4	0.0	< 37.3 *				
19/K1	3.4	.5	14.0	0.0	< 8.16 *				
21/K3	113.7	42.5	319.0	0.8	< 22.4 *				
23/W12	21.4	25.1	70.3	0.0	< 8.3 *				
24/K4	.6	1.6	11.3	0.0	< 31.1 *				

* Detectable Limit - Minimum detectable quantity calculated for sample size

TABLE 14, NO_x

MITRE # /MRI #	MITRE VALUES IN PPM				MRI VALUES IN PPM				
	TEST AVERAGE	INTERVAL AVERAGE	HIGH	LOW	INTERVAL AVERAGE	BAG A	BAG B	BAG C	BAG D
5/W4	22.2	22	47.9	0.0	< 3.5 *	< 2.16 *	6.20	< 2.17 *	
6/W5	42.2	40.9	103.8	1.4	34.5	< 12.48	56.59		
7/W6	124.9	95.7	483.8	6.0	< 124.7 *	< 2.19 *	6.3	< 2.19 *	488.4
8/W7	68.8	65.2	144.3	0.0	< 151.7 *	< 2.17 *	< 2.18 *	301.28	301.28
10/W10	57.9	50.6	120.5	0.0	< 2.18 *	< 2.17 *	< 2.18 *	< 2.18 *	
11/W11	82.7	91.2	365.4	0.0	< 29.6 *	< 2.16 *	< 2.15 *	3.09	110.95
19/K1	3.4	.5	14	0.0	< 1.96 *	< 1.96 *	< 1.97 *	< 1.94 *	< 1.96 *
21/K3	113.7	42.5	319.0	0.8	< 4.7 *	< 1.96 *	11.26	2.8	2.78
23/W12	21.4	25.1	70.3	0.0	< 2.38 *	2.79	< 1.97 *		
24/K4	.6	1.6	11.3	0.0	< 1.94 *	< 1.95 *	< 1.93 *		

*Detectable Limit - Minimum detectable quantity calculated for sample size

values are an average of five second averages (see Appendix C, page C-123) during the manual sampling period. "Test Average" values are averages of five second averages over the total test period. Under the "MRI Values" heading, the "Interval Average" is a simple average of the measured concentrations in the sample bags. Thus, only the "interval" values are comparable, whereas the "test" value represents an average over a longer period of time.

Also included in these tables are values of detectable limits for individual samples. This value is a function of sample size and is included to indicate that concentrations of the particular constituent below this level may have been present, but would not have been detected by the analytical techniques utilized. Thus, this value does not indicate the absolute absence or verified presence of the constituent.

In general, good agreement was observed between manual and continuous data for CO, CO_2, THC, and O_2. For these four gases, it was felt both systems were producing results that agreed within the constraints of the system. Generally, large disagreement for these gases on specific tests could be traced to some specific problem occurring during the test. Good comparisons were also found between the results of each test and the general qualitative descriptions of the emissions recorded on the voice tapes. The emission volumes determined for each of these gases were calculated using the continuous results. This was done because more continuous measurements were performed than manual, and hence, offered a large statistical sample.

The continuous SO_2 and H_2S data when compared with the manual data were found to be orders of magnitude higher. As a result, a number of laboratory tests were performed. These tests established the fact that certain aromatic hydrocarbons, probably present in coke oven emissions (especially phenol), interfere with the UV bands used to measure H_2S and SO_2; (215 m and 280 mμ, respectively). Therefore, even with the constraint of a smaller statistical sample, it was necessary to use the manual results to determine the typical SO_2 and H_2S emission volumes per charge.

Similarly, interference problems, as well as calibration problems, for the H_2 analyzer resulted in considerable disagreement between manual and continuous data, and it was concluded that manual data should be used for any computation requiring hydrogen.

Comparison of NO_x data shows values for certain tests in agreement, while others differ by as much as an order of magnitude. The data from both systems were compared to qualitative descriptions of each test, and it was determined that there were inconsistencies in the manual sampling results. As a result, it was concluded that the continuous measurements would be used for NO_x.

In summary, of the eight gases measured by both systems, the continuous results were used in the data reduction procedures for CO, CO_2, THC, O_2, and NO_x; and the manual data were used for H_2S, SO_2 and H_2.

COMPARISON OF GASEOUS EMISSIONS FOR WILPUTTE AND AISI/EPA CAR

During the field measurement program, it was not possible to monitor all emission points simultaneously. Therefore, the estimate of total gaseous emissions released by the car was prepared using aggregate data on measured gaseous concentrations from the series of individual tests. The average volume flow for each emission point was calculated for each test and summed to determine the average total volume flow of gases emitted during a charge. These values were multiplied by the average concentration of the individual gases and by the test times to calculate the volume of gaseous constituents emitted per charge. All volume calculations are based on average test times of 2.61 minutes and 3.48 minutes for the AISI/EPA and Wilputte car, respectively. A charge or test is defined as the period of time beginning when the larry car starts to unload its coal and ending when the lids are replaced by the automatic lid lifters (for the AISI/EPA car) or 15 seconds after all the coal is dumped (for the Wilputte car). Since the Wilputte car had to move away from the ports before the lids were replaced, and since monitoring could be performed only when the car was in place, the Wilputte test time was extended to allow for the emissions that would normally occur before the lidman replaced the lids. Fifteen seconds was considered the very minimum time

in which a man could replace the lids and only under the very best conditions. Table 15 lists the average volumes for gases monitored by the continuous measurement system for the Wilputte car and Table 16 lists them for the AISI/EPA car. The measured and corrected values represent flows and volumes calculated using measured and corrected (Equation 10) concentrations, respectively. The measured value can be interpreted in most cases as a lower limit value, while the corrected would indicate the upper limit of the emission levels. It can be assumed that the volume of emission escaping through the measurement points would lie in a range somewhere between the measured and corrected values. Hence, the closer the measured value is to the corrected value, the more confidence can be placed in the results. When the measured value is very close to the corrected value, this is an indication that the error caused by dilution of the sample with ambient air was minimized.

During testing of the AISI/EPA car, a combination of conditions caused number 3 drop sleeve during Test 21 fail to seal. The emission guide surrounding the drop sleeve presented detection of the faulty seal until the charge had begun. Hence, no alternative measures could be taken to correct this condition. Therefore, this test was not considered a fair representation of normal AISI/EPA emissions, and Table 17 lists AISI/EPA volumes excluding Test 21 values from the averages. The results are presented with and without Test 21 included, so as to give a representation of average emissions under poor conditions and under a more typical set of conditions which might require a reasonable amount of care to obtain.

Table 18 is based on corrected values and compares the Wilputte car to the AISI/EPA car for NO_x, NO, CO_2, CO and THC. As noted on Table 18, the volume of NO_x, NO, CO_2, CO and THC was shown to decrease significantly with the new car. Emission reduction ranged from 14 to 99%, with the greatest reduction being in NO emissions. The smallest reduction of these five constituents was still very significant, THC average emission volume for the new car averaged between 14% and 40% less than the other car.

TABLE 15

EMISSION VOLUMES FOR WILPUTTE CHARGING

Constituent	Average Volume Emitted/Charge (SCF)	
	Measured	Corrected
NO_x	.1107	.1144
NO	.0783	.0802
CO_2	29.00	29.36
CO	16.94	17.49
THC	33.28	33.77

TABLE 16

EMISSION VOLUMES FOR AISI/EPA CHARGING INCLUDING TEST 21

Constituent	Average Volume Emitted/Charge (SCF)	
	Measured	Corrected
NO_x	.0456	.0492
NO	.0059	.0061
CO_2	4.05	4.71
CO	8.18	9.04
THC	26.69	29.12

TABLE 17

EMISSION VOLUMES FOR AISI/EPA CHARGING EXCLUDING TEST 21

Constituent	Average Volume Emitted/Charge (SCF)	
	Measured	Corrected
NO_x	.0169	.0211
NO	.0008	.0011
CO_2	3.08	3.83
CO	5.30	6.28
THC	17.09	20.43

TABLE 18

PERCENT REDUCTION OF GASEOUS EMISSIONS

Constituent	(Wilputte Volume-AISI/EPA Volume)/Wilputte Volume x 100	
	% Reduction	% Reduction w/o Test 21
NO_x	56.8	81.6
NO	92.4	98.6
CO_2	83.9	86.9
CO	48.3	64.1
THC	13.7	39.5

Table 19 lists the average, maximum and minimum concentration for all the gaseous pollutants measured. The first five constituents were measured by the continuous monitoring system. The remaining seven constituents were measured by the manual sampling system. It should be noted that the averages of gases measured by the manual sampling system was based on 10 tests for the Wilputte car and three tests for the AISI/EPA, while the continuous system was operational on 18 Wilputte tests and 10 AISI/EPA tests.

Data for SO_2, H_2S, CH_4, NH_3, phenol, CN and pyridine are presented in Appendix C. For a substantial number of tests, measurement of these seven constituents produced concentrations below the detectable limit. It was felt, due to the small number of tests on which these constituents were measured and the large number of times they were below detectable limits, that no calculation of volume would be truly representative of their emissions. Instead, the comparison of cars was made on a measured concentration basis. Table 19 shows that the maximum concentration measured, excluding Test 21, was larger for the Wilputte car in every case. When Test 21 is involved in the comparison, the concentrations were reduced for the AISI/EPA car in every case except for the constituents of H_2S and CH_4.

In general, gaseous emissions from the AISI/EPA car were significantly reduced between 14% and 99% for NO_x, NO, CO_2, CO and THC, while for the other seven pollutants measured, a qualitative evaluation indicates reductions of better than 15% in all cases.

RESULTS OF PARTICLE SIZE ANALYSES

Along with the obvious health reasons for interest in the size distribution of coke oven particulate matter, its characterization is required to predict the physical behavior of particles relative to aerodynamics and optical characteristics.

TABLE 19

CONSTITUENT CONCENTRATIONS (MEASURED)

CONSTITUENT	WILPUTTE			AISI/EPA				
				Without Test #21			With Test #21	
	Average	Maximum	Minimum	Average	Maximum	Minimum	Maximum	Minimum
NO_x (ppm)	38.9	484	0.0	9.6	70.2	0.0	319	0.0
NO (ppm)	15.6	336	0.0	.13	20.3	0.0	52.8	0.0
CO_2 (%)	.5	8.1	0.0	.11	1.5	0.0	1.5	0.0
CO (%)	.69	3.76	0.0	.21	2.2	0.0	2.53	0.0
THC (%)	1.6	13.98	0.0	.59	11.4	0.0	11.4	0.0
SO_2 (ppm)	*	232.5	BDL	*	25.4	BDL	48.3	BDL
H_2S (ppm)	*	42.5	BDL	*	BDL	BDL	72.27	BDL
CH_4 (%)	.62	4.3	.01	.53	1.77	.01	7.79	.01
NH_3 (ppm)	*	130.6	BDL	*	BDL	BDL	12.37	BDL
Phenol (ppm)	*	31.1	BDL	*	BDL	BDL	17.72	BDL
CN (ppm)	*	16.5	BDL	*	BDL	BDL	5.48	BDL
Pyridine (ppm)	*	BDL	BDL	*	BDL	BDL	BDL	BDL

* A large number of tests were below detectable limits (BDL) and no average could be computed.

The particle size distribution determined is also required for use with anisokinetic mass loading and volume flow data to produce a set of calculated isokinetic mass values, and with optical data (opacity measurements) to calculate theoretical mass emissions.

In the calculation of theoretical isokinetic mass data from anisokinetic mass values, the size distribution of the sample is a critical factor. Anisokinetic sampling will result in correct particulate concentrations if the particles are aerodynamically small. For most conditions, particles <5 μ may be considered as small particles. The mass of large particles (those which move independently to gas stream) will produce the correct concentration values if sample volume calculations are made using stack velocity instead of sampling velocity. For the average particle density of coke oven emissions, particles <200 μ can be considered large particles which move independent of the gas stream. However, for particles between 5 and 200 μ, anisokinetic sampling can produce results far different from isokinetic sampling. Hence, to approximate isokinetic results, corrections are required and are partly dependent on the particle size distribution. The relations and calculations are discussed in the Analytical Methods section of this report.

A particle number distribution is also required to relate absorption and scattering effects measured by the optical measurement system to the mass of particulate matter in the plume.

Five methods of particle analysis were used during this test program:

Method	Range Measured	Number of Tests*
Anderson	∿20μ ∿ .5μ	10
Brink	∿ 3μ ∿ .3μ	2
Sieve & Sedegraph	325 mesh to .6μ	2
Coulter	∿100μ to 1μ	1
Optical	500μ to 4μ	9

Though data from all the methods were compared and considered, the Andersen data and optical analysis data of samples taken by the MITRE Carrousel were the primary methods used for development of the particle distribution. The following paragraphs explain the rationale for this decision, as well as discuss the methods and sample handling techniques.

Both the Andersen and the Brink samplers use aerodynamic sizing methods. The sample is simultaneously collected and sized. Weighing of the collection stages is performed within a few hours of the tests, and no redispersion of the sample is needed. The Andersen sampler was used on a total of ten tests (all were performed in the stacks or guides). Due to underloading or overloading or anomalies in stack velocities, five of the tests produced suspected data and were not used in the final compilation of the data. The Brink sampler was used a number of times, producing data from six tests. Three of the six tests concerned samples taken from emission plumes 20 feet above the car; two were of leaking door tests and only one test concerned sampling from the emission guides. The emission guides and stack areas are of most importance, since the mass loading samples were taken from these areas.

Sieve, sedegraph, Coulter and some optical analyses were performed on samples redispersed after various forms of collection. It is intuitively felt that dissolving the particulate matter could seriously alter the particle size distribution by reducing aggregation and floccing, and hence produce biased results.

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* This number indicates the total number of both "good" and suspect samples taken at emission guides and stacks. Test of leaking doors of free plumes, etc., are not listed here.

A number of the optical sizings were performed on samples collected on field constructed equipment (MITRE Carrousel) specially designed to collect the particles and retain them in a form that could be directly used for optical size analyses. The resulting optical size distribution was used to develop a weight distribution and combined with the Andersen results to produce a typical particle size distribution.

Data from the Andersen and MITRE Carrousel optical analyses are listed respectively in Appendices B and E. The Andersen sampler was used on ten tests. Only five of the ten were acceptable for determining a distribution function. Table 20 lists all ten tests, location of samplers and reasons why certain tests were suspect and, hence, not included in the average. The values of the remaining "good" tests were combined with the optical results and corrections applied to the anisokinetic distribution to determine an average calculated isokinetic distribution shown in Table 21. The cumulative distribution of Table 21 is plotted in Figure 18. Inspection of the figure implies that the distribution could fit a bi-populate lognormal distribution. To check this, the distribution was broken into two separate distributions - one between Range 1 and Range 7 (containing ∿46.6% of sample by wt.) and the other Range 8 to Range 12 (containing ∿53.4% of sample by wt.). These were then normalized (Table 21) and plotted on log probit paper (Figures 19 and 20). As expected, a straight line can be drawn through the data points implying that both curves can be approximated by log-normal distributions. The lower range curve has a mass mean diameter of about 8.5 μm and a sigma of about 2.5, whereas the larger range curve has a mass mean diameter around 235 μm and a sigma of about 3.9. The overall mass frequency distribution can be described by:

TABLE 20

ANDERSEN ANALYSIS

Test Number and Location	Status and Reason
7 - 1	Test was acceptable.
8 - 2	Test was acceptable.
8A - 3	Test was suspect due to stage overloading (the 2/3 stage had more than 120 mg on it).
9 - 1	Test was suspect, load on stage was very light (<.2 mg) and emission velocity was zero during much of the test making calculation of theoretical correction factors difficult.
10 - 6	Test was acceptable, loading was light.
11 - 5	Test was acceptable, loading was lighter than ideal.
23 - 2	Test was acceptable, one stage suffered minor overloading.
20 - K2	Test was acceptable.
21 - K3	Test was suspect, stages were over-loaded (as much as 590 mg).
24 - K1	Test was suspect, stages underloaded (some as light as .02 mg).

TABLE 21

SIZE DISTRIBUTION DUE TO COKE OVEN CHARGING

Assigned Range Numbers	1	2	3	4	5	6	7	8	9	10	11	12	13	
Range Mean Particle Diameter μ*	Filter	.584	.883	1.387	2.631	4.313	6.412	9.433	14.791	45	112	273	700	
Weight % in Size Range	14.7	4.3	6.2	11.8	6.5	1.9	1.2	1.7	4.5	3.3	11.0	18.7	14.1	
Cumulative Weight % < Upper Range Bound	14.7	19.0	25.2	37.	43.5	45.4	46.6	48.3	52.8	56.1	67.1	85.8	99.9	

NORMALIZED SEPARATE POPULATIONS OF BIPOPULATE DISTRIBUTION

Lower Mode Weight % < Upper Range Bound	31.5	40.7	54.0	80.6	93.3	97.4	100.0							46.6% of Sample
Upper Mode Weight % < Upper Range Bound								3.2	11.6	17.8	38.4	73.5	99.9	53.4% of Sample

* Assumed 1.2 gm/ml density. Some overlap of ranges occurs in sampling/sizing equipment. As a result, the mean value must be derived from theoretical range bounds.

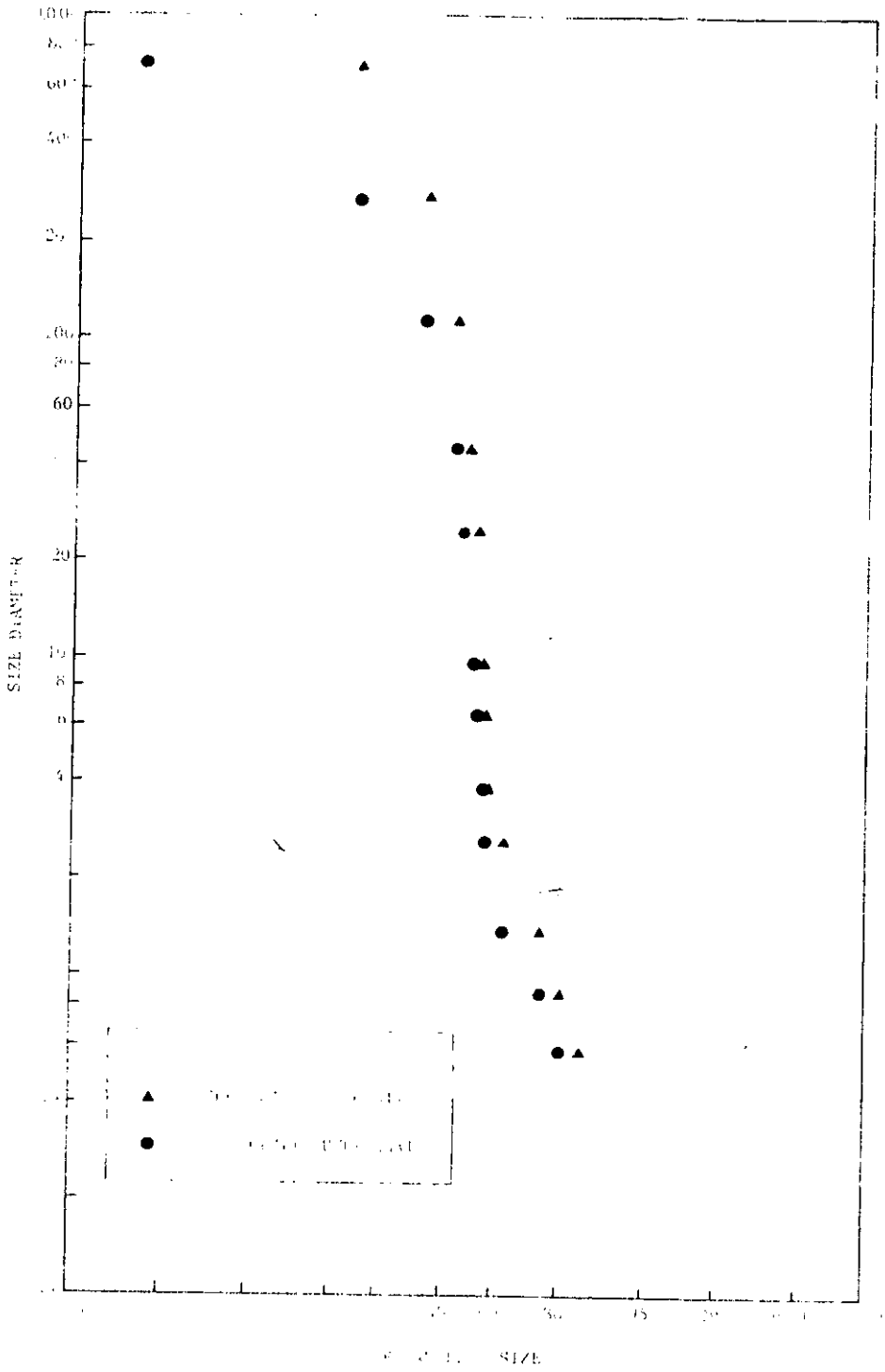

FIGURE 18
COKE OVEN PARTICULATE DISTRIBUTION

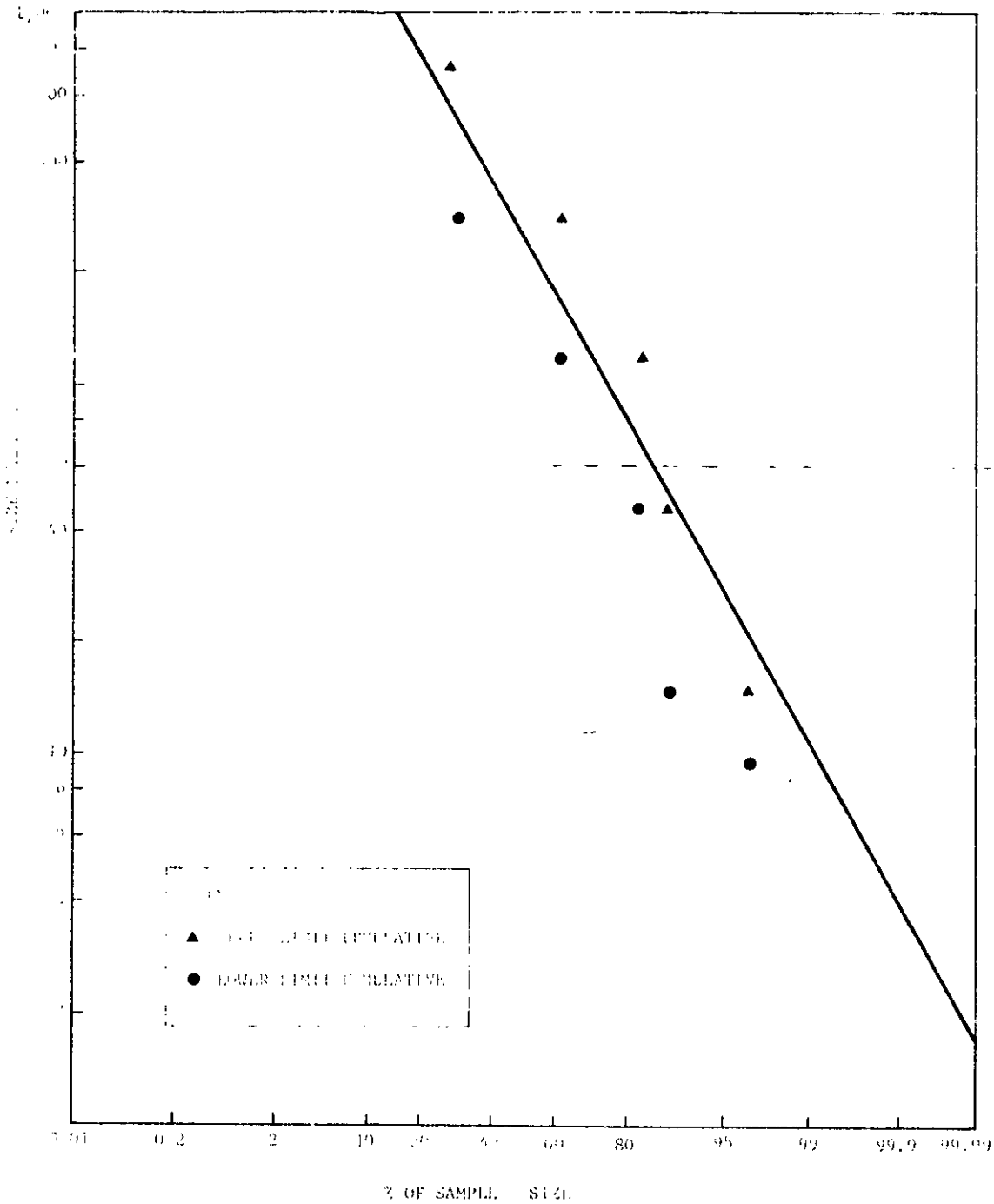

FIGURE 19
LOG NORMAL PLOT OF RANGES 1 THRU 7

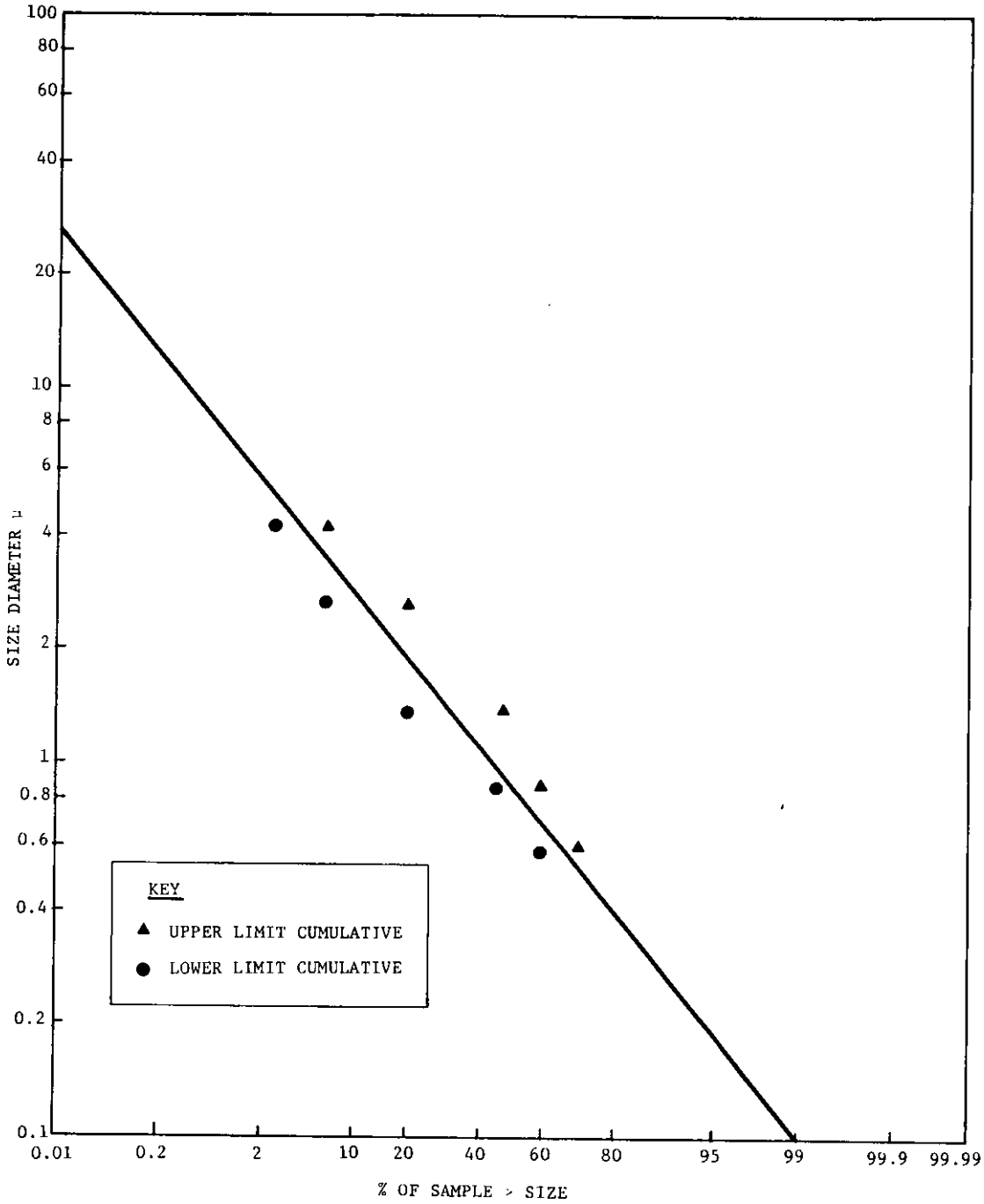

FIGURE 20
LOG NORMAL PLOT OF SIZE RANGES 8 THRU 13

$$f(D) = W_1 f_L(D) + W_2 f_u(D)$$

$$= \frac{W_1}{D\ 2\pi\ \ln\sigma_1} \exp - \left(\frac{\ln^2(D/\mu_1)}{2\ \ln\sigma_1} \right) \qquad (28)$$

$$+ \frac{W_2}{D\ 2\pi\ \ln\sigma_2} \exp - \left(\frac{\ln^2(D/\mu_2)}{2\ \ln\sigma_2} \right)$$

where it is assumed $f_L(D)$ is independent of $f_u(D)$

$f(D)$ = mass frequency distribution of bi-populate lognormal e

$f_1(D)$= mass frequency distribution lower lognormal curve

$f_u(D)$= mass frequency distribution of upper lognormal curves

D = diameter of range

W_1 = weight % of lognormal portion of bi-populate centered about .85 μ (46.6%)

W_2 = weight % of lognormal portion of bi-populate centered about .235 μ (53.4%)

μ_1 = mean of lower curve (.85 μ)

μ_2 = mean of upper curve (235 μ)

σ_1 = sigma of lower mode, 2.5

σ_2 = sigma of upper mode, 3.9

This distribution function would seem to give the best possible general description of the coke oven charging particulate emissions based on the collected data. However, it should be noted that this distribution is based on an average density of 1.2 gm/ml. Though the measured distribution fits the bi-populate lognormal form reasonably well, it is based on only five tests which cannot be considered the most ideal statistical example. Therefore, the bi-populate lognormal frequency distribution is not

presented as the absolute particle distribution, but rather as a simplified mathematical model to be used as a representation of coke oven charging particulate distribution.

Appendix E gives the particle distributions from Brink samplers for emission guide, boom, and leaking door tests. Due to the limited range of the Brink sampler, the data concerns only the lower lognormal portion of the bi-populate distribution and, hence, can only be compared against this portion of the curve. Furthermore, only Brink Test #4 can be used as a comparison because it was the only test performed at the emission points of the charging operation. Figure 21 is a plot of the cumulative weighted percent of Test 4. Assuming a lognormal distribution, a straight line drawn through the points produce a mean of about 1.2 μ and a sigma of 2.2. This is in good agreement with the calculated lower distribution of a mean ∿.85 μ and sigma ∿2.5. In addition, the Brink data are all based on an assumed density of .8 gm/ml and the Andersen data are based on 1.2 gm/ml. Equating the densities of both methods would tend to bring them into closer agreement.

The Coulter counter produced a volume mean of ∿27 μ. The sample was taken by scraping particulate matter off a 1/4" wire screen which had been exposed to the emission plume of the Wilputte stack.

Optical analyses were performed on portions of the samples removed from the cyclone and Andersen sampler. These samples were suspended in benzene when removed from the sampler and were later suspended in isopropyl alcohol just prior to sizing. The number mean diameter was found to be between 5.5 and 3 μm or around 30 μm mass mean diameter.

The sieve and sedegraph analyses were performed on particulate matter trapped in the case of the MITRE Carrousel Sampler (not on the collection slides of the sampler). The size distribution of these samples was found to be bi-populate. Seventy percent of the sample mass was greater than 43 μm (325 mesh by sieve) and 30 percent less than 3 μ with a mean of about 1.3 μ for the portion of the sample less than 3 μ. The sedegraph analysis was performed using water as the medium. This is in fair agreement with the

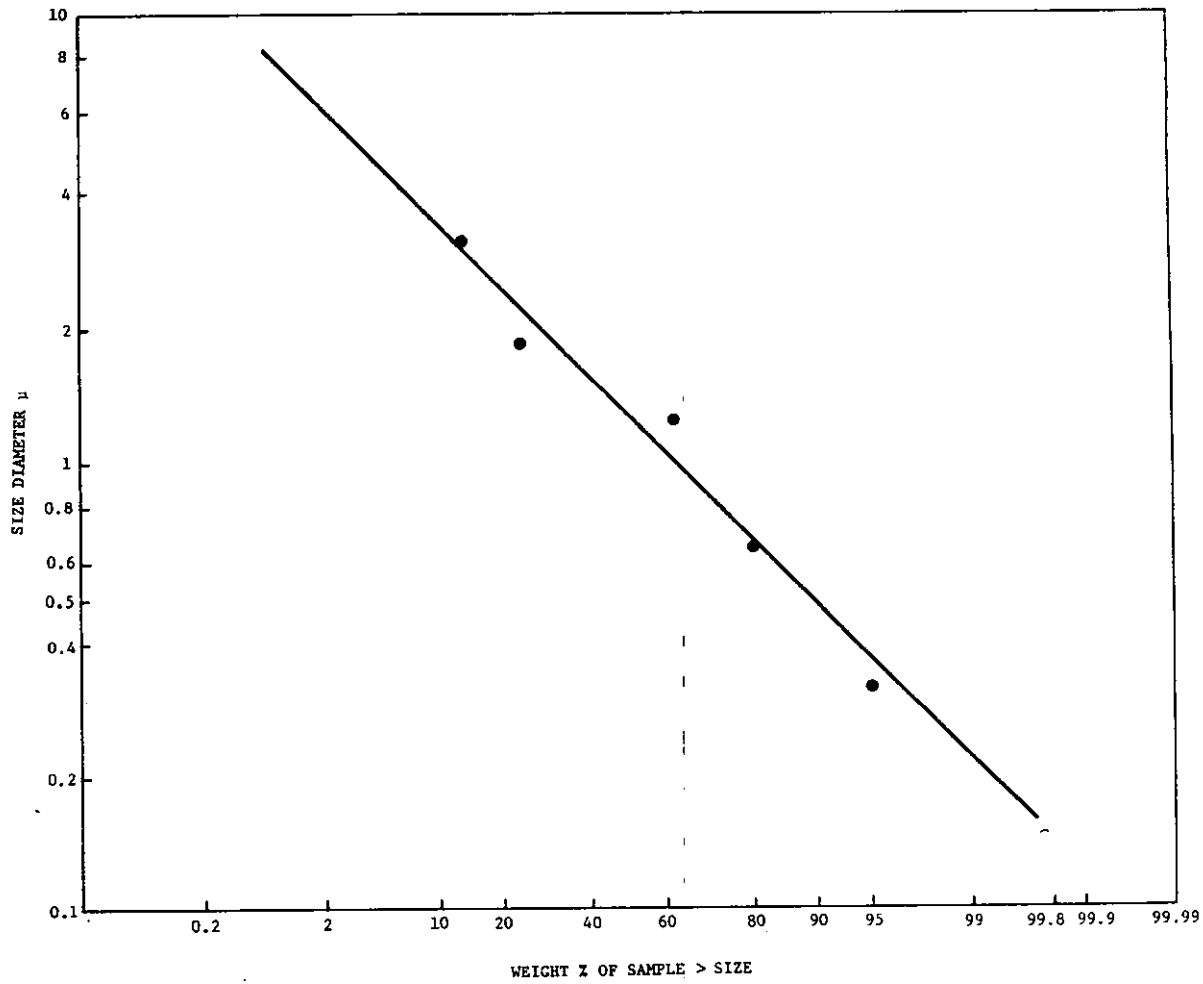

FIGURE 21
BRINK DATA

Andersen, Brink, and MITRE Carrousel analysis.

STATISTICAL EVALUATION OF SIZE DISTRIBUTION DATA

The arithmetic averages for the acceptable tests including anisokinetic and calculated isokinetic values are shown in Table 22. Chi-square (χ^2) tests were performed on both anisokinetic and theoretical isokinetic averages against the respective values for individual tests. As shown in the table, the theoretical isokinetic values produced equal or lower χ^2 values, hence, higher confidence levels. All χ^2 tests on the corrected data pass the goodness of fit test while only two of the anisokinetic tests pass the test. To pass the χ^2 test implies only that there is no reason to doubt the distribution fits by the hypothetical distribution.

The bi-populate lognormal distribution was determined from the values of the arithmetic average of all the corrected isokinetic values and passes the χ^2 goodness of fit test.* However, the data do suggest the distribution varies between guide and stack. The distributions from the emission guide tend to shift the mean of the lower mode toward a lower mean and higher standard deviation, while the stacks tend to the other extreme. Though these differences were noted, there was statistically insufficient data to produce separate distribution for the guides and stacks. Therefore, the bi-populate distribution previously described was used to approximate particulate emissions in all cases.

COMPARISON OF PARTICULATE EMISSIONS FROM WILPUTTE AND AISI/EPA CAR

A number of analyses were performed on the particulate mass samples. The primary analyses (for mass emitted) was performed on all samples and corrections (Equation 16) for errors due to anisokinetic sampling were applied. Secondary investigations include analyses for:

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* Herdan, G. H., Smith, M. L., Hardwick, W. H., Conner, P. Small Particle Statistics. London, Butterworths, 1960. p. 122-125

TABLE 22

SIZE RANGE

Assigned Range Numbers	1	2	3	4	5	6	7	8	9	10	11	12	13
Range Mean Part. Diam.	Filt.	.58	.88	1.39	2.63	4.31	6.41	9.43	14.79	45	112	275	700
Average Anisokinetic Distribution*	14.65	4.57	7.12	14.2	6.73	2.1	1.29	1.89	5.13	3.53	11.8	17.0	11.34
Average Calculated Isokinetic Distribution**	14.7	4.3	6.2	12.4	5.9	1.9	1.2	1.7	4.5	3.3	11	18.7	14.1
Bipopulate Lognormal Approximation at Mean Upper=235μ, σ_U=3.9, Mean Lower=.85, σ_L=2.5	12.58	8.39	8.85	8.85	5.22	1.93	.84	.73	2.74	6.62	12.28	13.99	16.92

Test	Chi-Square Test For***	
	Average Anisokinetic	Average Isokinetic
07	17.12	11.04
08	29.52	20.80
10	23.69	16.37
11	21.16	12.96
23	11.25	11.31
Bipopulate Lognormal	---	---

* Actual particulate sampling was conducted at a constant sampling velocity independent of variations in stack velocity.

** Theoretical corrections were applied based on instantaneous emission velocity measurements to yield a calculated isokinetic distribution

*** For 12 degrees of freedom if χ^2 is larger than 21.03 the probability becomes significant that the test does not fit the distribution.

% tar content

benzpyrene content

density

elemental

The major objectives of the secondary analysis were to develop baseline data on coke oven emissions with emphasis on the detection of potentially hazardous substances such as carcinogens and heavy metals, and an assessment of the state of the art in techniques for making such measurements and determinations. This analysis is necessary in any assessment of the importance and potential effects of coke oven emissions. These analyses were performed on only a portion of the total number of samples.

MASS EMISSIONS

The average calculated isokinetic mass emitted by the Wilputte car was 814.7 gm per charge, while the like value for the AISI/EPA car was 120 gm per charge. This is a reduction of about 85.2% from Wilputte to AISI/EPA emissions. These calculated isokinetic mass values were obtained by applying a theoretical correction process to the anisokinetic data.

All particulate samples were collected under anisokinetic conditions. Tables 23 and 24 present this particulate emissions data for the Wilputte and AISI/EPA car, respectively. The values in these tables were calculated by the following equation which assumes isokinetic conditions:

$$EM_i = \frac{A_i}{U_i} M_i \qquad (29)$$

where EM_i = total mass emitted at location I during the charge,

A_i = area of measurement duct,

U_i = area of sampling nozzle,

M_i = mass of sample collected at location I.

The tables show the average mass emission assuming isokinetic conditions to be 808.9 gm/charge for the Wilputte car and 245.5 gm/charge for the AISI/EPA car. These results are incorrect, however, since isokinetic conditions did not exist.

TABLE 23

ANISOKINETIC MASS EMISSIONS

WILPUTTE

TEST NO.		STACK 1	STACK 2	STACK 3	GUIDE 1	GUIDE 2	GUIDE 3	TOTAL
2						36.8	38.3	
5			250.6			28.7		
6				134.5			26.2	
7		201.5	182.0	132.4				
8		144.7	123.6	269.3				
9		42.0	294.2	355.3				
10					41.7	67.9	50.6	
11					37.6	34.0	48.7	
23			257.3					
8A		65.0	82.4	975.9				
Average		113.3	198.4	374.7	39.65	41.9	40.9	808.9

TABLE 24

ANISOKINETIC MASS EMISSIONS

AISI/EPA

TEST NO.		STACK 1	STACK 2	STACK 3	GUIDE 1	GUIDE 2	GUIDE 3	TOTAL
19		N/A*	N/A*	N/A*	30.8	108.1		
20						49.7	138.7	
21					9.52	62.6	2652.5**	
24					3.3	12.2	206.9	
Average					14.54	58.15	172.8	245.5

* The AISI/EPA car does not have coking stacks, and as a result these columns are not applicable

** Test 21 not included in average

A theoretical approximation of isokinetic mass values may, however, be obtained by applying Equation 16 to the anisokinetic data. Tables 25 and 26 present the calculated isokinetic values of mass emitted for the AISI/EPA and Wilputte cars, respectively, and from the basis for the 85.2% reduction figure.

A failure of the number 3 drop sleeve to seal during Test 21 may have been caused by a cocked emission guide. However, detection and hence, resealing of the drop sleeve was prevented by the emission guide. Therefore, Location 3 on Test 21 for the AISI/EPA car was omitted from all the average mass emission calculation. The magnitude of the mass, measured at 21-3, is another indication that it is not representative of a normal charge. It is almost two orders of magnitude higher than the next largest mass value for the AISI/EPA car.

Out of the 10 tests performed on the AISI/EPA car, no charge other than Test 21 demonstrated emissions of this magnitude.

The accuracy of the calculated isokinetic values in Tables 25 and 26 is difficult to assess. However, a comparison of the anisokinetic mass value to the calculated isokinetic values can be used to give an evaluation of the relative errors induced by anisokinetic sampling. It can be assumed that if the calculated value is close to the measured value, the error is minimized and the mass is representative of the emissions. As the difference between the calculated mass and measured mass increases, the values become less reliable. But they are still quite useful, for the difference between the values is a measure of the direction and magnitude of the error due to anisokinetic sampling. For example, in Test 10, Guide 1, the anisokinetic value was 41.7 gm; the isokinetic value was 42.9 gm; the masses are very close. One might, therefore, assume sampling was near isokinetic and if the sampling velocity (193.4/min) and the average stack velocity (204.3 ft/min) are considered, it is obvious conditions are near isokinetic.

TABLE 25

CALCULATED ISOKINETIC MASS

MASS IN GRAMS FOR WILPUTTE CAR

TEST NO.		STACK 1	STACK 2	STACK 3	GUIDE 1	GUIDE 2	GUIDE 3	TOTAL
2						19.0	30.1	
5			410.6			28.4		
6				221.9			29.3	
7		117.8	125.8	94.1				
8		132.7	77.4	182.0				
9		20.2	234.3	213.6				
10					42.9	71.2	56.9	
11					48.4	42.0	58.0	
23			141.9					
8A		35.9	52.5	1028.2				
Average		76.65	173.62	434.95	45.65	40.15	43.58	814.7

TABLE 26

CALCULATED ISOKINETIC MASS

MASS IN GRAMS AISI/EPA LARRY CAR

TEST NO.		STACK 1	STACK 2	STACK 3	GUIDE 1	GUIDE 2	GUIDE 3	TOTAL
19		N/A*	N/A*	N/A*	14.38	50.92	-----	
20					-----	23.20	74.26	
21					8.3	45.1	1736.78**	
24					1.3	5.68	86.78	
Average					8.0	31.5	80.5	120.0

* The AISI/EPA car does not have coking stacks, and as a result these columns are not applicable

** Test 21 not included in average

Conversely, there is a large difference between sampling velocity (470.5 ft/min) and stack velocity (209.9 ft/min) for Test 7, Stack 1. As expected, there is a large difference between the mass values (~41.6%).

If this rationale is extended by comparing the anisokinetic and isokinetic values for average mass/charge, the Wilputte anisokinetic and isokinetic averages differ by less than 1%, while the AISI/EPA values differ by about 50%. This would imply the Wilputte data offers a somewhat higher confidence level than the AISI/EPA.

However, the 50% difference found with the AISI/EPA data is still relatively good, considering the sampling problems encountered with coke oven charging emission monitoring. The data indicates the constant sampling velocity method employed at the coke oven is more precise than originally expected.

SUPPLEMENTARY ANALYSES

Supplemental analysis was performed on particulate material collected from coke oven emission streams as well as prepared coal prior to oven charging. The intent was to establish the quality and quantity of trace constituents in the material and access the technique for these determinations. The body of data presented below represents the results of this analysis. The difficulties or limitations applicable to each area are discussed.

Tar roughly defined as the particle fraction soluable in benzene was found to be a major constituent of the collected material. The average tar concentration for a particulate sample was 57.1%. No separation was made between the Wilputte and AISI/EPA emissions due to the small number of samples analyzed for tar.

Tar analysis was performed on 20 samples which were primarily Andersen catches. In most cases, the analysis was done on the entire sample collected excluding impinger catches. However, a few samples were separated into parts (i.e., in Test 21-3). The Andersen plates were done separately from probe tip and the Andersen front. Table 27 lists the test number and % Tar as measured in the entire sample.

TABLE 27

TAR CONCENTRATIONS

Test Number	Location	Tar Percentage
7	1	29.2
8	2	56.1
8A	3	25.9
9	1	75.0
10	6	86.2
11	4	42.1
19	1	64.8
21	3	54.5
Average		57.1

Polycyclic organic matter present in coke oven emissions will be found chiefly in the particulate fraction which has been defined as tar. Several of the more widely accepted carcinogens are species of benzpyrene. In order to establish and characterize the presence of this general group, Benzpyrene Analysis was performed on the tar portion of a group of samples. These tests indicate that benzpyrene is present in amounts ranging from 18,000 ppm to less than 260 ppm. (1ppm equivalent to 1 μ gram benzpyrene/gram of tar).

Sample sizes and lack of available analytical techniques precluded a more detailed examination of these samples. The data obtained is presented in Table 28 and gives the benzpyrene content for samples analyzed prior to and including the filter. A few analyses were performed on the impinger catches and are presented in Appendix B, but all measurements of impinger tests were below the detectable limits. The maximum concentration was 18,000 ppm found on the Andersen plates of Test 21-3. The Andersen front and probe tip also produced measurable values. The results indicate the general presence in the emissions of a species containing widely accepted carcinogenic substances in relatively heavy concentrations. Further conclusions are impossible because of the limited data.

An elemental analysis was undertaken to identify the trace constituents of the coal charged and the resulting emissions. The intended emphasis was the identification and quantification of hazardous elements, particularly heavy metals. The emissions analysis was performed on particulate sizing equipment catches, and was thus limited by the sample size, as well as available analytic techniques. These limitations resulted in a large number of instances where constituent concentrations, if they did exist, were below detectable limits. The emission constituent concentrations which were successfully measured and are reported in Table 29 are consistent with the constituents identified in the elemental analysis of the charging coal. The sample numbers can be cross-referenced with Table 30 to determine the portion of the sample that was analyzed.

TABLE 28

BENZPYRENE ANALYSIS

Test Number	Location	Sample Number	Description	Total Benzpyrene (μg)	Benzpyrene Concentration* (ppm)
7	1	1045	Andersen Front Probe Tip	30	510
8	2	1060	Andersen Front Probe Tip	70	1,000
8A	3	1066	Andersen Plates	100	560
8A	3	1067	Andersen Front	B.D.L.	<260
9	1	1095	Andersen Front Probe Tip	B.D.L.	<630
10	6	1102	Andersen Front Probe Tip	30	560
10	4	1105	Probe Tip Cyclone	B.D.L.	<1,300
11	4	1111	Probe Tip Cyclone	B.D.L.	<1,000
11	5	1114	Andersen Front Probe Tip	B.D.L.	<590
19	1	1208	Probe Tip Filter	B.D.L.	<980
20	2	1213	Andersen Plates	B.D.L.	<1,400
21	3	1222	Andersen Plates	22,000	18,000
21	3	1223	Andersen Front	520	3,000
21	3	1229	Andersen Back	B.D.L.	<610
23	2	1241	Andersen Plates	220	1,700

* μg of Benzpyrene/gram of Tar

TABLE 29
ELEMENTAL ANALYSES AND SUPPORTING COAL ANALYSES

AISI/EPA DATA

Test Number	Sample Number	Al %	Ba ppm	Be ppm	Ca ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	Fe %	Ga ppm	Ge ppm	Hg ppm	K %	Mg ppm	Mn ppm	Mo ppm	Na ppm	Ni ppm	Pb ppm	Sb ppm	Se ppm	Sn ppm	Sr ppm	Ti ppm	Te ppm	V ppm	Zn ppm
19-1	1208		5.1%	<.96		<11		.12%	90							140			770	250		<680	<710				<480	
20-2	1213		<.17%	<.83		110		750	750				83			410			.15%	.39%		<520	<560				<370	3.3%
21-3	1222		<380	<.16		<1.9		15	<6.9				.27			<2.8			11	35		<210	<84				<36	19
	1223		<290	.42		260		160	80				3.4			26			110	.37%		<160	<63				<28	.11%
	1224		<670	<.40		25		180	.31%				80			97			270	330		<260	<280				<190	.22%
	1229		11%	<2.4		200		170	180				61			170			.18%	.59%		<3300	<.13%				<540	
	1230		<.95%	<4.2		28		860	.57%				28			260			1.30%	<830		<2900	<.31%				<2100	.19%

WILPUTTE DATA

Test Number	Sample Number	Al %	Ba ppm	Be ppm	Ca ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	Fe %	Ga ppm	Ge ppm	Hg ppm	K %	Mg ppm	Mn ppm	Mo ppm	Na ppm	Ni ppm	Pb ppm	Sb ppm	Se ppm	Sn ppm	Sr ppm	Ti ppm	Te ppm	V ppm	Zn ppm
7-1	1045	2.27	4.1%	<7.4	.65	<9.4	<59	.14%	280	.84	<360	<110	46	1.1	690	340	<360	2.5%	.12%	140	<540	<180	<.18%	400	540	<74	<74	1.1%
8-2	1060	0.39	4.7%	<8.8	1.14	<12	<73	.11%	110	.51	<460	<180	96	.8	480	96	<460	.8%	.10%	6.4	<680	<230	<.22%	560	390	<88	<88	.64%
8A-3	1067	1.06	<1.7%	<3.5	.75	<4.7	<28	.11%	50	.87	<180	<69	12	.35	.38%	69	<180	1.57%	880	27	<260	<88	<880	31	820	<35	<35	940
-3	1066	.54	<0.3%	<6	<60	<7.8	<48	36	<18	.22	<300	<120	20	.06	30	36	<300	<300	61	<24	<450	<130	<.15%	<30	392	<60	<60	30.0
9-1	1095	3.74	15%	<31	1.56	<40	<240	430	130	.36	<.15%	<610	59	4.0	31%	190	<.15%	9.5%	500	500	<.23%	<780	<.78%	.17%	950	<310	<310	3.3%
10-6	1102	1.73	11%	<19	1.16	<25	<150	.13%	62	.96	<990	<400	150	1.6	.13%	250	990	3.2%	.10%	190	.19%	<490	<.49%	640	590	<190	<190	1.3%
-4	1105		<.32%	<.14		45		16%	730				19			300			.17	490		<970	<.10%				<700	1.5%
11-5	1114	280	15%	<29	1.40	<38	<230	.29%	120	1.64	<.15%	<590	36		480	450	.15%	4.8%	.21%		<.22%	<740	<.74%	480	880	290	<290	1.9%
-4	1111		4.5%	<.86		270		.29%	390							1106			.88%	3.40		<560	580				<390	.86%
23-2	1241		.41%	.35		16		2.0	380				13			41			350	410		<350	<130				<57	

COAL ANALYSES

Test Number	Sample Number	Al %	Ba ppm	Be ppm	Ca ppm	Cd ppm	Co ppm	Cr ppm	Cu ppm	Fe %	Ga ppm	Ge ppm	Hg ppm	K %	Mg ppm	Mn ppm	Mo ppm	Na ppm	Ni ppm	Pb ppm	Sb ppm	Se ppm	Sn ppm	Sr ppm	Ti ppm	Te ppm	V ppm	Zn ppm
8A (W8)		1.06	<362	1.1	<99	<1.9	<79	49	9.2	.50	<490	<200	<.06	.12%	180	9.2	<490	<490	66	<32	<740	<250	<81	<49	890	<99	<36	11
10 (W10)		.94	<320	<.14	240	<1.7	<56	42	<5.8	.49	<350	<140	.24	.09%	210	6.6	<350	<350	12	<28	<520	<210 <170 <180	<71	<35	690	<69	<32	8.4
23 (W12)			<360	<.16		<1.9		65	8				.27			3.8			57	44		<210	<80				<36	16
24 (K4)			<360	.54		<1.9		47	<6.7				.54			12			20	<32		<210	<82				<36	8.6

TABLE 30

COAL ANALYSIS (ULTIMATE AND PROXIMATE)

Test	As Received				Dry			
	8A	10	23	24	8A	10	23	24
% Carbon	72.94	73.23	73.89	72.91	78.28	79.01	78.16	77.77
% Hydrogen	5.34	5.29	5.13	5.11	4.92	4.83	4.78	4.71
% Nitrogen	1.16	1.13	1.27	1.35	1.25	1.22	1.34	1.44
% Sulfur	1.12	1.13	1.13	1.27	1.20	1.22	1.19	1.35
% Ash	6.90	6.56	7.36	7.40	7.40	7.08	7.78	7.89
% Oxygen	12.54	12.66	11.22	11.96	6.95	6.64	6.75	6.84
% Moisture	6.82	7.32	5.46	6.25	--	--	--	--
% Volatile Matter	30.34	30.50	31.90	30.59	32.56	32.91	33.74	32.63
% Fixed Carbon	55.94	55.62	55.28	55.76	60.04	60.01	58.48	59.48
(BTU/lb) Heat of Combustion	13.142	13.121	13.140	13.162	14.103	14.157	13.905	14.039

Some of the more important elements identified in detectable concentrations in the emitted particulate material were Cu, Fe, Pb, and Zn. Due to the variances in particulate sample sizes, it is not possible to make a generalized statement concerning constituent concentrations in the emissions. It should be pointed out, however, that no constituent concentrations in excess of what can be reasonably explained by coal constituents also reported in Table 29, was identified in the particulate material. In order to obtain more definitive information on particulate constituents, much larger samples distributed as a function of particle size must be obtained and analyzed. The particle size information is important in assessing the results, since this property will determine whether the particles fall or settle out quickly (i.e., particles >200 μ), or behave similar to a gas in the atmosphere (i.e., <3 μ).

Further coal analysis was performed as support for the particulate analysis. Table 30 reports the ultimate and proximate analyses of the coal as received and dry. The size analysis is listed in Appendix B. One hundred percent of all four samples passed the 1" round sieve size and always less than 6% of the sample passed the number 200 square sieve size. The average size was between square #8 and square #30 sieve size.

The density of the particulate matter was investigated at the MITRE lab where float tests indicated the specific gravity of the solid portion of the sample ranged between 1.6 and .9 relative to water. Generally, better than 50% of the solid particles were greater than 1.3. The tar portion of the sample was assumed to have a specific gravity similar to that of coal tar between 1 and .85. To simplify calculations using density throughout this document, 1.2 g/ml was used as the approximate density. This is probably on the high side of the average. However, there was not enough data concerning the density of the tar portion of the sample to justify any other value.

As a part of the supporting analyses, a sample of the collected particulate was provided by EPA to the Columbus Laboratories of Battelle. The sample consisted of a number of black granules, and a loaded 5 cm

diameter filter. Several of the granules were placed in a probe tube and inserted into the MS9 mass spectrometer. Eight high-resolution mass spectra were obtained starting at 60°C and terminating at 350°C. The spectra were dominated by hydrocarbon fragments and a strong phthalate ester peak at mass 149.024. This latter peak was thought to be attributable to a contaminant from the plastic bottle top of the container.

No evidence of carcinogens was found in this analysis. However, ions with mass 228.094 ($C_{18}H_{12}$) and 252.094 ($C_{20}H_{12}$) were detected. These peaks correspond to the molecular ions for benzphenanthrenes and benz-(α)pyrene, or their structural isomers. It is, of course, impossible to determine from high resolution spectra whether the carcinogens are actually present or whether the peaks are due to their noncarcinogenic isomers. Detailed chromatographic studies would be required to confirm the presence or absence of the carcinogenic PNA's. Unfortunately, extraction of the few remaining black granules with methylene chloride yielded insufficient soluble material to permit gas chromatographic-mass spectrometric analysis.

The sample filter was Soxhlet extracted with methylene chloride for 30 hours, and the extract concentrated to approximately 0.25 ml. A portion of this extract was injected into a MS9 probe sample tube, and the sample was thermally volatilized. Six high resolution mass spectra were obtained, starting at a probe temperature of 60°C and terminating at 300°C. Despite repetition of these high resolution runs, the exceedingly complex mixture and high number of compounds present precluded detection of the most important reference calibration peaks. Consequently, no useful high resolution data was obtained from this sample.

The filter extract was subsequently subjected to gas chromatographic-mass spectrometric analysis, using both OV-17 and Dexil 300 columns, in an attempt to detect OSHA carcinogens and carcinogenic polynuclear aromatic hydrocarbons, respectively. The total mass chromatogram, obtained using OV-17 (150 to 280°, programmed at 6° min^{-1}), exhibits a large number of quite well resolved peaks. In only one instance was there a possibility of the presence of a carcinogen, benzidine. Three

lower polynuclear hydrocarbon, anthracene, pyrene, and fluoranthene, were readily identified from their mass spectra and chromatographic data.

In order to examine the possibility of the loaded filter extract containing known polynuclear aromatic hydrocarbon carcinogens, gas chromatographic-chemical ionization mass spectrometry was carried out using a 10-foot 2-1/2 percent Dexil 300 at 260°C, programmed at 1°C min^{-1} to 300°C. The combination of mass spectra and chromatographic data clearly indicated the presence of benz(c) phenanthrene (potent carcinogen), benz(a) anthracene (carcinogen), a benzfluoranthene isomer (possible carcinogen), a benzfluoranthrene isomer (possible carcinogen), benz(a)pyrene (potent carcinogen) and/or benz(e) pyrene, and cholanthrene (carcinogen).

OPTICAL SYSTEM PROGRAM RESULTS

The primary objective of the optical measurement program is to determine the feasibility of a compliance monitoring system for charging emissions based on the technique of plume optical transmittance measurements. This assessment of feasibility is logically divided into three areas; technical feasibility, implementation feasibility, and operational feasibility. The technical feasibility of the optical system concerns the demonstrated ability to measure plume transmittance with conventional light sources and photographic recording techniques. The basic measurement concept has been established under laboratory conditions by several other investigators. MITRE's optical measurement program extended this work to establishment of feasibility under field conditions for polidisperse emission plumes with high dynamic characteristics. The second area, implementation feasibility, concerns the availability and practicality of equipment and materials needed to implement and operate the system in the environment of an operational coke oven. The feasibility of this approach for other extended emission sources should be investigated independently, however, the coke oven environment is sufficiently severe and demanding so as to provide a basis for a valid implementation feasibility test. The last area, operational feasibility, concerns the cost of fabricating, installing and operating a number of such systems on typical coke ovens, where operating costs cover the upkeep and maintenance of the equipment, as well as the cost of film densitometry and data analysis. Other factors to be included in a feasibility assessment are the accuracy and dependability of the system, how information from this system might be used in a compliance system, and what equipment configurations might be applicable for such a system.

Technical Feasibility

In order to provide a theoretical background for the proposed measurement, the basic theory of particle and light interaction had to be shown to be compatible with the expected polydisperse characteristics of the coke oven emissions. Such a compatibility can be shown mathematically and was developed in the preliminary optical system report, MTR-6546. In

addition to the basic transmission measurement theory, a theoretical technique for the detection of non-source light interference (plume air-light) was developed and explained. The theory showed how the system could be self-compensating for long term variations in light source conditions and ambient lighting conditions.

The objective of most optically oriented systems has been to estimate mass loading value by dealing with a known volume of intervening space between light source and detector. The intent of this system is to estimate total mass emitted. With such an intent, the geometry of the system is relaxed and variability in size of the emission plume is diminished in importance. The theory of this system has been to estimate the mass in a cross-sectional area in the path of the light source. In order to produce an estimation of total mass emitted, a measurement of the vertical rise speed of the plume must be made. The mass rate indicated on a single photographic frame multiplied by the rise velocity was shown theoretically to be a reasonable estimation of total mass emitted over time. The characteristics of plume dynamics for the charging cycle were studied and reasonableness of plume consistency over a period of a few seconds established. In addition, it was found that a characteristic velocity for plume rise rather than a continuously measured value did not seriously affect the validity of the measurement system.

A study of photographic material characteristics was conducted to establish the availability of a suitable film for the proposed measurements. The study showed that the material having the widest exposure range and longest linear portion of the exposure curve was one of the most common photographic films. This fact simplified the selection of film for use in this system. The choice of film was then considered in the determination of the required intensity for the system light source. This investigation showed that there were several common light sources available which could produce the required intensity.

A limitation basic to the proposed system configuration was the probable undependability of mass calculations in situations where the transmission fell below 10%. This is because in such a situation, multiple scattering

has an increased likelihood of occurrence. A lower limiting value for transmittance was selected after consideration of the distance between the light source and detection, the acceptance angle of the detector, and the expected nature of the emissions. Based on this limitation, the system will calculate a maximum mass value for the point corresponding to the lower limit and indicate that the calculated value is $\geq$ the actual mass rate.

It is now felt at the conclusion of our test period that all theoretical aspects of the system have proved to be feasible within the constraints expressed at the outset of the project. Some questions have arisen stemming from the highly variable nature both in size and composition of the particulate as to the ability of developing average characteristics. However, such a limitation would have equal impact on other mass measurement approaches and is not considered a detriment unique to this optical system concept.

Implementation Feasibility

During the selection, fabrication, and assembly of system components, one criteria which was stressed was off-the-shelf availability. The major components of this system meet this criteria. The selection of components also considered the adaptability of components to other locations or environments. This objective was accomplished to a lesser degree.

The test system utilized a standard sequence camera which was modified to provide a secondary exposure of a digital clock. This system proved to be a virtually trouble free recording device. Although the camera was not run in an unattended mode, its performance was such that the feasibility of unattended operation was established to a great extent. All tests performed on the camera to establish its reliability yielded positive results. Specifically, the test for accuracy and repeatability of shutter timing shows a repeatability of better than ±4% of the marked values at 1/1000 and 1/50 second speeds. On continuous runs of 12 and 24 hours at one frame per second exposure rate, no malfunctions occurred in the camera system. Modification which might be desirable to increase

the film capacity of the camera should not affect the basic reliability and operability of the unit.

For extended periods of operation (one month) camera equipment would require a minimum of a "dust proof" housing with a suitable transparent window which can be cleaned regularly without optical damage. Such an enclosure could be constructed using a NEMA water tight box with a hard plate glass window installed. A cleaning and maintenance routine similar to those used for pen-type pressure and temperature recording instruments in use in the oven environment should be sufficient for reliable operation.

The camera was operated using an AC power supply during the field test period. The basic camera, however, was designed to operate from a 12 volt DC power source, such as a battery. The camera was tested in the laboratory using a 12 volt battery and found to operate in essentially the same manner with no detectable degradation in performance. Such a capability provides operational flexibility needed in situations where temporary operation in a remote or difficult to reach location is required.

Additional details of tests performed on the camera system can be found in Appendix C of this report.

The camera control used in the test configuration was somewhat more complex than would be required for an operational system. This complexity was the result of control flexibility needed in performing the tests. The test, however, demonstrated the feasibility of the control concept. Specifically, a control circuit based on a clock locked to the AC line provides a satisfactory time base for the system. This clock consists of integrated circuit counting modules which drive both the digital display recorded on each film frame and exposure control. A fixed exposure rate (one frame per one or five seconds) would be wired into the system.

During the test period, occasional electrical noise would cause the clock counter to advance. The environment of the coke oven contains much high power electrical equipment which can generate electrical spikes on the

AC power line. For this reason, additional attention should be given to the power supply of the control unit to eliminate this interference. This problem is not, however, considered serious and should be relatively easy to solve.

The camera control unit is designed to operate from either 110 volt AC commercial power or 12 volt DC power. In the DC operational mode, the camera exposure rate is continuously adjustable using an RC circuit. The digital display then becomes a counter operating on the frequency of the exposure pulse. Should a realtime clock display be desired on DC operation, a time standard oscillator operating at radio frequency must be added. Such an oscillator would provide a standard with accuracy of better than ±5 seconds in 24 hours. All other functions of the control remain the same.

The system light source is the one component which must be considered "custom made" for the specific observation site. The unit fabricated for this test utilized all off-the-shelf electrical lighting components with the exception of the reflector surface. The intent of the special reflector was to obtain maximum apparent source width with uniform light output across this width. The parabolic reflector proved to be very efficient in the achievement of this objective. Densitometry traces across the width of test frames showed excellent uniformity. It was originally expected that a 10 inch width might be required to provide for densitometry alignment error. Experience has shown, however, that the densitometry trace can accurately follow an image of a source having a width of less than 200 μ. For this reason, it is felt that the special reflector could be replaced by 4 or 5 parallel fluorescent tubes, each having a diameter of 1-1/2 inches.

The stroboscopic effect of fluorescent tubes was discussed in the document containing initial design considerations. It was decided that the simplest method to eliminate this problem was to use a shutter speed that would capture one complete cycle of light source supply current. Test exposures using this method showed minimal variation in image density less than ±5% exposure change for the overall system. It is felt, however,

that this might be improved by using a DC supply voltage for the fluorescent tubes. Discussions with tube manufacturers indicate that such operation is possible and can be implemented with few changes. These consist primarily of isolating a filament supply source and provision for periodic polarity reversal to prevent breakdown of the tube through the plating effects present in DC operation. It should also be noted that the light output of the unit would be increased for a given supply voltage and any shutter speed could then be used without stroboscopic related problems.

The system light source is physically the largest system component. In addition to this fact, its configuration is affected more by the physical details of the observation site than any other unit. The light source for the test system was designed and fabricated to provide maximum flexibility both at the test location and for possible reuse at some other site. Even with this in mind, major structural components would probably require considerable modification for reuse. It is difficult to imagine a suitable "portable" unit which would be designed for quick assembly and disassembly. It is expected, therefore, that each site to be observed would require a unit designed for that location and permanently installed on suitable support structures.

All other details of the light source configuration are considered feasible and desirable and would be recommended for inclusion in specifications for new units.

The environment of a coke oven is quite severe on all types of equipment. The pervasive heat, corrosive gases, and dust/grit, act upon all equipment in the area. It was necessary to select or develop system components which could function continuously in this environment. During the course of the tests, no significant problems were encountered in maintaining the various system components selected for system implementation. The system light source was left in place and is still operating as a lighting facility for the P4 battery.

The densitometry analysis of film from this system was the area where the most difficulty in performance was encountered. It is well within the capability of standard densitometers to measure density with the required accuracy for small image areas. There are also many machines which produce a computer compatible magnetic tape output. The primary difficulty with such machines is that they are not normally used to selectively scan a small portion of the image area, but rather to scan the complete area and allow computer processing to locate and reconstruct the area of interest. Although such an approach might be applicable to our system data, it was decided that the necessary computer programming for image recognition was excessive in terms of the desired test results. A rather specialized machine with the ability to provide usual image alignment, selectability of small scanning areas and computer compatible magnetic tape output was selected for film analysis. The resolution, accuracy, and stability of the machine were somewhat greater than would be required for our analysis. As a result of its unique features and versatility, the machine availability was less than desirable and the operational cost higher than expected. Film analysis using this machine and associated operational practices is not considered to be feasible for any large scale operation of the system.

Film processing and calibration is an important phase of system operations. Although the actual processing of the film is not complex, very few service facilities were found which would guarantee the control necessary in the processing operation. This is explained by the fact that such control is not normally necessary in processing for standard image photography and the amount of processing which we projected for the conduct of the test was not sufficient to persuade a supplier to change his operations to accommodate our needs. It was determined, however, that the facility providing densitometry analysis could provide the required processing on a custom basis. They were also equipped to provide the sensitometric exposure calibration. It was decided that total film analysis service at one location was more desirable than a possible reduction in film processing costs.

Although not feasible for large scale implementation under the cost structure applied during this test period, the basic processing techniques are considered feasible. It is reasonable to assume that given some amount of assured business, a service organization would be willing to establish a facility where the required processing could be done on a routine basis.

Operational Feasibility

The operational feasibility of this system for coke oven monitoring is difficult to assess for two reasons. First, the standards for emission compliance are not accurately defined or generally expressed in direct quantitative terms. Second, there are few, if any, alternative systems against which to compare the technique on a cost and operability basis.

The camera equipment required for such a system is available as an off-the-shelf item. The cost of this type of equipment ranges from $1500 to $8000 per unit. The primary difference in the various units is the level of versatility and ruggedness. The less expensive units provide acceptable performance and are suggested for system implementation. Since it is feasible to use one type of camera for a wide variety of site configurations, the modification required to place the secondary exposure of the digital clock display on the frame might be offered as a standard option on that type. The cost and availability of the equipment discussed above is considered reasonable and feasible for such a system.

The camera control system was a custom designed unit but could be greatly simplified when a routine is established for system operation. Reliability of the system is such that no change in the basic components is necessary. An improvement in line noise interference is needed but this should not affect the complexity, reliability or cost of the unit. It is estimated that a control suitable for system operation could be constructed in quantities of 10 or more for under $300. Because of the limited quantity, they would be produced by a custom or small run fabrication facility. The basic concept and design is considered practical and feasible for

system application with a per-unit cost of up to $500. If the cost should exceed this figure, it might be advisable to utilize a commercially available digital clock and display and an electromechanical exposure control.

The physical arrangement of the light source for the system is highly dependent on the characteristics of the monitoring site. The support structure for the source must be designed to allow normal operation of the coking plant. This involves minimization of interference to the oven top so as to provide the access necessary in the maintenance and operation of the battery. The structure must span the battery and extend over each end by several feet. The side sections must extend downward as close as possible to the oven surface. The support structure can be expected to represent at least half of the total light source cost.

The test activity showed that fluorescent lamps of the "very high output" type provide suitable light sources for this system. Placing four such bulbs side by side should provide suitable source width and eliminate the need for the rear reflecting surface. If these lights are operated from an A.C. source, the required case, lens, electrical components and fabrication are estimated to cost $250 per 8 foot section. To operate these lamps on D.C. current would add approximately $50 per 8 foot section to the cost. The costs would be the same for the side or "wing" sections of the source.

In general, coke ovens runs 45 to 55 feet wide. The light source should be placed above the larry car height which runs between 15 and 20 feet. With these assumptions, the typical installation would consist of 10 to 12 eight foot light sections. The total cost including a supporting structure, is estimated at between $3500 and $6000.

The light source should require a minimum of maintenance which can be performed by regular plant electrical maintenance personnel. Assuming a continuing requirement for emission surveillance and compliance monitoring and the costs of continuous equipment or trained personnel for visual observation, the cost of the light source and supporting structure is considered economically feasible. This assessment also takes into

account the direct operating cost of electricity supplied to the unit.

Processing of the film from this system must now be accomplished on a "custom" basis. The processing cost currently runs 29 cents per foot of film processed. At approximately 750 frames of data per 100 foot of film, the processing cost would be approximately 3.9 cents per data frame. At an exposure rate of one frame per second for approximately 2.5 minutes needed to charge a coke oven, 150 frames of data would be taken. The processing cost per average charge observed would then be approximately $5.85.

If some volume of business could be guaranteed to a service organization, the cost could probably be reduced from 20% to 40%. However, the current cost of 3.9 cents per frame is not considered prohibitive for a system which would operate only during charges or during periods of high emission detected by some secondary system.

Densitometry analysis of the film output from the measurement system presents the greatest problem in current system operational feasibility. Because of the unique nature of the scanning requirement, the use of a highly flexible and sophisticated microdensitometer is required. As a result, the cost of analysis is high and the response time for this service is relatively slow because of the large demand for the instrument in question to perform other work. The standard rate set by the particulate supplier used in the test program is $30 per hour for the instrument and $16 per hour for the instrument operator. The machine must be set up for the particular scanning job which requires 15 to 30 minutes. This time is charged as operating time at the regular rate.

At these rates, the data frames scanned during the course of the tests cost between $10 per frame including all test frames, calibration, special uniformity checks and set up, or $15 per frame counting only test data frames scanned as production runs.

The use of a microdensitometer can only be considered feasible if the machine can be dedicated to this particular type of film analysis. This would allow the machine to be modified to facilitate quick and accurate

mounting of the system film size. It would also eliminate the "set up" operation since it is reasonable to assume that film from different observation sites would be very similar in terms of light source image size and density range. The utilization of such a machine would also lower the required skills of the operator. Since the machine could be made automatic once a scan is initiated, the operator would only be required to initially position the film in the machine and monitor the operation for obvious malfunctions. Output from the machine would be placed in computer compatible form on magnetic tape.

A machine capable of performing the required analysis is estimated to cost between $5,000 and $8,000. The machine could probably scan one complete frame of data in three to five minutes. If film was taken or analyzed at one frame every five seconds, the typical coke oven charging operation extending over three minutes would involve 36 frames. The optimal analysis time of the data frames would then be about two hours. To completely cover all oven charges on one battery during a typical eight hour shift (40 charges), the scanning time would be about 80 hours of machine time. Such coverage and analysis is not considered operationally feasible. Both time and money are considered to be excessive for such coverage. Should complete surveillance be considered necessary, a comparison would have to be made between this system and other systems with similar capabilities with particular emphasis placed on the data retrieval aspects of system operation.

If one hypothesizes the use of analysis by exception, the system analysis feasibility is greatly enhanced. As an example, if the camera is only activated during periods of excessive visable emissions, the amount of analysis required could be greatly reduced. The analysis load could be still further reduced if some specific number of film frames were to be established as a basis for non-compliance [i.e., visible emissions in three consecutive frames (15 second period) exceeding some set level]. Then analysis could be reduced to 20 to 30 minutes machine time for any charge during which violation is suspected.

The job of initial emission detection could be accomplished by several long path transmissometers crisscrossing the oven surface above the level of the larry car top. When one or more of these units detected some lower level of opacity, they would cause activation of the camera unit which in turn would take some predetermined number of data frames. This record could be correlated with over activities through the operation time logs.

Under the above assumptions, the use of a microdensitometer is considered feasible for use in data acquisition in the optical monitoring system.

Data processing of the densitometer output is a fairly straightforward task. The algorithm involves simple arithmetic and a relatively small amount of core memory is required to execute the program. The input to the program can be totally on tape and the output can be a single line giving the mass rate for a particular frame or a more detailed report displaying the quantities involved for each scanned point across the bar. During the course of the test data analysis, the latter option was chosen to allow a more detailed examination of the data and the results of the computations. Although helpful in gaining an understanding and confidence in system operation, the additional printed information is not necessary to the operational output of the system.

Computer compatible data (in a form which can be directly input to the computer) is feasible and indeed necessary to the efficient operation of any such system. The amount of raw data obtained from this system would be unmanageable in printed or strip chart form for any operational extension of the concept.

System Accuracy

Because of the multiple steps involved in system operation, opportunity for error is increased substantially over any single step measurement. In addition, some assumptions must be made to allow the application of this technique to a practical situation. The most important assumption is that the size of the emission particles can be accurately represented by some size distribution and that that distribution remains relatively

constant over the test period and to a lesser extent constant from one test to another.

Based on the information originally available on particulate sizing for coke oven emissions, a much larger particle size was anticipated. Under varying size distributions for larger particles, the effective light removal capabilities of a particle remain essentially constant at a value equal to about two times its cross-sectional area. For small particles, however, the effective light removal capability of a given particle varies between one and four as a function of particle material, wavelength of source light, and size of particle.

Coke oven emissions were found to be very dynamic in nature. The quantity of emissions varied widely over the total charging period, between source points in the charging system, and between the old and new charging cars. In addition, the visual characteristics of the emission varied widely from a puffy black smoke generally associated with visible flames around the car, to thick brown or mustard colored plumes which appeared to be the raw gases driven off the coal with little or no combustion taking place. Any investigation as to how each type of emission behaved in terms of optical system considerations was beyond the scope of this investigation. A further complication in the measurement process was the bi-populate nature of the particle size distribution. This fact negated the simple analysis of a single distribution and the establishment of a single mean diameter value to use in volume calculations.

In order to facilitate measurement calculations, the two distributions were considered separately. Through analysis of the particulate material, it was determined that the larger particles were made up primarily of carbon or coal particles, while the smaller particles were composed primarily of tar. Using this information, curves of K values versus particle size were selected for these materials, and the geometric mass mean radius of each separate distribution established. The representative value for K was determined from the curves using the mean radius. The two values were combined to produce a single value for computation by weighing each value as a function of the particle sample mass distribution.

The above discussion is included as an example of how difficult the accurate determination of particle size distributions can be, and what assumptions must be made if the distribution is found not to fit some standard form such as a single normal or lognormal curve. In addition, if the particle size tends toward values below 10 μ in diameter, the mass values calculated for assuming one mean diameter can vary by a factor of four with very small changes in the particle distribution and thus in the actual effective mean diameter.

Actual experience with some particular source or type of source can greatly improve the accuracy of the system through increased knowledge of the typical optical properties of the emission. The system could only approach 100% accuracy if the emissions were all of the same material with similar optical properties (surface conditions) and all particles were of the same size. With minimal knowledge of the particulate characteristics, only order-of-magnitude accuracy can be expected for total mass measurements. However, relative measurements performed on some small source which exhibits reasonably constant particle characteristics (either observed or measured) can be expected to have an accuracy factor on the order of 2-5. It is this range of accuracy which appears reasonable for measurements made with the experimental system.

To make the operation of this system feasible, two other assumptions must be made which are multiplicative in terms of mass measurement errors. The basic assumptions are that a representative value can be determined for particle density and emission rise velocity, and that these values once determined, remain relatively constant. In both situations, it is difficult to conceive of a case where the selected value for either quantity would introduce an error greater than 25% and indeed, the error actually experienced would probably be <10%.

Analysis of particle samples show that the primary constituents are tars and carbon or coal. The densities have ranged between $\sim.9$ Gm/cm^3 and 1.4 Gm/cm^3. The apportionment between the two materials has shown reasonable consistency. Based on these observations, a representative density of 1.2 Gm/cm^3 was established. In the presence of very low emissions, we

would expect the material make-up to tend towards a predominance of tar and the selected value would tend to be high. If emissions were particularly heavy indicating considerable combustion and turbulence in the oven, the emissions would probably tend toward carbon and the selected value would tend to be low.

The selected value for emission rise velocity was based on a large number of photographic observations of plume behavior. Few inconsistencies in behavior were rated. This is probably because the position of the plume, when observed by the system, is removed from the larry car stacks and hopper structure, and its behavior is primarily determined by ambient air conditions which remain relatively constant.

The exception to this is when a relatively strong crosswind is blowing. The plume in this situation can have a horizontal velocity $\geq$ the vertical velocity. In such a situation, the plume will probably pass across one of the light source vertical wing using units rather than the horizontal light source. In such situations, it might be necessary to make some wind measurements to obtain a reliable value for emission velocity pass the vertical bar units. In any case, the representative vertical velocity, when applied to the horizontal bar under minimal wind conditions, should cause minimal error in system measurements.

A second area of system error apart from the necessary quantitative assumptions, is the inability of the system to see or detect all emissions occurring on the oven battery during charging. This deficiency is a result of the geometry of a feasible system installation on a typical coke oven. In Figure 22 the field of view of the camera with respect to the light bar and the oven surface is shown. As the field of view narrows toward the camera, additional portions of the oven surface and space above that surface are excluded from detection by the system. The drawing shows what are considered ideal locations in terms of image size and detection locations. The camera could be moved further away from the source to provide an enlarged field of view, but this would have the effect of increasing the differences in plume behavior caused by the variations in distance from emission source for different positions on the

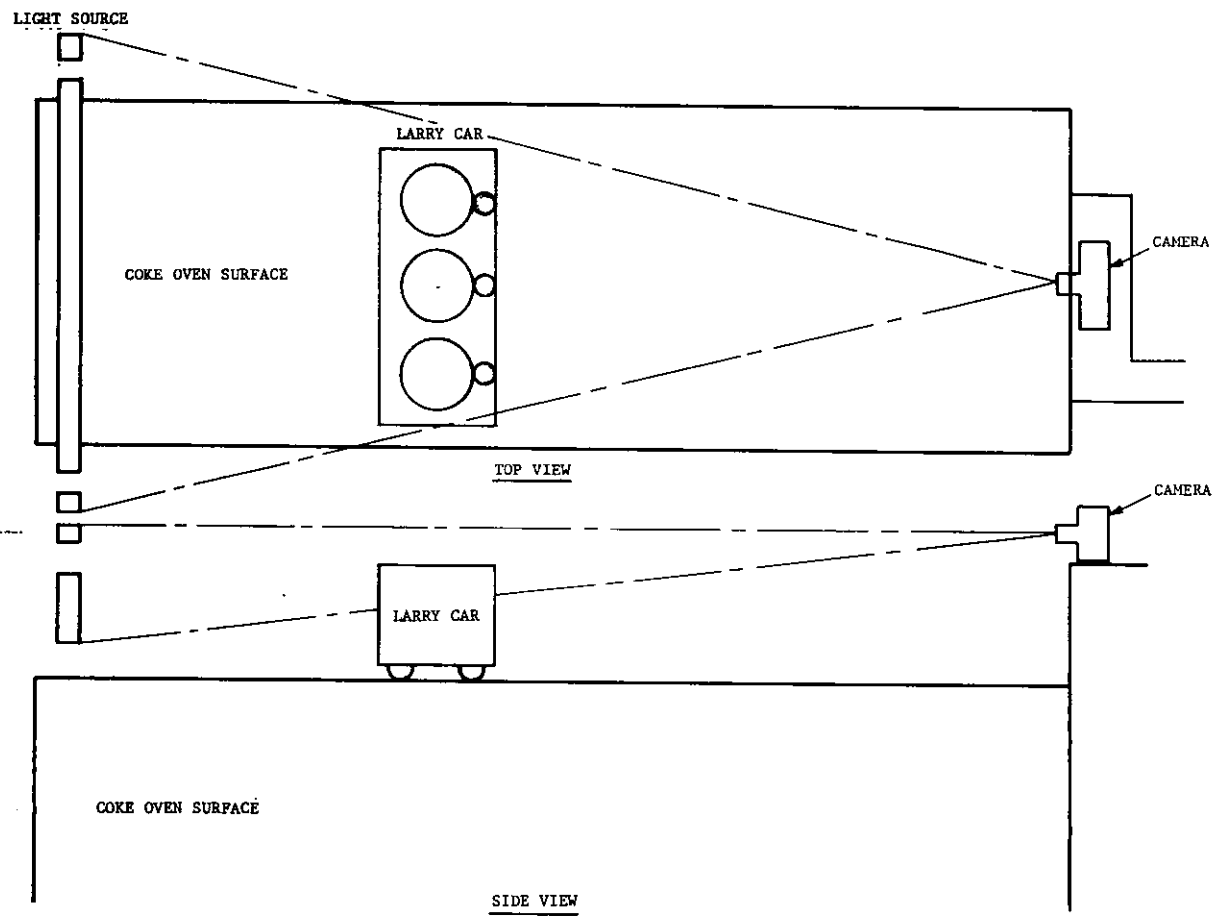

FIGURE 22
TYPICAL SYSTEM GEOMETRY

oven. It would also tend to decrease the photographic image size which in turn makes densitometry more difficult. The light source might be increased in size, but this quickly approaches the practical limitations of available support for the structure. Additional cameras could be added, but the costs of implementation and operation would be increased proportionately.

It also appears possible, based on test experience, that light emissions occurring around the base of the car could become so diffused before rising to a detectable point above the car that the system would have considerable difficulty distinguishing them from heavy background or ambient.

In general, the conclusion must be drawn that this monitoring concept in configurations similar to the experimental system cannot be expected to provide 100% coverage or positive detection of any light emissions. Change to the system configuration can be made, but this would result in substantial increases in both cost of experiment and operation.

System Configuration, Operation, and Data Analysis

The configuration of system components in the implementation of this measurement concept does not provide a large latitude of possibilities. The detector (camera) must be positioned on one side of the emission plume and a light source must be positioned on the opposite side. The use of a reflector in place of the light source considerably complicates the system implementation, as well as data interpretation, and is not felt to be a practical alternative. As we stated previously, some secondary system for initial emission detection should be considered. This would allow the optical system to operate on an exception basis rather than continuously or on every charging sequence. Such a system might include relatively simple transmissometers operating over long paths over the oven top. These paths might use a single reflector at one end in order to minimize the number of units required. A simple path configuration is shown in Figure 23.

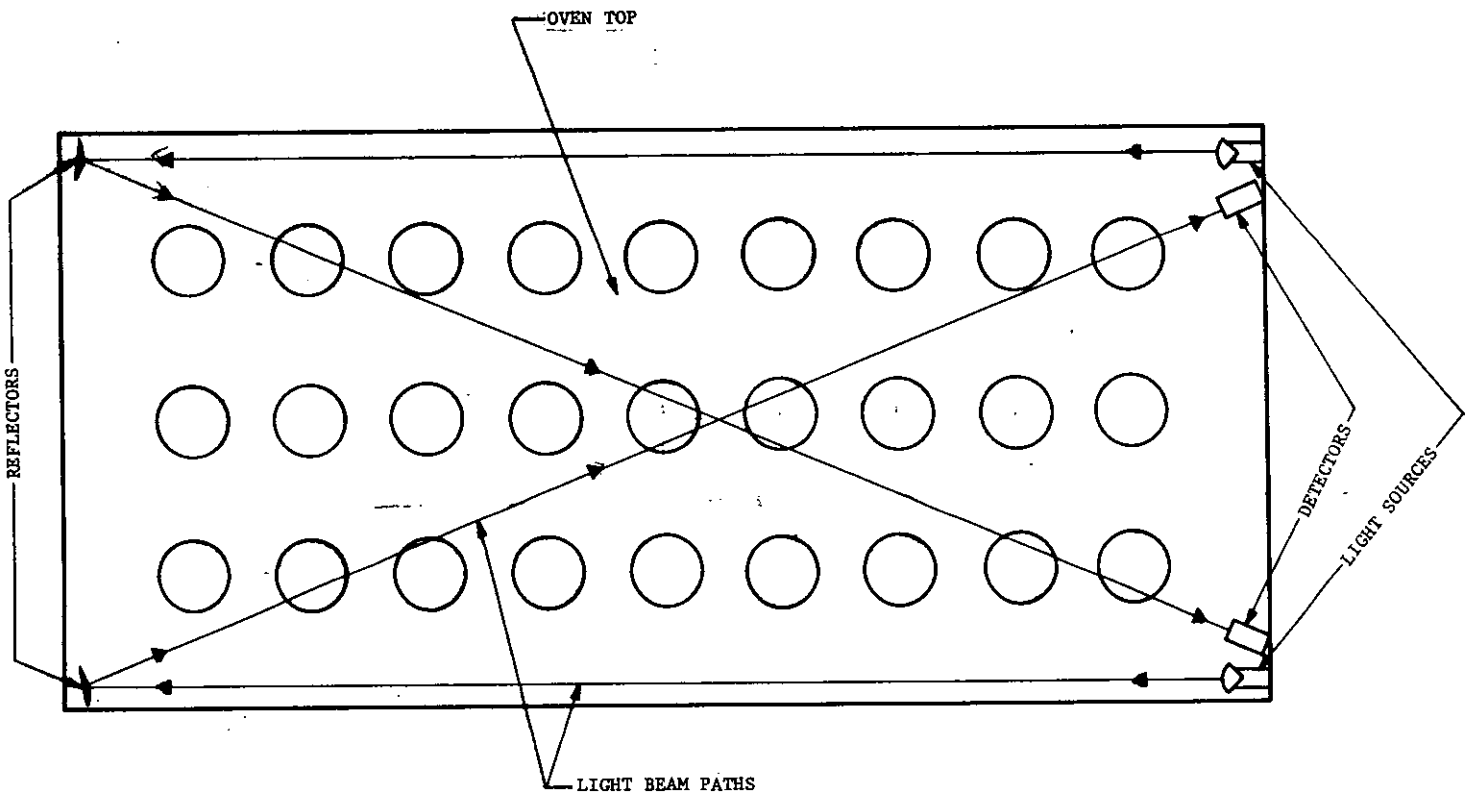

FIGURE 23
SECONDARY EMISSION DETECTOR ARRANGEMENT

The system operating in this mode could function unattended for periods of days or weeks, assuming an 80% or greater compliance record and large capacity film magazines. The primary attention need by the system would be the occasional cleaning of the light source and camera/associated optics, the changing of film magazines, and checks of data clocks and secondary detection system operation.

In comparison to a Ringelmann assessment of emissions, the experimental optical system can provide additional data with higher quality. As applied to coke oven observations, the Ringelmann technique cannot account for the quantity or size of the emission plume. This is important in determining the total emission because of the wide variation in point source characteristics on and around the larry car. The coke stacks for instance, release large quantities of dense opaque emissions while small leaks around the drop sleeve may release equally dense emissions, but of a much lower volume. The situation where a large number of small leaks release a large quantity of diffused emissions as contrasted to a small dense emission from a stack is also not adequately differentiated. As understood for current compliance monitoring, the Ringelmann observer would time the period over which he observed a certain opacity, not noting the quantity (plume size) of emission at that opacity. This could obviously give a distorted picture of the actual emission volume in comparison to observations made on other charges. The optical system should be able to provide information that more truly reflects the actual quantity of emission and allows a better basis for comparison of this quantity between individual charging activities. The system has also been shown to adjust for conditions beyond the control of the Ringelmann observer, such as light conditions and color of the emission.

As previously stated, the optical system, although not providing a highly accurate value of absolute mass emitted, should provide a reliable basis for relative mass measurements within the system. If, however, the quantitative aspects of mass measurement are not sufficiently accurate or reliable for use in a compliance system, the basic transmission (the reciprocal of opacity) measurement capability of the system provides an

improvement over Ringelmann in terms of accounting for emission volume. By dividing up the light source into many point sources, the system makes the equivalent of many instantaneous Ringelmann assessments over a wide area with the advantage that variables, such as emission color or ambient lighting, have been eliminated or compensated for.

An example can be given to demonstrate this capability. Assume a light source whose photographic image can be divided into 500 equal sections for purposes of density measurement. If the bar is 50 feet long, then each of the 500 spots would represent a .1 foot wide area of the light source. Suppose that transmission values were determined for each of the 500 points along the bar, and that corresponding Ringelmann numbers were assigned to each of the points. These numbers could then be summed to provide a composite value (referred to here as a Ringelmann "Quotient" - RQ) which would take into account the size or extent of the emission plume or condition. A perfectly clear bar would produce a sum of zero, corresponding to a Ringelmann of "zero." Assuming a Ringelmann 1 condition across the entire bar, the sum would be 500. If a Ringelmann 2 condition exited across the bar, the sum would be 1000. The other Ringelmann sums would be proportional for constant Ringelmann numbers. The system upper cut-off limit at 90% opacity would yield a Ringelmann sum of 2000, which would also be obtained for an 80% opacity condition.

Since conditions can be expected to vary from point to point on the bar, the Ringelmann sum would be expected to vary as a function of emission quantity between 0 and 2000. Since a value for one photographic frame represents an instantaneous rate, the sum values for several frames might be totaled and divided by the number of frames to provide a rate average over time. As an example of how a Ringelmann Quotient would work for actual data, two optical system data frames of contrasting emission conditions along with their assigned Ringelmann Quotient (RQ) and calculated mass emission rates are presented in Figure 24. Additionally, the values used to compute the RQ from transmission data are presented in Table 31. For the test system, 539 spot transmission measurements were made yielding a possible maximum RQ value of 2156. This value would

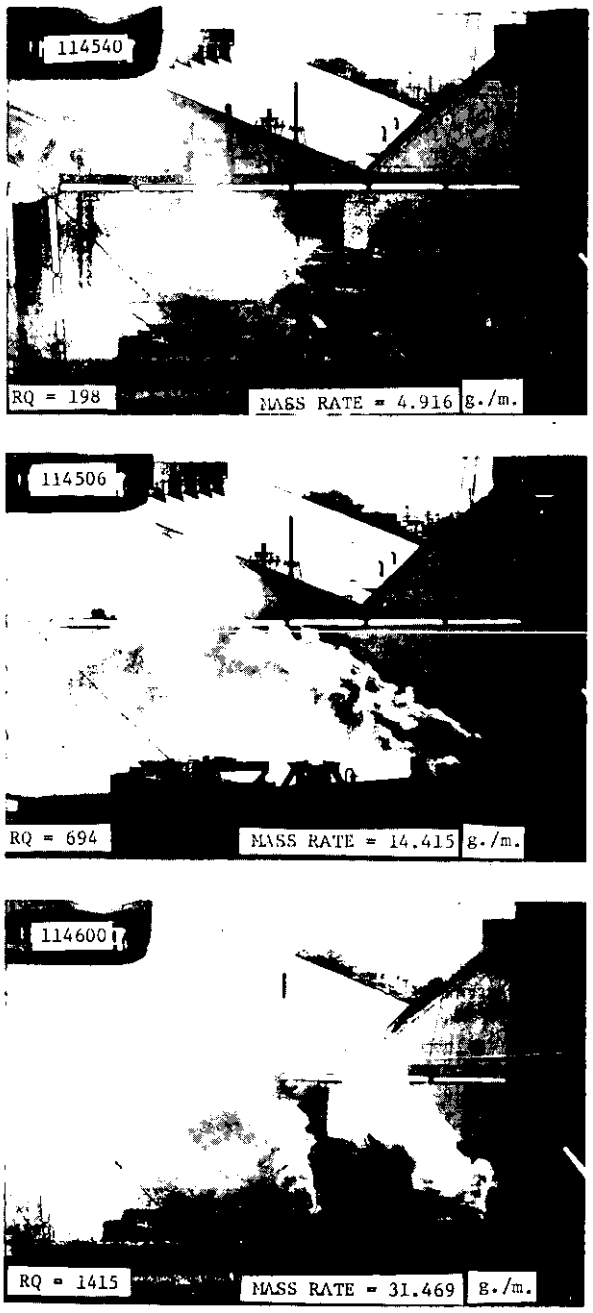

FIGURE 24
EMISSION CONDITIONS AND CALCULATED RQ VALUES

TABLE 31

CONVERSION OF TRANSMISSION VALUES

TO RINGELMANN VALUES

% Transmission	% Opacity	1/T	Corresponding Ringelmann Value Assigned
100	0	1	0
90	10	1.11	
80	20	1.25	1
70	30	1.43	
60	40	1.66	2
50	50	2.00	
40	60	2.50	3
30	70	3.33	
20	80	5.00	4
10	90	10.00	

correspond to a Ringelmann condition 4 measured at all 539 points along the light source. The test system cannot, however, reach this absolute value since about 30 points fall on gaps in the light source and are assigned 0 mass values. It is easy, however, to see the difference between the two RQ values in comparison to the emission conditions pictured. It can be seen that such a technique might offer an improved capability in assessing the amount of emissions actually released to the air during a charging operation.

Data Processing Output

The basic output of the data analysis for the optical monitoring system is a total mass rate value per unit vertical height of the emission plume. This value is in turn made up of 539 individual mass rate values calculated for corresponding spots along the length of the light source. In an operational situation, the only number of interest is the mass rate associated with a particular frame. For purposes of system performance assessment, however, additional information was included on the data analysis print-out for the selected tests. Figure 25 presents one page of a typical analysis print out.

The header information contains frame identification consisting of test number and frame time in hours, minutes, and seconds. The base and scan numbers used in "housekeeping" refer to the base frame number on the data tape and the scan number performed against that particular base. Each of the seven line groups on a page present data from fifteen consecutive points in the left to right scan of the light source. A total of six pages are required to present the 539 points from one complete scan of the light bar. A seven space column associated with a single point contains the base exposure value (no emission) for that point on the light source labeled "BASE L". The base exposure value for the corresponding spot on the black portion of the bar is obtained by averaging black area readings over some specific number of points at the end of the light source and designating this average as a constant to be used in all calculations involving that base frame. This value is presented as part of the header information and is labeled "ZERO PAL",

TEST 7 ZERO PAL = 1.077 HR:MIN:SEC 15:23:29 BASE 2 SCAN 5

* LIGHT BAR GAP	+ PAL > BL	$ DL > BL	# DL < DD (NOISE)	? DL < DD (INVALID)	¢ 1/T > RCUT	@ BL < AVG BD (INVALID)								
DATA D	1.906	1.962	2.020	2.020	1.962	1.962	1.906	1.962	1.906	1.904	1.906	1.906	1.906	1.962	1.906
BASE L	9.903	9.903	10.048	10.655	10.855	10.815	10.499	10.346	10.346	10.346	10.105	9.903	9.903	9.348	9.484
DATA L	4.712	4.477	4.400	4.633	4.633	4.633	4.400	4.555	4.477	4.477	4.477	4.477	4.400	4.325	4.325
1/T	3.146	3.509	3.769	3.666	3.586	3.646	3.778	3.575	3.606	3.606	3.547	3.633	3.539	3.501	3.477
LN(1/T)	1.14612	1.25542	1.32280	1.29905	1.27710	1.29363	1.32915	1.27401	1.28247	1.28247	1.26612	1.23355	1.28386	1.25311	1.24606
EL MASS	0.050	0.054	0.057	0.056	0.055	0.056	0.058	0.055	0.056	0.056	0.055	0.053	0.055	0.054	0.054
FLAGS 106															
DATA D	1.851	1.851	1.906	1.906	1.962	1.962	1.962	1.962	2.081	2.144	2.021	2.020	2.020	2.021	2.021
BASE L	9.484	8.955	8.955	9.084	8.456	8.827	8.702	8.702	8.335	7.982	7.745	7.061	5.556	3.491	1.951
DATA L	4.477	4.325	4.325	4.555	4.477	4.555	4.633	4.477	4.477	4.633	4.477	4.325	3.883	3.189	2.529
1/T	3.202	3.185	3.258	3.024	2.934	2.990	2.855	3.032	3.030	2.774	2.714	2.597	2.404	2.152	1.000
LN(1/T)	1.16365	1.15858	1.18110	1.10645	1.07634	1.09513	1.04907	1.10914	1.10349	1.02026	0.99843	0.95439	0.87721	0.76626	0.00000
EL MASS	0.050	0.050	0.051	0.048	0.047	0.047	0.045	0.046	0.048	0.044	0.043	0.041	0.038	0.033	0.000
FLAGS 91															** $ 11
DATA D	1.906	1.797	2.020	1.962	1.906	1.962	1.906	1.906	1.962	1.962	1.962	2.021	1.962	1.906	1.906
BASE L	1.421	1.348	1.797	3.529	5.929	7.284	7.982	8.456	8.335	8.335	8.827	8.578	8.456	9.084	9.084
DATA L	2.463	2.398	2.529	3.324	4.249	4.712	4.955	5.121	5.121	5.121	5.292	5.379	5.379	5.739	5.929
1/T	1.000	1.000	1.000	1.801	2.071	2.757	2.265	2.295	2.297	2.297	2.328	2.233	2.160	2.089	1.991
LN(1/T)	0.00000	0.00000	0.00000	0.58831	0.72795	0.81404	0.81765	0.83063	0.83181	0.83181	0.84486	0.81354	0.76997	0.73672	0.68547
EL MASS	0.000	0.000	0.000	0.025	0.032	0.035	0.035	0.036	0.036	0.036	0.037	0.035	0.033	0.032	0.030
FLAGS 76	** $ 18	** $ 18	** $ 12												
DATA D	1.906	1.962	2.020	2.020	1.851	1.851	1.962	1.962	1.962	1.851	1.797	1.797	1.906	1.851	1.851
BASE L	9.084	9.215	8.456	8.578	8.456	9.084	8.702	8.335	8.578	8.327	8.827	8.456	8.216	8.099	8.099
DATA L	6.123	5.739	5.833	5.833	5.379	5.646	5.929	5.646	5.646	5.739	5.556	5.646	5.646	5.467	5.556
1/T	1.899	2.155	1.935	1.967	2.092	2.110	1.922	1.970	2.036	1.994	2.062	1.917	1.909	1.942	1.896
LN(1/T)	0.64125	0.76761	0.66017	0.67660	0.73809	0.74668	0.65351	0.67813	0.71103	0.68991	0.72367	0.65075	0.64658	0.66283	0.63951
EL MASS	0.028	0.033	0.029	0.029	0.032	0.032	0.028	0.029	0.031	0.030	0.031	0.028	0.028	0.029	0.028
FLAGS 61															
DATA D	1.797	1.851	1.851	1.797	1.851	1.797	1.851	1.851	1.851	1.689	1.743	1.797	1.797	1.636	1.639
BASE L	8.216	8.335	8.335	8.955	9.215	9.034	9.343	9.484	8.827	9.215	9.084	8.792	8.955	8.827	8.827
DATA L	5.556	5.833	5.833	6.123	6.323	6.424	6.631	6.631	6.737	6.952	6.737	6.527	6.631	6.737	6.631
1/T	1.899	1.823	1.823	1.821	1.820	1.730	1.730	1.759	1.586	1.647	1.603	1.693	1.577	1.544	1.558
LN(1/T)	0.64154	0.60039	0.60039	0.59935	0.59889	0.54834	0.54837	0.56460	0.46152	0.43604	0.48838	0.52635	0.45568	0.43687	0.44391
EL MASS	0.028	0.026	0.026	0.026	0.026	0.024	0.024	0.024	0.020	0.019	0.021	0.023	0.020	0.019	0.019
FLAGS 40															
DATA D	1.636	1.636	1.797	1.689	1.689	1.689	1.743	1.689	1.743	1.743	1.797	1.636	1.743	1.689	1.639
BASE L	8.955	8.955	8.792	8.827	8.702	8.335	7.512	7.284	6.952	6.737	6.527	6.424	6.424	6.527	7.172
DATA L	6.952	6.843	7.172	7.284	6.952	6.952	6.843	6.631	6.222	6.123	6.424	6.222	6.527	6.631	6.737
1/T	1.482	1.313	1.419	1.385	1.449	1.379	1.262	1.256	1.312	1.292	1.178	1.166	1.000	1.000	1.207
LN(1/T)	0.39343	0.41397	0.34976	0.32605	0.37091	0.22163	0.23237	0.22786	0.27118	0.25630	0.16367	0.15554	0.00000	0.00000	0.18854
EL MASS	0.017	0.018	0.015	0.014	0.016	0.014	0.010	0.010	0.012	0.011	0.007	0.007	0.000	0.000	0.008
FLAGS 31															
DATA D	1.689	1.742	1.743	1.689	1.743	1.743	1.636	1.636	1.636	1.743	1.689	1.689	1.689	1.639	1.636
BASE L	7.397	7.864	8.099	7.864	8.335	8.216	7.982	7.626	7.512	7.397	7.172	6.737	6.631	6.424	5.929
DATA L	6.952	7.172	7.284	7.284	7.172	7.284	6.952	6.737	7.172	7.172	6.952	6.631	6.527	6.424	6.123
1/T	1.201	1.250	1.267	1.213	1.337	1.289	1.299	1.284	1.162	1.164	1.154	1.145	1.148	1.127	1.000
LN(1/T)	0.18319	0.22333	0.23691	0.19327	0.29050	0.25352	0.26166	0.25018	0.15051	0.15206	0.14687	0.13564	0.13815	0.12165	0.00000
EL MASS	0.008	0.010	0.010	0.008	0.013	0.011	0.011	0.011	0.007	0.007	0.006	0.006	0.006	0.005	0.000

TEST 7 ZERO PAL = 1.077 HR:MIN:SEC 15:23:29 BASE 2 SCAN 5

* LIGHT BAR GAP	+ PAL > BL	$ DL > BL	# DL < DD (NOISE)	? DL < DD (INVALID)	¢ 1/T > RCUT	@ BL < AVG BD (INVALID)								
DATA D	1.689	1.742	1.743	1.689	1.743	1.743	1.636	1.636	1.636	1.742	1.689	1.689	1.689	1.689	1.636
BASE L	7.397	7.864	8.099	7.864	8.335	8.216	7.982	7.626	7.512	7.397	7.172	6.737	6.631	6.424	5.929
DATA L	6.952	7.172	7.284	7.284	7.172	7.284	6.952	6.737	7.172	7.172	6.952	6.631	6.527	6.424	6.123
1/T	1.201	1.250	1.267	1.213	1.337	1.289	1.299	1.284	1.162	1.164	1.148	1.145	1.148	1.129	1.000
LN(1/T)	0.18319	0.22333	0.23691	0.19327	0.29050	0.25352	0.26166	0.25018	0.15051	0.15206	0.14687	0.13564	0.13815	0.12165	0.00000
EL MASS	0.008	0.010	0.010	0.008	0.013	0.011	0.011	0.011	0.007	0.007	0.006	0.006	0.006	0.005	0.000
FLAGS 16															

ZERO PAL = 1.077 TOTAL FRAME MASS RATIO 22.753

FLAG SUMMARIES

*	44
+	22
	13
$	37
#	0
?	0
¢	32
@	0

ALIGNMENT SHIFT = 0
NUMBER OF HOLES MATCHED 0

FIGURE 25
SAMPLE OPTICAL DATA ANALYSES PRINTOUT

meaning a value for zero plume air light.

Exposure value information for the point obtained in the scan of that particular data frame is labeled "DATA D" for the value of the black area and "DATA L" for the value of the lighted area. The three exposure values plus the value for "ZERO PAL" are used to calculate a reciprocal value for transmittance which is printed and labeled "1/T". The value labeled (LN(1/T)" is the natural log of the 1/T value and is presented as an interim quantity to be saved for possible re-run of the data. The quantity labeled "EL MASS" is the calculated mass rate in grams per meter vertical plume size for that particular point. This value is obtained using constants whose values are assigned and listed at the start of each data reduction run. In order to obtain a total mass rate for a complete frame, "EL MASS" values for each of the 539 points are summed. This value is presented on the last page associated with the particular scan as "TOTAL FRAME MASS RATE." The last line of each group summarizes special situations which may occur on a particular frame. An abbreviated explanation of the "FLAGS" is presented as part of the header information for each page. The "*" signifies a point at which the value for "BASE L" falls below some pre-set value. This situation occurs for points falling on the gaps between bulbs of the light source and is generally 5-8 points long. In general, no mass rate is calculated for these points and the value of "EL MASS" is set to zero.

The "+" denotes a situation in which the frame plume-air light value, "DATA D", is high when compared to a corresponding base light value (BASE L). This situation can logically occur under two different conditions. The first occurs when a gap value for "BASE L" is compared to a slightly high value of "DATA D", caused by light smoke over the black area. The second occurs when very heavy smoke of a bright or highly reflective color occurs and the smoke image density appears brighter than the light source in the base frame. Few situations of the latter type were detected and in general, indicated that the light source remained dominant for most conditions of plume air light. A "$" signifies that a value for "DATA L" was found to be larger than a corresponding

value for "BASE L." This occurs in the presence of heavy emissions where the light source is still visible, giving rise to an addition of plume air light to the apparent light source brightness. It may also occur to a lesser degree in a no emission situation due to system inaccuracies. To differentiate, the difference between the two values is compared to a threshold value. If it is less than that value, a "¢" flag is raised and the computation continues. If it occurred during a high emission condition, the calculation will force the value of "EL MASS" to its maximum value. If it occurred during a light or no emission situation, the calculations will generally produce a zero or very low value for "EL MASS." If the difference is greater than the threshold value, a "$" is printed and the calculation continues. This situation, when valid, usually occurs in a high emission condition and the calculation will generally enter a high value for "EL MASS." The situation "¢" can also occur at gaps in the light source and is handled in the same way. The "#" flag signifies that a comparison between "DATA L" and "DATA D" values showed the dark area to be brighter than the light area. Again, this situation occurs in conditions of very heavy emissions and if the difference is small, is probably caused by system inaccuracies. To check, the difference is compared to a threshold value. If it is less, the maximum value is set for "EL MASS." If it is greater than the difference threshold value, a "?" flag is entered and the "EL MASS" value is set to zero since no valid calculation can be made under these conditions. The "%" flag indicates that the calculated transmission has dropped below 10%. In this situation, the maximum value of "EL MASS" is entered for that spot. The exposure and transmission data is retained for examination. The last flag, "@", signifies that a "BASE L" value is below the "ZERO PAL" value and can only occur in a light source gap (already signified by "*" flag) or in an invalid measurement. In the presence of this flag, a zero value for "EL MASS" is entered.

Using the flag summary at the end of a frame scan, a quick assessment of possible processing problems can be made and a judgement formed as to the quality and potential validity of the results. Printed below the flag summary are data shift values. This shift is performed on the data

frame if its start point does not coincide with that of the base frame. The alignment is based on the position of the gaps in the base and data frames and in general, require little or no shifts. The total print-out provides a convenient method for scanning individual data frames for areas of interest such as observed areas of high or low transmission or suspected interferences. In short, it provides a valuable tool in the understanding and assessment of optical system performance.

Test Data

During the course of the overall test program, 21 tests were photographed by the optical system which were also observed using the continuous monitoring system. In addition to the 21 tests in common, a number of other charges were photographed using the optical system to provide test data for that system. The original intent at the outset of testing was to process and analyze all optical system output for comparison with the continuous monitoring results. This became impractical in the light of higher than expected processing and analysis costs and unexpected but necessary alterations in the original test schedule. As a result, the selection of a sub-set of optical film was made and analysis accomplished prior to the processing and analysis of the continuous monitoring system data.

The original test concept involved monitoring all emission source points simultaneously (six points on the Wilputte car and three points on the AISI/EPA car). The combination of volume flow from all points on a test would have provided a reasonably good second-by-second picture of visible emission volume against which the optical system data could be compared. Problems encountered during the course of testing precluded the measurement of all points on the Wilputte car simultaneously and made necessary the use of aspirating fans on the three AISI/EPA car test points with the result that the absolute volume flow was a function of the fans rather than the volume of emission.

An alternative selection of tests where all three stacks on the Wilputte car were monitored for volume flow or all three guides of the AISI/EPA car were monitored for gas concentrations was made. The rationale was

that during the charging period for the Wilputte car, a high percentage of the total emissions escaped through the stack. Also, that on the AISI/EPA car, the concentrations of selected emission constituents such as total hydrocarbons could be used as an indicator of visible emissions volume at that instant in time. A further selection of specific frames was made by visual observation of the test film to include periods of highly contrasting emissions (high versus low volume visible) and transients. The results of this comparison are presented in the following material.

Presented in Figures 26 through 30 are graphs of actual volume flow, in cubic feet per second, combined for all three stacks on the Wilputte larry car or measured concentrations in % total hydrocarbons for the three combined guides on the AISI/EPA car. The second trace on each graph presents calculated mass emission rates as measured by the optical monitoring system. These values expressed in grams per meter vertical plume size, are plotted on the same time base to show event correlation. After inspection of the film, and comparison of photographed events with the data acquisition system record, it was obvious that some loss in synchronization between the optical system clock and data acquisition system had occurred. This was probably caused by noise pulses causing the optical system clock to jump ahead in time a few seconds. The events displayed were graphed using the time displayed by the clock rather than arbitrarily correcting this time. In general, however, it appears from several observations that in the absence of wind, events in the Wilputte stacks are seen by the optical system with about a five second delay and events in the AISI/EPA guides are seen by the optical system with a five to ten second delay.

Also, since the continuous monitoring system volume flow measurements are taken in a confined stack on a one second basis, abrupt changes in flow can be detected and represented in a very precise fashion. The optical system, however, detects the emission after it has had an opportunity to diffuse and, in general, become more spread out over both time and space. The analysis interval for the optics system was selected

at five seconds as opposed to the one second frame rate so abrupt changes cannot be detected with the same resolution as the volume flow measurement system. Association of event records displaced by an abnormally long period in time according to the two clock values, will be noted in the text discussing that test. Also, trend arrows showing the smoke conditions before, after, and between optical data points are included on the graphs. These were placed on the basis of visual observations of the subject data frames and are not intended to be quantitative, but instead to aid in the correlation of the two sets of results.

Shown in Figure 26 is data obtained during Test 7. The trace of volume flow represents a typical example of conditions during a Wilputte car test. The optical system data is divided into two parts, each of which cover an observed transient condition during the charge. The large volume flow peak occurring just after the start of observations was detected as a less abrupt peak in mass rate by the optical system with some time delay. Visual inspection of the optical system film showed a smoke condition corresponding to approximately the next to last calculated point of the first trace persisting until the first part of the second optical system trace. In the second trace, the actual shape of the volume flow curve was more closely matched by the optical system results. This is probably because the changes in trend of volume flow were less abrupt and of a more consistent nature. It is also interesting to note the optical system saturation point ("optical-system maximum value") with respect to the measurements displayed here. Roughly speaking, a 10% transmission or 90% opacity condition covering the complete length of the bar would correspond to a mass rate of 53 grams/meter, allowing for the gaps between bulbs in the light source and not including the "wing" light source units. One can easily see that the smoke densities typically experienced during a Wilputte car charge could approach or exceed the measurement capability of the optical system. In such cases, the rate would have to be expressed as 53 grams/meter or greater. It would appear, however, that this condition would lie well outside any standard for visible emissions which might be established. The volume flow data

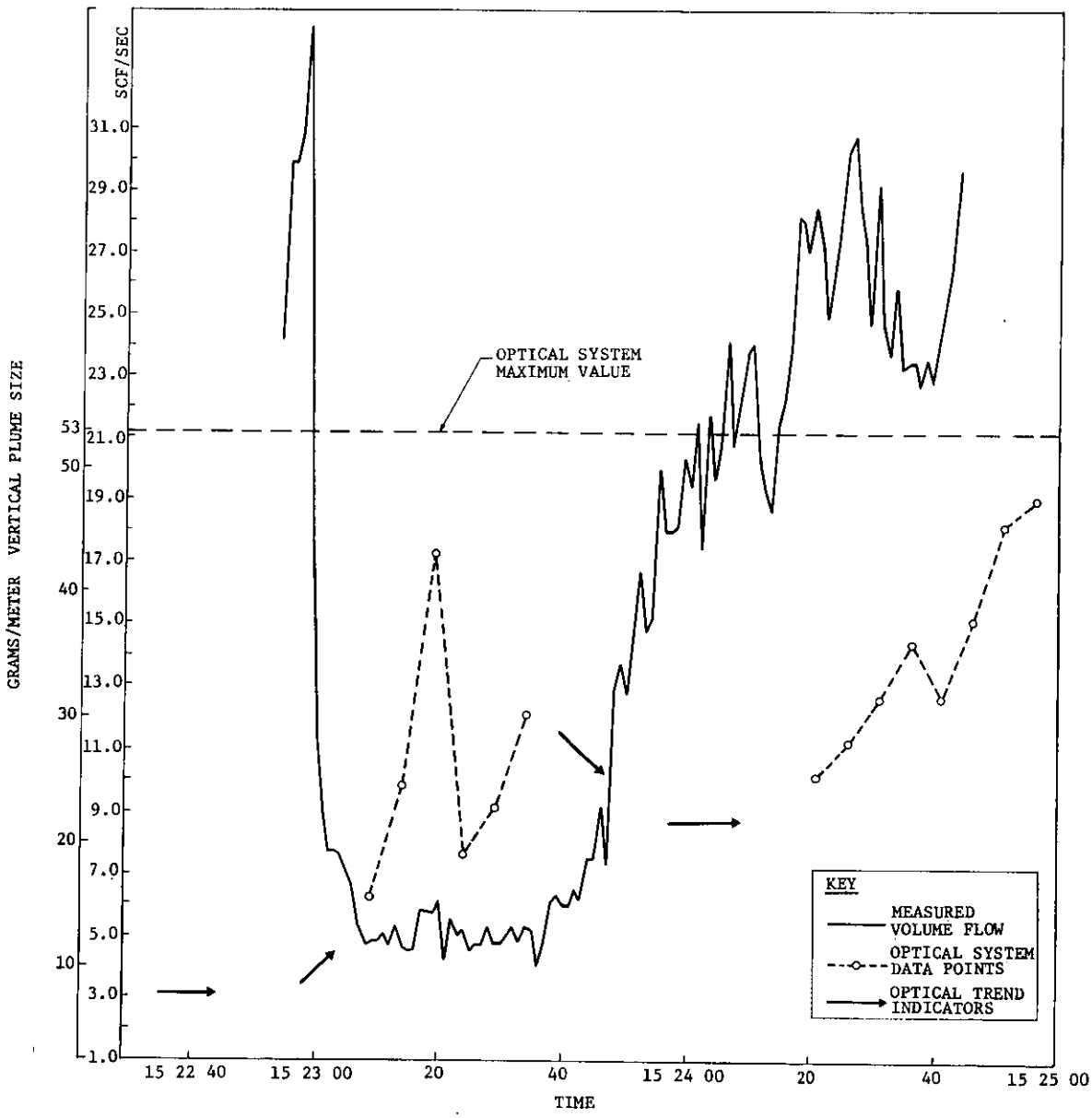

FIGURE 26
TEST 7 DATA

available from the continuous monitoring system ends with an increasing flow rate. This trend is also observed in the optical system data as an almost totally obscured light source after the last measured point. This condition corresponds to the maximum measureable value for the optical system.

Presented in Figure 27 is data obtained during Test 9. Again, the optical data is divided into two sections covering obvious transient flow conditions. During the first part of this test, a strong cross wind caused a large portion of the emission to pass undetected below the light source. The data frames displayed in Figure 24 are from Test 9 and show the effects of the wind conditions. The arrow shown on the second data point indicates that the measured value was much lower than the actual emission because of the cross wind condition. During the second portion of the optical data trace, the wind subsided allowing a truer measure of the actual emission condition. Lower peak values were recorded because of the wind condition and the resulting emission dispersion. The flow characteristics are similar to Test 7 showing an initial abrupt high flow rate, decreasing toward the middle of the test and then building up again toward the end.

Figure 28 shows data collected during Test 17. This test was performed on the AISI/EPA car and shows total hydrocarbon concentrations rather than volume flow data plotted against optical system data points. The optical data is divided into three parts on this test. The first and the last parts have been identified as quench steam interference using the photographic film record and voice tape commentary. The center optical system trace shows the detection of the heavy emission flow near the center point of the test. The peak values are much lower than those noted for the Wilputte tests because of the lower quantity of emission and the fact that the smoke source is at the oven surface under the car. As a result, the emission has been diffused to a greater extent by the time it rises to the light source detection area. The trend of the data recorded by the optical system closely follows the density of emission as indicated by the concentration of total hydrocarbons. The values

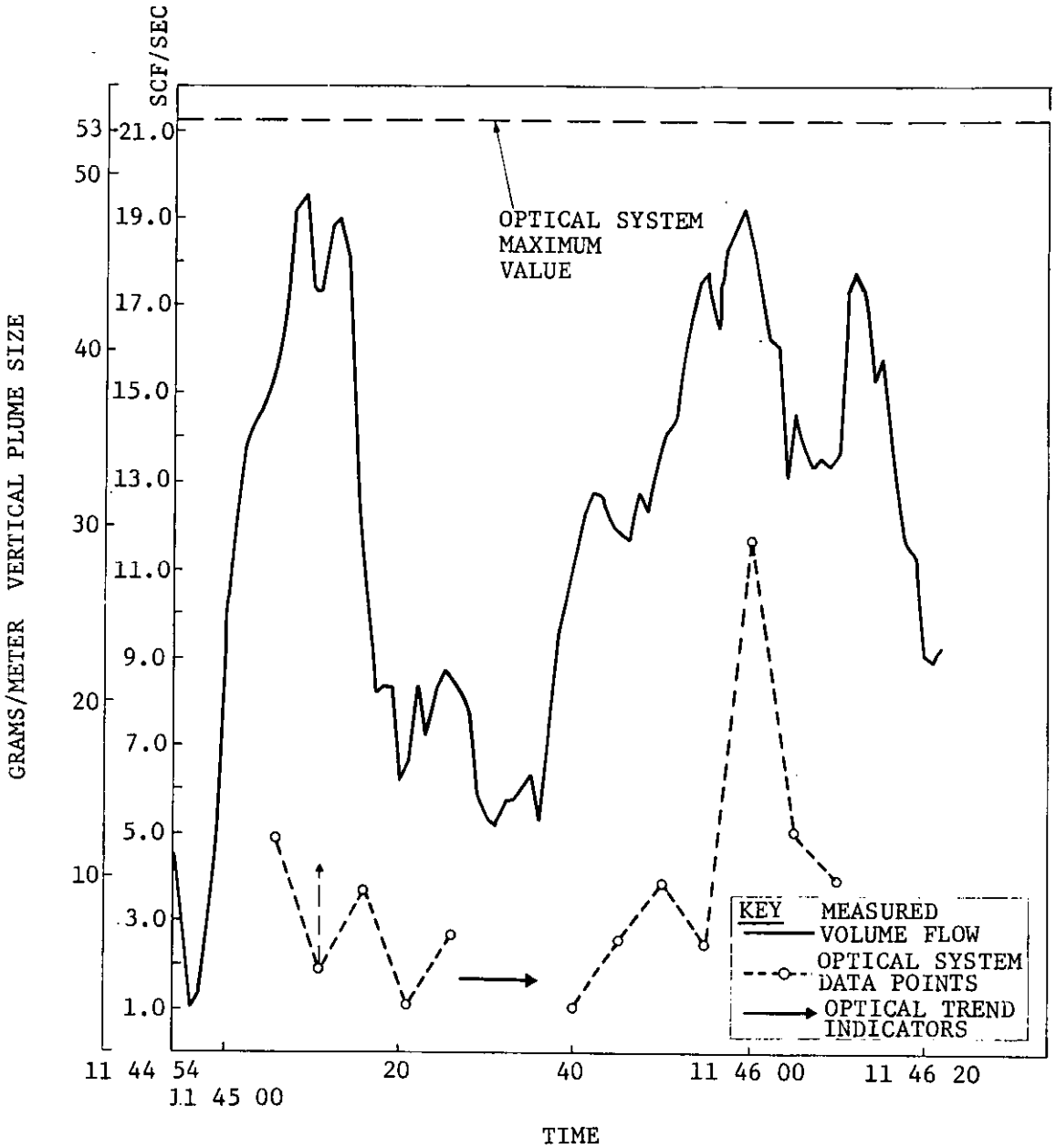

FIGURE 27
TEST 9 DATA

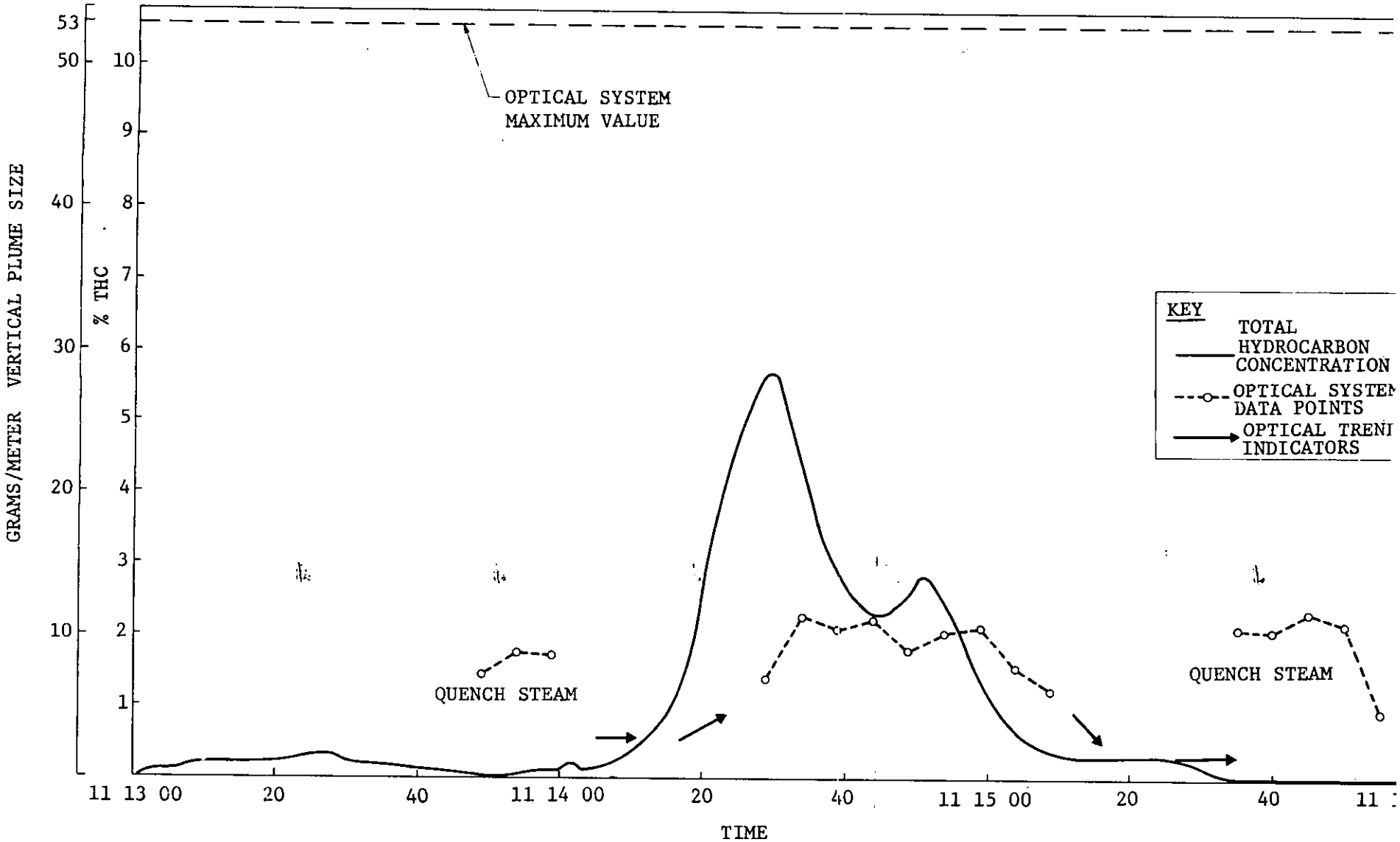

FIGURE 28
TEST 17 DATA

detected are well below the saturation point for the optical system.

Figure 29 presents data taken during Test 20. During the first part of this test, a large quantity of emissions escaped through an open "chuck door" and ascension pipe cap. This smoke rose past the light source and in preliminary selection of optical data to be analyzed was mistaken as emissions from the drop sleeve area. The optical data frames selected showed a rapid rise in density during the first part of the trace followed by a rapid decrease in density during the second part of the optical data trace. This condition correlates with a slight increase in recorded THC concentration, but since the emission occurred through unmonitored points, was not recorded directly by the continuous monitoring system. The primary emission around the drop sleeve occurred later in the test but was of fairly low volume. The sequence of events and the source of emissions was determined by examination of the optical system film data. The data is presented to show the ability of the optical system to track rapidly changing emission conditions but also points out a deficiency in the system in that it has no way of differentiating between emission sources. Emissions originating from an ascension pipe or oven door will appear as part of the total emission detected if they pass between the light source and the camera. It might be necessary to develop some rather arbitrary rules to cover this situation since it may not always be possible to identify the exact source of the detected emission.

Figure 30 presents data obtained during Test 25 performed on the AISI/EPA car. During the first part of this test, an unusually heavy emission release occurred around the drop sleeve area. This event was easily identified on the optical system film record, but the optical system digital clock time associated with the event was approximately one minute later than the data acquisition time. The only reasonable explanation was a missetting of the optical system data clock in the minute position. A rather remote possibility exists that a line noise pulse caused the optical system clock to jump ahead one minute as opposed to one second. A check of the two observed emission periods on the optical

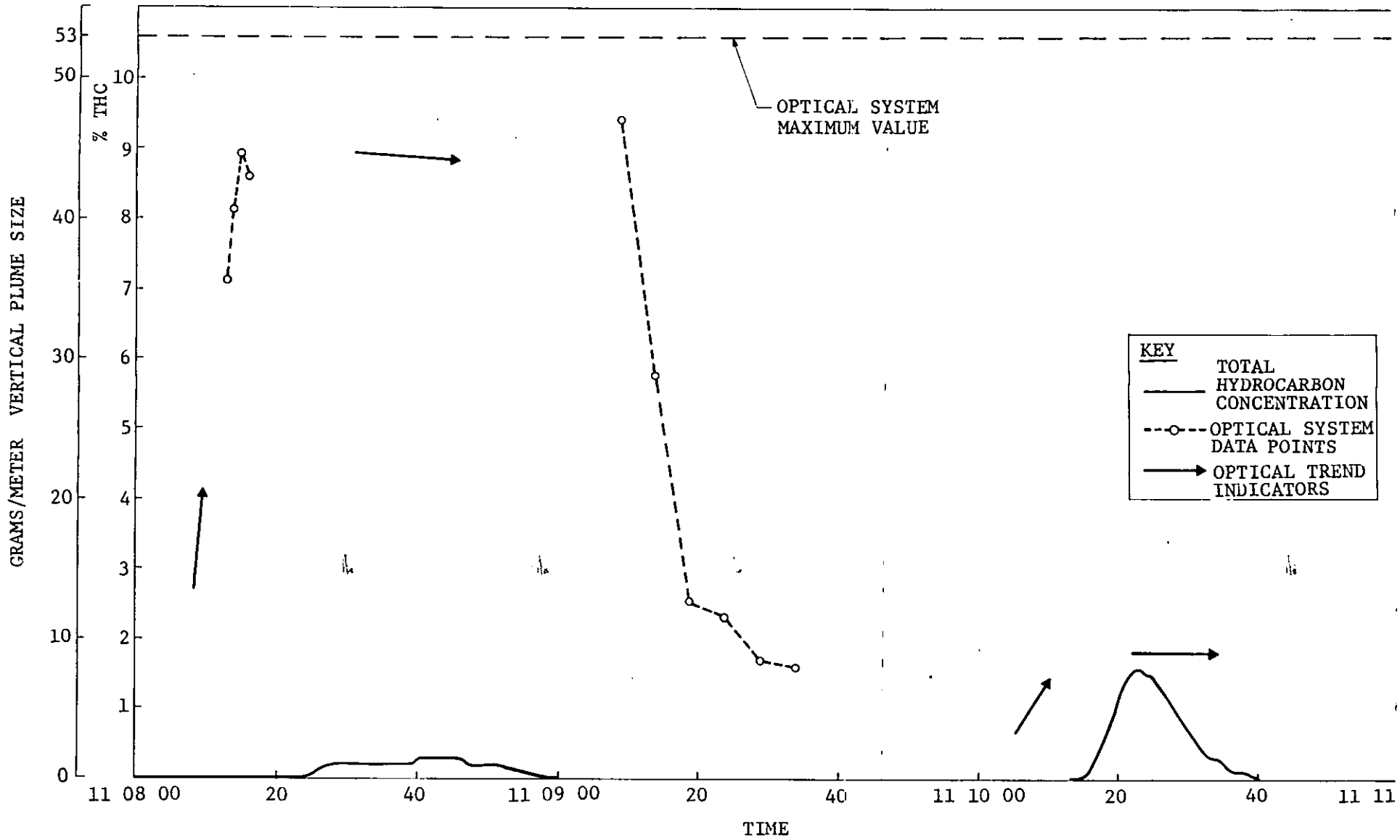

FIGURE 29
TEST 20 DATA

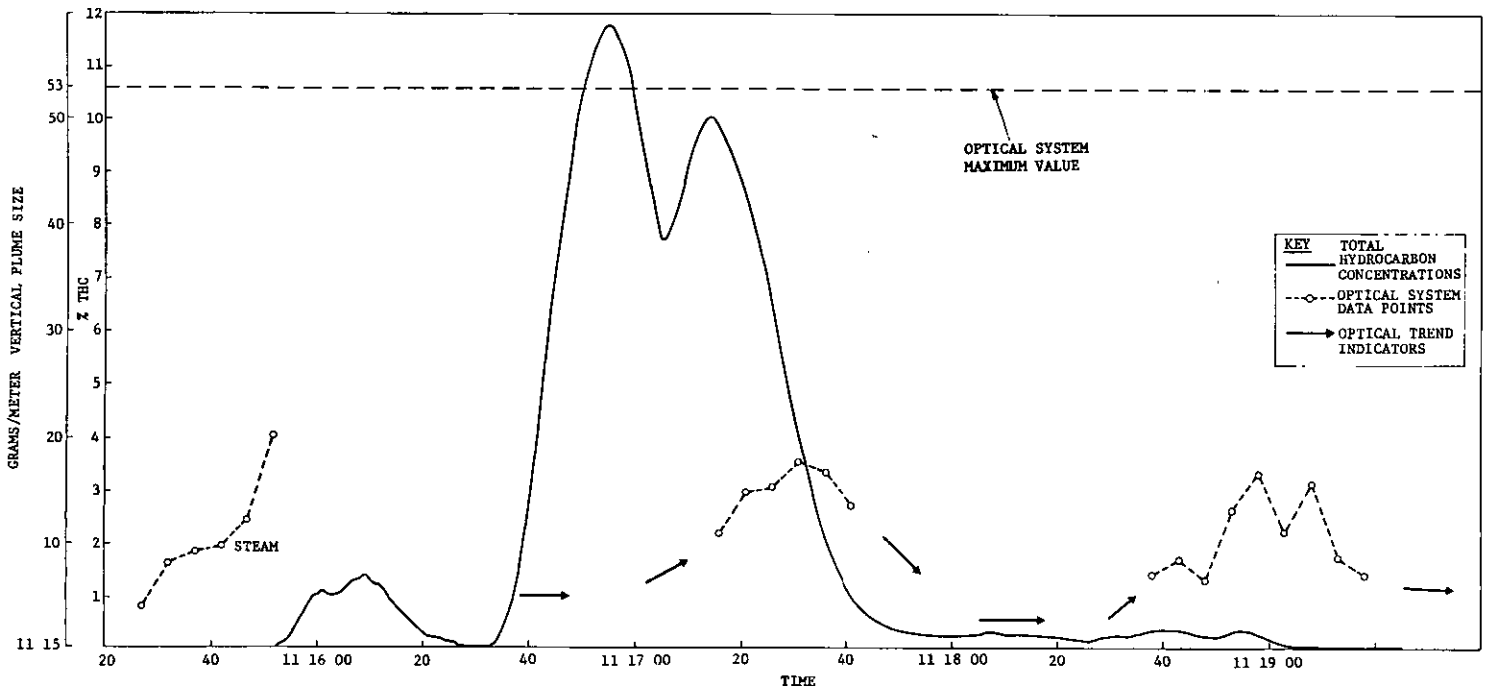

FIGURE 30
TEST 25 DATA

data films show good agreement in spacing when compared to the continuous monitoring system record. The steam condition also detected by the optical system was identified as occurring about one minute before the test providing a further basis for a time adjustment. Assuming that the second portion of the optical trace should be associated with the first peak in THC concentration and that the third portion of the trace should be associated with the high THC concentration peak, good agreement is observed in the data comparison. The third portion of the optical system trace does not exhibit as high a value as might be expected from the THC trace, but examination of the data film showed only a highly diffused emission condition existing in the area of the light source at that time. It is possible, however, that a mild wind condition at that time might have blown the bulk of the diffused emission out of the camera view. It is difficult to identify sharp emission peaks in a diffused smoke condition, but the general concentration conditions are indicated by a number of frames selected over an extended period of time.

Several conclusions can be drawn based on the optical data completely analyzed and the large amount of optical data film manually examined. First, the system is capable of detecting trends in total emissions using opacity measurements. Second, the mass concentrations appear reasonable in light of the data available for comparison. Third, the system has obvious limitations in measuring very heavy emission concentrations or very high concentrations which are highly dispersed or which may be blown laterally beneath the light source and thus pass undetected. In contrast, the minimal interference caused to plant operations and the system potential for unattended operation offer positive reasons for consideration of this concept for application to compliance monitoring.

SELECT PROJECT DOCUMENTATION LIST

MTR 6055	November 1971	Management Plan
MTR 6182	May 1972	Overview of Measurements
MTR 6215	July 1972	Continuous Monitoring System (Specifications COK-1 through 23)
WP 8788	15 July 1972	Important Considerations Concerning Sampling
MTR 6260	October 1972	Emissions Guide Systems
WP 10149	14 Dec. 1972	Design of an Optical Emissions Measurement System for Coke Oven Monitoring
MTR 6288	December 1972	Manual Sampling System
WP 10179	16 Feb. 1973	Manual Sampling and Analytical Requirements for the Coke Oven Charging Emissions Test Program
WP 10427	25 Oct. 1973	Coke Oven Data Analysis Workbook
WP 7905 Vol. XXI	19 Nov. 1973	Test Plan for Coke Oven Emissions
MTR 6546	November 1973	Optical Emissions Measurement Program for the Smokeless Coke Oven Charging Demonstration
WP 10459	15 Jan. 1974	Monitoring Emissions from Leaking Coke Oven Doors
WP 10480	31 Jan. 1974	Direct Impaction Particulate Collection Carrousel
WP 10445	15 Feb. 1974	Correction and Conversion Factors of Coke Oven Emissions Data
MTR 6566	28 Feb. 1974	A Continuous Monitoring System for Coke Oven Emissions Due to Charging

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16. ABSTRACT

The report summarizes results of a coke oven charging emission control test program conducted at the P4 Battery of the Jones and Laughlin Pittsburgh Works between April 1971 and May 1974; actual field testing was between May and August 1973. Objectives of the test program were: to quantify atmospheric pollutants resulting from the coking process charging operation; to provide a comparative evaluation of a pollution abatement system (an improved design larry car versus an existing larry car); and to determine the feasibility of a compliance monitoring system concept based on optical measurement. All program objectives were accomplished: emission characteristics of the charging operation have been defined in terms of both gases and particulates released to the atmosphere. Emissions were also defined from leaking seals on the pusher side doors of the oven. Several pertinent conclusions were also developed relating to coke oven emissions measurement technology.

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Iron and Steel Industry		Stationary Sources	11F
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COKE OVEN CHARGING EMISSION CONTROL TEST PROGRAM - SUPPLEMENTAL OBSERVATIONS

by

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ABSTRACT

The larry car, developed jointly by the American Iron and Steel Institute and the Environmental Protection Agency, was tested at the Jones and Laughlin Pittsburgh Works by The MITRE Corporation during the Spring and Summer of 1973. The purpose of these tests was to demonstrate the improvement in atmospheric conditions that can be obtained while charging a slot type coke oven. New larry cars having both similar and contrasting features are currently in operation on other slot type coke ovens, and their effectiveness should logically be assessed as an adjunct to the J & L car evaluation process. This report describes the procedures used to gather comparative operational information at the Weirton Steel Corporation, Division of National Steel Corporation, Brown's Island Coking Plant, where two charging cars, similar in several ways to the J & L car, are in production operation.

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The authors would like to express their appreciation for the splendid cooperation and support of Weirton Steel personnel, particularly Mr. Houston Woods, Director of Environmental Control; Mr. Gene Current, Assistant Director of Environmental Control; Mr. Thomas Emmerth, Assistant Superintendent of Brown's Island Coke Plant; and their respective staff members. The task of gathering the required information was aided immeasurably by the help of these gentlemen.

The design of the particulate sampling equipment represents the adaptation of an earlier MITRE design to the unique problems encountered in the proposed observations. Mr. Andrew Wallo III, played a major role in the adaptation and fabrication of the particulate sampling equipment used and described in this report.

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1.0 CONCLUSIONS

Information was gathered on the design and operation of the new charging cars operating on the Brown's Island battery of the Weirton Steel Division, National Steel Corporation. A comparative analysis with the AISI/EPA charging car demonstration of the ability to reduce emissions due to charging was then performed. A direct comparison was made in areas where the similarities between the Weirton cars and AISI/EPA car designs are strong. In areas where contrasting features or procedures were observed, assessment of their success relative to design intent and EPA objectives is reported.

The strong similarities between the two designs are: basic automation of the coke oven top side activities, specifically control of the damper, steam and ascension pipe caps, ascension pipe cleaning, and lid removal-replacement; improved operator environment; improved coal handling systems to control coal flow and contain emissions. An integral part of the improvements in emissions containment is the improved drop sleeve-to-oven port seals and aspiration of the ovens to the collection main during charging. These features are considered part of the charging system.

Both systems appear to have had reasonably good success in automation of the oven controls. Although the Weirton car has a somewhat more complex set of functions (dual collection mains), both cars performed required functions with only an occasional malfunction, usually caused by misalignment of the actuating or control arms. Both cars had lid lifting mechanisms which adequately performed the required

functions. Both cars experienced similar problems with the lid lifting electromagnets and their associated wiring. The re-lidding cycle for the Weirton car was a few seconds slower than the AISI/EPA car, but this appears to be a function of the control system adjustment rather than a basic difference in the design capability. The ascension pipe cleaning device on the Weirton car appears to work quite well. There is still, however, an occasional need to manually clean the ascension pipe goosenecks. The original design of the cleaner for the AISI/EPA car was unsuccessful, reportedly because of alignment problems. We have not observed the operation of the replacement unit so we cannot comment on its operation. We understand, however, that its design is similar to the Weirton unit. If so, similar results should be expected.

Both cars have had reasonable success in the improvement of operator environment. This comment is not based on quantitative data, but rather on conversations with several operators and "in the cab" observations. There were, however, some comments at both locations to the effect that the cab placement and configuration makes direct observation of the car operation and oven conditions difficult, if not impossible. Such restrictions of view may represent a safety as well as an operational problem.

The two cars employ contrasting approaches to coal flow control. The Weirton car uses a screw feed transfer conveyor, while the AISI/EPA car depends on gravity to feed the coal directly from the

hopper down through the drop sleeve into the oven. The screw feed arrangement controls coal flow by stopping or starting the screw transfer unit. The gravity feed is controlled by a butterfly valve in the drop sleeve assembly. We understand that screw or turntable feed is generally recognized as providing better coal flow control, but that coal hopper clearance restriction on some batteries may prevent the consideration of these designs for retrofit or replacement cars. This was a major consideration in the choice of the gravity feed system for the AISI/EPA demonstration car. A detailed analysis of system performance is somewhat beyond the scope of this paper, but observations to date would tend to substantiate the superiority of the screw and possibly the turntable feeds over gravity feed. It does appear that correction of certain proven design problems, such as drop sleeve packing and side wall angle may substantially improve the performance of the AISI/EPA gravity feed car.

Both the AISI/EPA and Weirton cars represent substantial improvements in emission control compared to older cars observed. While the AISI/EPA car seems more capable of sealing the emissions during the charge, it is less consistent in overall emission control than the Weirton car. The relief (coking) stacks on the Weirton car appear to be the source of 50% of more of its emissions, especially near the end of the charge. The AISI/EPA car, on the other hand, seems more able to reduce emissions during this period, assuming that the drop sleeves have properly seated in the ports. The Weirton car drop

sleeve seal usually exhibits some leakage, but the rate (i.e., the seal) is fairly consistent. The AISI/EPA car seal exhibits a more "very good" or "very bad" tendency, perhaps because of its weight and resistance to movement sometimes necessary to seal alignment. It was concluded, however, that both the AISI/EPA and Weirton charging car drop sleeve-to-oven port seals represent considerable improvement over older types of drop sleeves in the areas of both coal spillage reductions and emission containment.

Containment of the emissions during the charging process at both J & L and Weirton is heavily dependent upon the reduction of oven pressure through steam aspiration. The original concept for improvement of aspiration at J & L involved the replacement of steam ejectors and the raising of steam pressure supplied to the ejectors to 175 pounds. Marginal improvements were obtained using the higher pressure and the potential problem of increased coal carry over was recognized. Experimentation showed that a reasonable compromise could be achieved by running approximately 120 pounds pressure to the new ejectors. It has been reported that further improvements have been accomplished through the installation of jumper pipes between existing "smoke holes." This has the effect of connecting two oven aspirating systems in parallel and supplying an off take passage at both ends of the oven as in a dual collection main system. Substantial improvements in oven aspiration have been reported.

The double collection main system at Weirton has performed well under most charging conditions. Improvement has been attempted by raising steam pressure to the ejectors, but coal carry over problems were experienced causing some pressure reduction. The system is now operating at an acceptable level and generally holds the oven close to neutral during charging. A major portion of emissions for both cars occurs after the drop sleeves have been raised for re-lidding and are thus beyond the control of the car itself. The elimination of these emissions will depend primarily on oven aspiration, leveling procedures, and to a much lesser extent, the details of how the coal was placed in the oven.

We recognize the impossibility of generalization as to production rates for all battery conditions, much less production rates for other batteries, but investigation and observations indicate that a rate of 40 to 45 ovens per 8 hour shift from a single set of functional machines would represent a reasonable production goal. On batteries where operating units must be shared, this rate may be substantially altered. Such sharing is praticed at J & L, but is not currently practiced at Weirton. Observations and associated discussions of the Weirton and AISI/EPA car indicate that the Weirton car has never been and is not expected to be pacing unit of the battery under present operating practices. This conclusion is consistent with the average observed charging time of five minutes for the Weirton car. The AISI/EPA car has displayed a tendency to be the pacing factor,

particularly when operations are running behind the normal production schedule. This statement is consistent with observed charging times ranging from 7 to 10 minutes. The situation might be affected substantially, however, by changes in operating practice, such as the adoption of stage charging (i.e., the cars might be more closely matched).

Both cars provide flexibility in their opreation through the use of independent/step controls for each function. This flexibility allows the adoption of modified procedures, such as stage charging or the circumvention of problem areas when mechanical or electrical problems occur. Judging from discussions with maintenance and operating personnel, the Weirton car has undergone more extensive additions and modifications to the control system than the AISI/EPA car. The changes, most of which have been initiated by the local supervisory and maintenance personnel, have for the most part proved to be useful in both maintenance and operation under conditions of malfunction.

The training of operators to run the Weirton car has not presented a problem in terms of production rates or lost production. The new operators go through a break-in period during which time they work in parallel with an experienced operator. The operators we spoke to did not express any problems in learning the operation of the new cars.

Based on discussions and observations, the Weirton car has few problems in the area of operability/dependability. With the exception of the two instances reported here, involving some damage by fire, no lost oven production was attributable to the Weirton charging cars. During the observations, one car operated 24 hours a day for five straight days without any malfunctions which caused production delays or loss of production. We feel that much of this record can be attributed to the mechanical arrangement of the Weirton car. Elements of the hydraulic and electrical system are positioned away from the drop sleeve, open charging port and potential flame and heat. We also feel that the relatively light weight of the drop sleeve assembly contributes to the lack of mechanical/hydraulic problems. An additional factor which we feel has a significant impact is a thorough understanding of car operation and control by individual operators. This certainly reduces the incidence of equipment damage caused by improper or negligent operation.

Equipment malfunctions will inevitably occur, but their impact can be magnified by delays in remedial actions. An important factor which tends to reduce the time required for resolution of maintenance problems is the centralization of responsibility for initiation and control of necessary work. At Weirton, the electrical department is totally responsible for all equipment maintenance work except for the heaviest mechanical work that may require special assistance. All necessary trades are included in the make up of electrical department

personnel. When outside help is required, they operate under the centralized direction of the electrical department. These factors improve coordination, reduce worker availability delays and generally expedite required repairs.

One final point should be made to help place the comparison of the two cars in perspective. That is, that the AISI/EPA car represents the retrofit of a new car to an older oven (P4 battery is nearing 20 years of age), while the Weirton car is a new car designed for and placed on an entirely new battery. Many of the problems experienced by the AISI/EPA car can be traced to battery equipment wear and misalignment problems. The difficulty experienced in predicting relative position changes caused by oven expansion, wear, and modifications, tend to indicate that equipment intended for retrofit should be designed to provide the maximum tolerance to "misalignment" practical, and consistent with emission control, and that new equipment should be given similar consideration in order to minimize maintenance and operating problems as it ages.

2.0 INTRODUCTION

The larry car, developed jointly by the American Iron and Steel Institute and the Environmental Protection Agency, was tested at the Jones and Laughlin Pittsburgh Works by The MITRE Corporation during the Spring and Summer of 1973. The purpose of this testing was to demonstrate the improvement in atmospheric conditions that can be obtained while charging a slot type coke oven. New larry cars having both similar and contrasting features are currently in operation on other slot type coke ovens, and their effectiveness should logically be assessed as an adjunct to the J & L (AISI/EPA) car evaluation process. This report describes the procedures used to gather comparative operational information at the Weirton Steel Corporation, Division of National Steel Corporation, Brown's Island Coking Plant, where two charging cars, similar to the AISI/EPA car, are in production operation.

MITRE observed these two charging cars in production operation in March and April of 1974 using observers familiar with the coke oven environment and the operation of the AISI/EPA car during the original test period. This report presents three general subject areas for which information was obtained. The first area concerns a description of the Weirton coking system, including oven configuration, larry car operation, and the coke oven charging procedures in general. The second area involves the actual observation of the two Brown's Island larry cars during the coal charging operation, which involved recording of emission characteristics and electro-mechanical

performance. The last area discussed is a brief work history of the two larry cars obtained through interviews with coke plant personnel responsible for the operation of the larry cars.

3.0 SYSTEM DESCRIPTION

3.1 Historical Background

One of the newest slot type coking facilities in the United States is located at the Weirton Steel Division of National Steel Corporation in Weirton, West Virginia. The battery, comprised of 87 ovens, is located on Brown's Island in the Ohio River adjacent to the main plant facility. At this time, the ovens and their associated by-product recovery facility are the primary activities on the island.

Work on the construction of the Brown's Island facility was started in August 1970. The oven was brought to a point where construction of the charging cars could commence in August of 1972. The oven first produced coke on May 31 of 1973 having experienced some delay caused by a gas explosion during initial firing of the facility. The ovens were considered to be in regular production operation at that time and have been operating continually since that time.

The break-in period of the facility is defined as the time from the first production of coke until the establishment of routine operational and maintenance procedures with the associated substantial reduction of production delays caused by nonfamiliarity with the new equipment and procedures. Based on discussions with supervisory operating personnel, reasonably smooth operation of the charging car was achieved in December of 1973. Although occasional problems arise which cannot be immediately resolved, supervisory maintenance

personnel say they now feel confident in their ability to understand the machine operation, and to solve problems in a timely manner as they occur.

3.2 Oven Description

The Brown's Island facility employs some of the most recent coke oven technology, including an enclosed pushing and quenching capability. The pushed coke is received by a closed refractory-lined hopper car which is connected via ducts to a car mounted scrubber. The hopper car is unloaded through bottom gates into stationary refractory lined hoppers beneath the track. These hoppers in turn feed the hot coke to the enclosed quench units. The resulting gases are cleaned prior to release to the atmosphere.

The ovens are of the tall (20 feet) configuration and utilize a double collection main by-product recovery system. Each oven charge contains approximately 70,000 pounds of coal. The oven is charged through four ports spaced unequally across the width of the oven.

The port design features a tapered oven top seat contoured to accept and seal the lower portion of the larry car drop sleeve (boot) and a matching lid which uses a "sharp edge" seal especially suited for "setting" by rotation by the car mounted automatic lid lifter mechanism. The cast iron lid has a sealing edge diameter of ~19-3/4 inches and the oven port has a minimum diameter of ~17-3/4 inches. This diameter extends downward through the brickwork for a distance of approximately 1 to 1-1/2 feet where the passage fans out laterally to a width of 3 to 5 feet at the oven inner roof.

During the oven charging cycle, aspiration of the ovens is accomplished using steam ejectors. The ejectors located in the collection main side of the ascension pipe bend are of standard configuration. They are currently operated at 100 pounds pressure and approximately 400°F+ steam.

During recent periods of operation at higher pressures, problems were encountered in the by-product primary cooler spiral heat exchangers. The excessive coal carry over caused fouling of the liquor side of the spiral heat exchanger. In addition, this problem was aggravated by the cooling unit water having a high iron content which in turn caused excessive scale to be deposited on the water side of the spiral heat exchangers. The two problems combined to produce high by-product input temperatures that came very close to causing facility shutdown. The improvement of cooling water quality and the reduction of aspirator steam pressure are credited with the current solution to this problem.

During discussions of the carry over problem with Weirton personnel, they voted some continuation of excessive coal carry over build ups in the liquor traps and on damper valves. As a result, they found it necessary to initiate more frequent trap clean outs. Although J & L operating personnel reported no problems with by product cooling units, they also reported a requirement to clean the traps at more frequent intervals as compared to operation with lower ejector steam pressures. A possible explanation for the differences in operating experiences

between the two sites is that the Weirton coal preparation process produces a higher proporation of fines than the J & L process. This could allow a higher preparation of cool dust to pass the trap and potentially foul the cooler units. This situation is being investigated and appropriate action will be taken.

The seal of the ascension pipe caps is an area in which problems are frequently encountered. The design of the cap is similar to the charging port design in that a sharp edge seal is employed. The cap is allowed to "float" with respect to the hinge mechanism to provide a self-centering seating action. Considerable leakage around caps was observed immediately after a charge, with many continuing to leak for several hours into the coking cycle.

It appears that the relatively short "leak path" around the "sharp edge" seal is not readily plugged by the self-sealing action of condensing and hardening tars and carbon build-up. An investigation of the problem is currently under way by Koppers and two new cap configurations are undergoing tests on operating ovens. A solution to the problem is important, since observation indicates that the cap leaks account for a substantial portion of the ambient background emissions (conditions between charging operations). Also, cap leaks occurring during charging and aspiration diminish the vacuum capacity available at the charging ports. Although probably not sufficient to make the difference between a negative and positive port condition, the lost capacity would allow emissions to the atmosphere which would otherwise be contained by the recovery system.

3.3 Charging Car Description

The two charging cars operating on the Brown's Island Battery utilize some of the most significant improvements in modern coke oven technology. The cars are of the basic screw feed design, but several features have been added to improve car operation and the conditions in which the machine operators work. These features are discussed in the following section.

The charging car coal handling system (Figure 1) for each of the four charging sleeves is comprised of a car mounted hopper, a screw type conveyor fed by gravity from the hopper, a "slide plate" valve, a "drop-boot", and a device for mechanically removing and replacing the charging port lids. The significant difference between this coal handling system and the system used on the AISI/EPA car (Figure 2) is the use of the screw conveyor to control the coal flow as opposed to an oscillating "butterfly" valve in the lower portion of the "drop sleeve" on the AISI/EPA car.

The coal is gravity fed from the main hopper to the screw conveyor which can be stopped or started using separate controls in the control cab. The slide valve at the drop sleeve end of the screw conveyor is not used to control the primary coal flow. Its primary function is to seal the drop sleeve after the charge and also to prevent coal tailings from the conveyor tube from falling on the oven surface or the lid lifting mechanism. This arrangement provides a positive coal feed through the screw to a point above the slide plates. From this point, the coal drops loosely through the open slide plate, through the drop sleeve assembly and into the open charging port. In

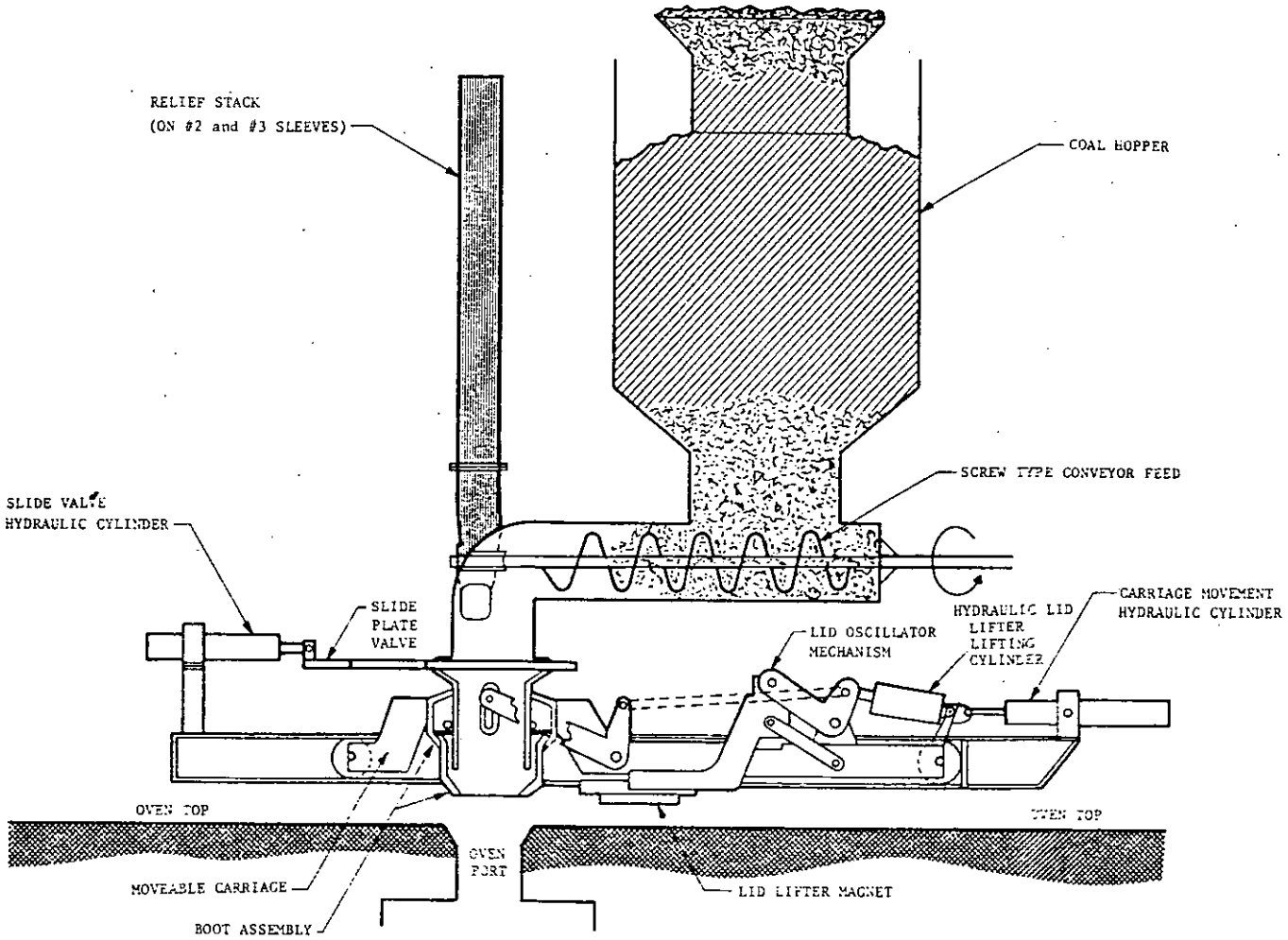

FIGURE 1
WEIRTON CAR ARRANGEMENT

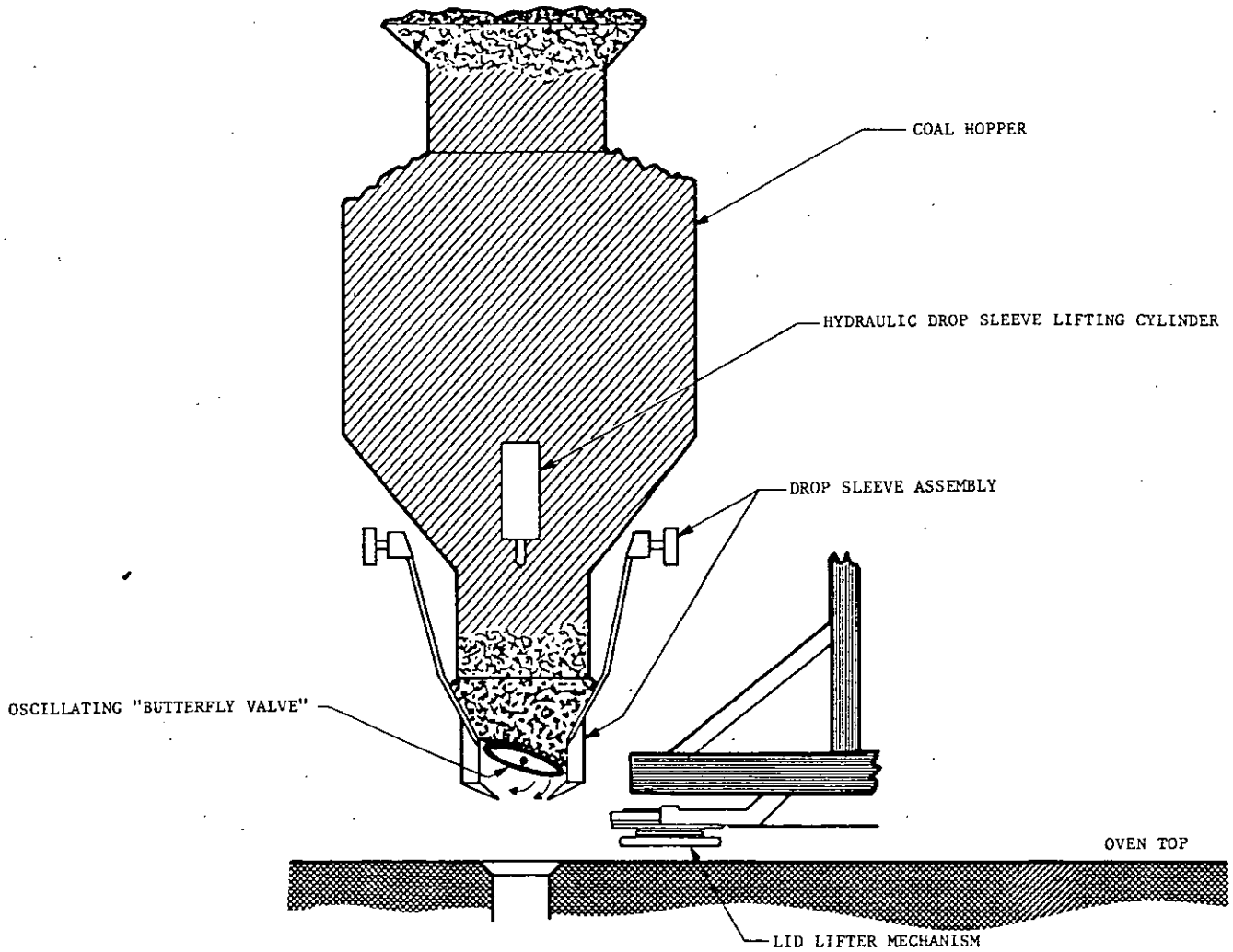

FIGURE 2
J & L CAR ARRANGEMENT

contrast, the coal in the AISI/EPA car is fed by gravity to the drop sleeve assembly. The flow of coal is controlled by the butterfly valve in the lower portion of the sleeve which oscillates back and forth to allow the coal to feed past it into the open charging port. The AISI/EPA car is designed to maintain some coal on top of the butterfly valve to improve the sealing function of the drop sleeve after the charge. The intent of both systems is to seal the lower portion of each drop sleeve after the hopper has emptied until the re-lidding sequence can be initiated.

The Number 2 and Number 3 sleeves on the Weirton car are equipped with relief stacks connected to the system at the drop sleeve end of the screw conveyor above the slide plate valve. The other two sleeves (Number 1 and 4) also have attachment points for similar stacks but these are blocked off by cover plates installed at the time of car fabrication. During the latter portion of the charge when Number 3 and Number 2 hoppers have emptied, the stacks vent emissions caused by oven back pressure until slide plate valve closure is initiated. If emissions caused by oven back pressure are present on sleeves 1 or 4, and the slide valve is not closed, the emissions are vented through the screw conveyor and up through the empty hopper. Closure of the slide plate valves effectively stops emission venting through both the stacks and the empty hoppers.

The lid lifting mechanism on the Weirton car utilizes an electromagnet to secure the port lid to the lifting mechanism. The lifting

and lateral motion is supplied by a combination of hydraulic piston cylinders. When the lid is replaced after a charge, the lifter mechanism rotates the lid in its oven-top seat to improve the lid seal. This rotating action is supplied by a hydraulic rotary actuator.

The lid lifting mechanism is mounted on a wheeled carriage along with the drop sleeve assembly. The drop sleeve or "boot" is fairly light in weight. It is composed of two interlocking sections with a self-aligning inner seal ring. The horizontal movement of the carriage places either the drop sleeve or the lid lifter over the charging port on which the car is spotted. The complete carriage unit moves beneath and is independent of the slide plate valve. The action of each sleeve carriage can be controlled independently or they can be operated as part of the automatic master charge sequence.

The horizontal carriage motion is controlled by a cylinder located at the extreme end of the track assembly. The vertical lifting motion for both the drop sleeve and lid lifter are supplied by a cylinder located on the back end of the moveable carriage. Because the same lift cylinder is used for the lid lifter and the drop sleeve, they move up and down in unison regardless of which is in current functional use. The lid rotating motion is supplied by an actuator forming a part of the vertically moveable portion of the lid lifting unit. It is located behind the lid magnet and is connected to it by two operating rods. The arrangement described maintains maximum separation of system hydraulic components from the area directly above an open charging port.

The major difference between these functional systems on the Weirton car and the AISI/EPA car is the separation of the drop sleeve assembly from the moveable carriage. On the AISI/EPA car, the drop sleeve is raised to allow the lid lifter mechanism to move horizontally under it. The lifter mechanism is lowered to secure and lift the cap. It is then retracted to allow the drop sleeve to be lowered for the charge. No horizontal movement of the drop sleeve is necessary during the sequence. The drop sleeve is quite heavy on the AISI/EPA car. Added to this is the weight of the coal being gravity fed into the top of it. This weight is utilized to achieve seat alignment and seal integrity in the oven top port during the charging operation. The separate hydraulic cylinder used to raise the drop sleeve assembly is located on a heavy frame along the upper side of the sleeve assembly.

The Weirton car is designed to minimize the requirements for oven top workers. The lid lifting and re-lidding mechanism performs one of the functions normally handled by these personnel. A second function, the control of the collecting main damper and the steam ejectors, is accomplished through the use of operating arms attached to hydraulic rotary actuators mounted on the car. Eight such arms are used, four on either side of the car to operate the pusher and coke side ascension pipe controls. The arms operate in pairs, one to open the damper and one to close it; one to open the ascension pipe caps and one to close them and simultaneously turn on the ejector steam. The steam can also be turned off by the proper operation of

the arms. All arms operate on controls of the oven on which the car is spotted. All control functions can be performed on this oven without moving the car.

The chore of ascension pipe cleaning (normally handled by the car operator) is performed by two car mounted mechanical cleaning devices controlled from within the cab. The units rotate outward from the car to contact the edge of the open ascension pipe. An interlock prevents the completion of the operation unless the caps are open and the frame of the device is properly seated on the edge of the open pipe. When seated, the device extends a shaft into the open pipe. A serrated scraper known as a "cookie cutter" mounted on the end of the shaft cleans the sides of the ascension pipe bend. At the end of the outward stroke, the scraper is automatically retracted and raised back to the stored position on the car. The complete cleaning system is operated hydraulically.

The functions of ascension pipe control and cleaning are achieved in a similar manner on the AISI/EPA car. A few operational differences are, however, worthy of mention. The AISI/EPA car employs a single operating arm to control the functions on the oven to be charged. A second operating arm is positioned so as to control the lid and damper on an oven to be charged in the next sequence. The car mounted ascension pipe cleaner is positioned to operate on the same oven.

The ascension pipe cleaner on the AISI/EPA car was originally designed to employ a rotary flail-type cleaner, however, recent changes

in design have modified this concept. It is understood that a scraping action similar to the Weirton device will be utilized on the new system.

The original design of the Weirton cars did not call for vibrators on the hopper units to assist in coal flow. After experiencing some occasions where wet coal clung to the hopper side, the decision was made to install and test electro-mechanical hopper visbrators on the car. Two such units were attached to the sides of hoppers 2 and 3. A manual control switch for the two vibrators was installed on the control panel in the cab. The switch is connected in such a way as to allow vibrator operation only during a charging sequence.

During the normal operation of the car (as observed during the two week period), the vibrators were not used. On two occasions in which the car capabilities were being demonstrated to new operators, the vibrators were turned on for a short period. Operating personnel report that the vibrators are needed only during the most severe "wet coal" conditions and are generally capable of clearing the hoppers with only a short burst of operation. We were told that no plans had been made to install vibrators on all the hoppers at this time.

The occasional use of vibrators on the Weirton car is in contrast to the programmed use of vibrators on the AISI/EPA car. The vibrators are automatically controlled as part of the AISI/EPA car charging sequence and operate for a set period of time. Controls on the cab panel do, however, allow the operator to turn off the vibrators.

The control of the Weirton car during a charging operation is accomplished through the use of electro-mechanical timers and relay logic circuitry. Solid state circuitry is utilized only in the traction drive motor proportional control units. In addition to the normal relay logic circuitry, a number of circuits which bypass certain logic interlock strings have been added. These bypasses which have limited access and are not used in normal operation, provide an emergency capability to clear the car functions and allow it to move or be moved along the top of the battery. It is also possible using certain types of these bypasses to manually operate some of the car functions should a malfunction occur in the normal control logic. It was reported that this bypass capability has been responsible for maintaining production in several instances when malfunctions occurred and the spare car was not immediately available for relief operation. Operation of the car using these circuits generally requires a second operator in the car equipment room and close coordination between the cab operator and the bypass operator.

No method is provided on the Weirton car for the indication of coal level in the hoppers or coal flow in the system. The initiation of an automatic charge cycle starts timing devices which open the slide valves and sequentially start the conveyor screws. The screws continue in operation until the timed sequence runs out or the car operator judges that the hoppers are empty. The operator uses several observations to aid him in this decision. They include elapsed time from the start of the charge, observed activity around each drop

sleeve, the position of the leveler bar, flow of smoke from the 2 and 3 sleeve stacks, and the observed drop in screw motor current when the hoppers go empty. The operator can also leave the cab and visually check the coal level in the hoppers through ports cut in the side of each hopper. This, however, is seldom necessary.

The lack of level sensing devices is in contrast to the multi-point level sensing system used on the AISI/EPA car. The charging control system senses the "20% remaining" level signal and interrupts the coal flow at this time to start the leveling sequence. Coal flow is started again when the pusher operator confirms the start of leveling. The lower level sensor ("hopper empty") is responsible for stopping the coal flow to insure the presence of a coal plug above the butterfly valve.

The last feature of note is the improvement of the operating cab environment. The cab is closed and was observed to be generally free from charging emissions during relatively heavy smoke conditions. An air conditioning unit in the cab seems to be quite effective. In addition to this unit, a second unit has been added to the cars electrical equipment room to hold its temperature at a lower level. The operators seemed quite pleased with the conditions compared to those generally associated with the operation of a larry car.

4.0 CHARGING OPERATION

4.1 Coking Cycle

As in most plants, the coking time is a function of several variables including product demand, coal characteristics, manpower availability and raw material availability. During the two weeks of observation, the coking time had been raised to 23.5 hours because of shortages of delivered coal. The longer cycle decreased the plant production rate, and thus the number of charging operations performed in a shift.

The operating pace had been slowed to 30 ovens per 8 hour shift. We were told that a rule of thumb for a normal production rate change is to add or drop 1 over per 8 hour shift. Their normal production pace utilizes between a 17 and 18 hour coking cycle. To this date, the Brown's Island Battery has reached and maintained a maximum of 39 ovens per shift. It is expected to be able to maintain a maximum production schedule somewhat above this rate.

4.2 Charging Sequence

After the larry car fills its hoppers at the coal bin, it then proceeds to the oven that is scheduled to charge (A-1 in this example). A sequential numbering system is used in which the 87 oven batteries are divided into three equal sections; A, B and C. Figure 3 presents a small portion of Section A to clarify the discussion of the charging sequence, while Table 1 displays a portion of the Weirton charging and dampering sequence. The first operation the larry car operator performs is to spot the larry car over the oven to be charged. He accomplishes this by aligning pointers on the larry car with the

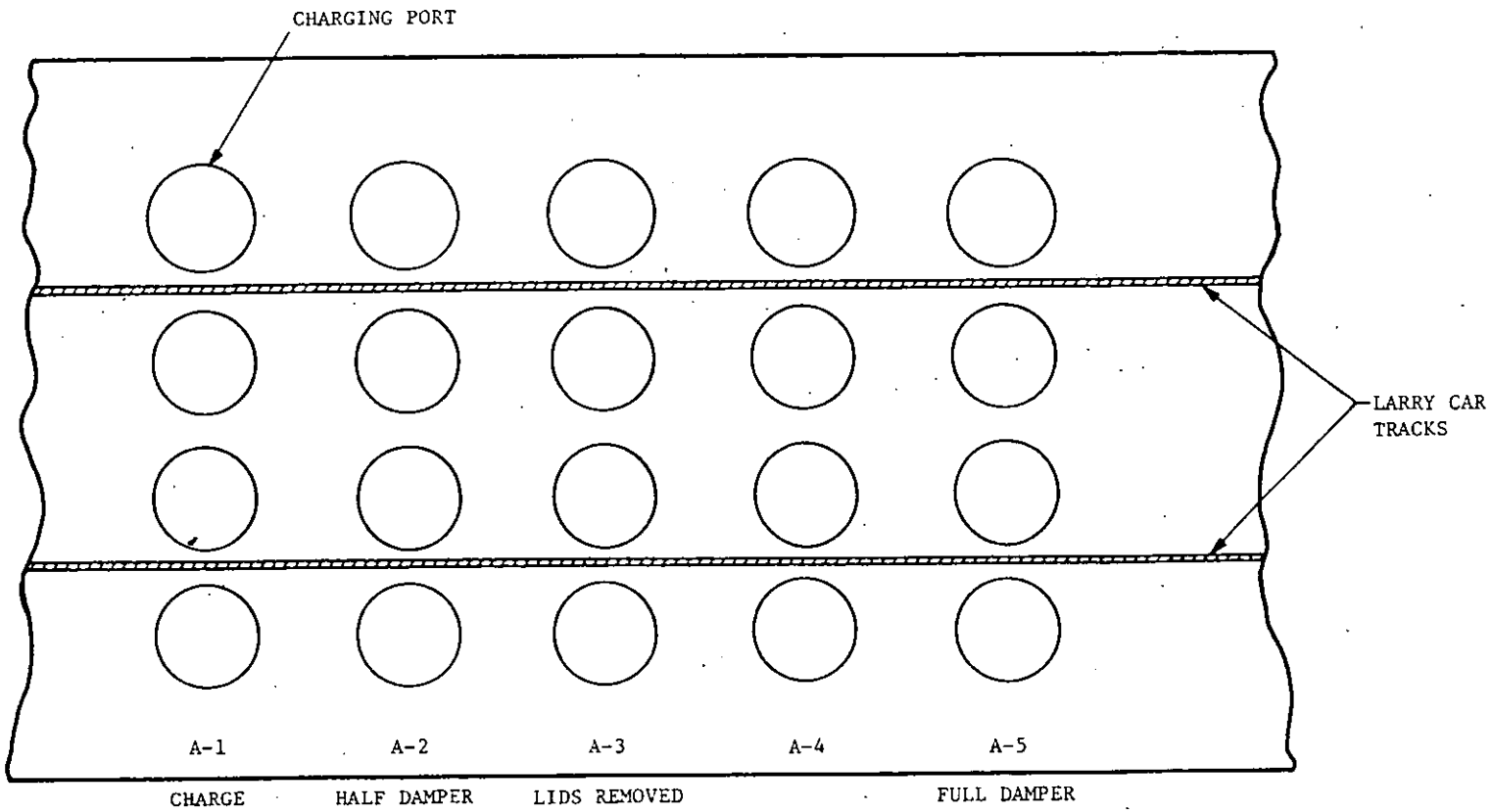

FIGURE 3
OVERHEAD VIEW OF OVEN POSITION IN THE CHARGING SEQUENCE

TABLE 1

DISPLAY OF WEIRTON CHARGING AND DAMPERING SEQUENCE

Charge	Half-Damper	Remove Lids	Damper
A-1	A-2	A-3	A-5
B-1	B-2	B-3	B-5
C-1	C-2	C-3	C-5
A-3	A-4	A-5	A-7
B-3	B-4	B-5	B-7
C-3	C-4	C-5	C-7
A-5	A-6	A-7	A-9
B-5	B-6	B-7	B-9
C-5	C-6	C-7	C-9
A-7	A-8	A-9	A-11
B-7	B-8	B-9	B-11
C-7	C-8	C-9	C-11
A-9	A-10	A-11	A-13
B-9	B-10	B-11	B-13
C-9	C-10	C-11	C-13

oven flue caps two ovens behind. Once this is done, the operator activates the automatic gooseneck cleaner buttons, and the necks of the ascension pipes are purged automatically. The larry operator is now ready to charge, and waits for the go ahead signal from the pusher car. Upon receiving the signal, the operator activates the actuator arm which closes the ascension pipe caps and turns the collecting main steam on simultaneously. When these tasks are complete, the operator presses the master charge button which initiates the actual charge. The larry car now operates automatically until the end of the charge, at which time the lid return cycle is initiated by the automatic timers, or by the operator, depending on the selected mode of operation. After the charge is over, the operator backs up and half dampers oven A-2 to stop cross flow across the oven caused by unequal pressures in the collecting mains. Next the operator removes the lids from the oven being pushed, A-3, which will undergo a decarbonization cycle of approximately 40 minutes. The operator then backs up to the next oven to be pushed, A-5, and full dampers it, while also opening the ascension pipe caps. During the week of March 24-29, the lids were left on the charging ports during decarbonization in order to build up a layer of carbon at the top of the oven. Because of this, lids had to be removed just prior to the gooseneck cleaning step in the ordinary charging sequence. As a result of a lid lifter malfunction, an indicator lamp signaled that a lid had been removed when it had not. The operator, thinking he had a clear port, initiated the charge into a closed port. This caused considerable coal spillage on the oven top before the condition was

detected and the feed stopped. This problem had reportedly occurred several times on the night shift. No problem was discovered in the lid lifter mechanism, but in order to insure proper removal of the lids, the larry car operator would come off his spot following the lid lifter operation, to visually check lid removal. The car was then respotted and the charge was performed in the normal fashion. This practice added several seconds to the normal time required for a charge, but the larry car was generally ahead of the other elements of the operation.

4.3 Leveling Procedure

After the larry car has charged the oven with about 80% of its coal, the leveling sequence begins. The pusher car receives a signal in the form of a loud buzz from the larry car. This buzz is activated by a timer in the master charge button electronic control circuitry. Leveling is then initiated in the pusher car by pushing the automatic leveling sequence button. All leveling from this point in time is automated. The leveling is performed with the coal flowing from the number 2 drop sleeve. This was a very consistent leveling practice at Weirton, and no deviations from this scheme were observed.

There has been a problem at the Brown's Island Battery involving coal spillage during the leveling procedure. During the earlier operation of the Brown's Island Battery, the leveler bar had been inserted into the oven considerably earlier in the charge, and was leveling for some longer period of time. The Weirton personnel observed excessive amounts of coal spillage during this time, and as a result, the leveling sequence was altered. A shorter leveling

period was initiated and the coal spillage was decreased because of the lower number of leveler bar strokes, each of which drags some coal out of the chuck door. This represents a trade-off of changing of the leveling time to prevent coal spillage against the fact that waiting a longer period of time to level causes the open gas passage to both ascension pipes to be reduced.

There having been two alternative coal spillage reduction methods proposed at Weirton. The first was the use of air hoses to blow the coal wedged between the leveler bar baffles loose to keep the leveler bar operating at peak efficiency through each leveling stroke. Heat seemed to be a problem as far as hose maintenance was concerned, and the idea was abandoned. Another proposed solution was the use of a chain to drag along the top of the leveler bar to knock the coal loose between the leveler bar baffles in its reverse stroke.

4.4 Collecting Mains

The Brown's Island Battery utilizes a double off-take collecting main system to service each four charging port oven. The coke side and pusher side collecting mains are interconnected by two overhead cross-over pipes that span the oven approximately at one third and two thirds of the oven's distance lengthwise.

The standard pressure and temperature at which the mains operate are 11 mm and 72°, respectively. These are variable controls and are increased and decreased as the coke plant superintendent deems necessary during different coking schedules and special situations.

4.5 Coal Description

The Brown's Island Battery is equipped with its own separate coal preparation plant which is divorced from the mainland coal preparation plant. The coal is currently sized at 72% passing an 1/8 inch screen.

5.0 CHARGING OBSERVATIONS

5.1 Reporting Procedures

Direct observations of the larry car performance in production operation were made by personnel familiar with details of the charging operation and the coke oven environment. In order to make the observations simple and efficient, no instrumentation was employed to measure emission quantities. The observation scheme relied instead upon the judgement of the observer to assess the relative quantities of observed emissions from some pre-defined points on the larry car. The observer characterized the emissions from each designated point as either a blank box (none observed), L (light flow), M (medium flow), or H (heavy flow). The basis for this judgement was developed by watching several typical charges by the car and moderating the observations based on recalculations of emissions flows on the J & L cars, including the AISI/EPA car. In addition to the flow information recorded, other observations such as the general color of emission, the presence of flame at a point, and the dynamic flow characteristics (puffy, increasing, decreasing, changing to) were also noted.

The points designated for observation were the areas around and immediately above each drop sleeve (boot) seal, the four hopper tops, and the stacks attached to the number 2 and 3 sleeves. It is estimated that these points account for at least 90% of the emissions through the car during a charging operation. All of these points are visible from a point on the oven surface approximately 50 feet in

front of the car. The observer remained at this approximate position throughout the charging operation under observation. From this point, it is generally possible to differentiate emissions from sources other than the car and to judge the flow characteristics.

During the charging operation, a record was made of observations at 15 second intervals. This interval was found to provide a reasonably accurate account of the charging conditions. This interval was too short to allow the observer to record information directly on the form, so a portable tape recorder was used to record the observer's verbal commentary. This technique allowed the inclusion of sufficient detail and added commentary to provide a basis for completion of the observation form. The completed forms are included as Appendix I of this report.

A hand-held stop watch was used by the observer to provide timing information on the various segments of the charging operation. An overall time for just the charging operation (coal flow start to last lid on) was obtained for each of the observed charges. In addition, other segments and combinations of segments were timed to provide a comprehensive picture of the cars' operational pace. The total operation during the week of March 11-15 was on a reduced production schedule, therefore, steps involving operator initiated operations may not have been performed in the shortest practical time.

During the period of the observations, the general weather conditions remained relatively constant. No rain was experienced and the temperature ranged from the 50's up to the 70's. Due in part to the location of the oven (unshielded by adjacent structure on an island in the middle of a river), a constant breeze was present, ranging from a light 2-4 mph to continuous 15-18 mph wind. This wind was responsible for the rapid dispersal of emissions as they rose from the top of the oven or car stacks.

5.2 Summary of Performance Observations

The basic impression obtained from the observations is that the larry car is very consistent in its operation. For example, the observed charging times for 57 operations was between 1 minute, 30 seconds and 1 minute, 50 seconds with an average time of 1 minute, 39 and 2/10 seconds. Most of the observed spread in time can be accounted for by variations in the start of the operator initiated re-lidding cycle. A second example is the occurrence of a small puff of emissions from number 2 stack during the first 10 seconds of the charging operation.

Examination of the reporting forms shows that the first 30 seconds of the charge is fairly free from emissions except for this puff. Certainly this is due in part to the mechanical timer control, but the overall consistency of charge quality (emission level) cannot be achieved unless all goes smoothly, such as coal flow, leveling, re-lidding and oven control operation. The dependability was further

attested to by the fact that the lid man spent much of his time riding in the larry car cab. When a malfunction did occur, such as a lid not seating properly, he came down, quickly fixed the problem and returned to the cab. Discussions with the car operators confirmed the fact that little trouble has been encountered with coal flow. They also related a feeling of overall dependability, with some commenting that this car was more complicated than the other cars they had operated but that it worked well "in spite of this." In general, the mechanical problems observed were minor in nature and were handled by the car operator and lid man on duty at the time.

The spotting of the car on an oven is accomplished by aligning a car mounted pointer with flue caps set in the oven top. This is done by sighting down through a window on either side of the control cab. The system appears to provide the needed accuracy and it is simple to use. The only observed problem with the system was the visibility of the pointer and cap during certain light conditions. Late in the afternoon, the sunlight would strike the surface of the cab window in such a way as to obscure the spotting pointer and cap. The condition was similar on both sides of the car. It appears that the problem could be eliminated by shading the lower windows in an appropriate manner.

The drop sleeve units appear to have little problem in seating properly in the open charging ports. The lower portion of the unit can be canted considerably before a reasonable seal is lost.

Mis-spotting of the car can, however, cause a visible gap in the boot-to-oven seal. This seemed to occur primarily when the car was being respotted after a check to insure that all lids had been removed. No explanation was obvious since the same spotting facilities are used for both the initial and re-spotting operations.

The ascension pipe cleaners worked well during the period of observation. No malfunctions were observed and their cleaning ability appeared adequate. It was reported that on two occasions the scraper, or "cooky cutter," had fallen off the end of the ram into the collection main. In order to prevent this, a steel cable has been fastened around the scraper and to the ram shaft. The reported production delay caused by a malfunction of the cleaner involved the premature extension of the ram as the unit was swung down to the operating position. This was traced to a sticking interlock switch in the logic circuit. The event has not been repeated, and no remedial action is felt to be necessary.

The lid lifters performed well during observation. The only problem involved two occasions in which two separate units failed to remove lids. On an occasion, the unit was recycled and operated properly on the second try. On the other occasion, the lid was removed by the lid man without a second try by the lifter. On both occasions, the lifters worked without further problems on succeeding charges. We were told that occasionally the lid detector interlock switch does not actuate when in contact with the lid, and the magnet does not

energize. We were told that on one occasion, the magnet picked up a flue cap cover instead of the port cover. The cap detector interlock was made, and a charge was attempted with the lid in place. This resulted in a considerable coal spill before the coal could be stopped.

No serious problems in unit operation were observed or reported but it was noted that the electrical connections for this unit show rapid deterioration and are reported to be difficult to keep in good repair. No problems were observed in the unit hydraulic system, but it was reported that flexible elbows and couplings in the system had shown some tendency to leak prematurely. A more durable replacement for these units is being sought.

It seemed that the rotating action of the lifter is slow in comparison to the operation of the AISI/EPA car. The time between a rotation in one direction and a reverse rotation is long. This caused no observed problems but a "ready to travel" car condition might be achieved a few seconds earlier if the delay could be shortened.

The car mounted actuators which control steam, ascension pipe cap closure, and damper action, performed with only minor malfunctions during the periods of observation. On several occasions, the lid failed to travel over center when closure was attempted. Recycle of the system did not solve the problem and the cap was closed manually by the lid man. On two occasions, the actuator arms became jammed in the control levers and had to be freed manually using a long pry bar. We were told that the control levers are occasionally bent

causing misalignment of the arms. It was reported that this problem is solved by occasionally checking the levers and re-aligning them using a sledge hammer and wooden wedges. No serious delays have been reported as a result of control misalignment.

The screw conveyor and slide plate valve functioned normally during the observation period. No malfunction in their mechanical operation was observed, however, a coal plug did occur once on number 4 drop sleeve. It was reported that the coal had plugged in the charging port and caused a packing action back through the system. It took about 5 to 10 minutes to clean the plug in the port and complete the charge. During a discussion following the incident, operating and supervisory personnel did not feel that any car associated malfunction had caused the problem. It was suspected that the possibility of late leveler bar entry had caused or contributed to the problem.

During observed activities, attempts were made at timely closure of the slide valves based on an observed drop in screw feed motor operating current. The slight drop in current proved hard to detect and coordination of the activity was difficult to accomplish. The results of the trial runs did, however, indicate the value of timely valve closure by the observed reduction in emissions through the stacks. It appears that a valid and perhaps easier-to-implement approach would be the monitoring of coal flow in the sleeve just above the slide valve. When the detector indicates the end of flow, the valve can be closed immediately and the screw stopped. The sensor might be

arranged to mechanically operate a switch which would provide a signal or initiate closure of the slide plate valves automatically.

The electro-mechanical vibrators were not used in connection with normal charging during the observation periods. They were turned on twice to demonstrate their use to new car operators and they were turned on once as a demonstration for the observer. Conversation with car operators and supervisory operating personnel indicate that the vibrators are dependable in their operation and effective in removing coal clinging to the sides of the hoppers.

5.3 Functional Operating Times

As a part of observation activity, various segments of the charging cycle were timed to determine the cars' current operating pace. This section presents the results of this activity.

During each charge for which an observation record was made, a time for the charge was taken. The total charging time as observed by MITRE was defined as the time period between the initiation of the coal screw feed and the completion of the lid replacement cycle. This "total charging time" was recorded for 57 individual charges, and the average was found to be 1 minute and 39.2 seconds. The maximum charging time observed was 1 minute, 50 seconds, while the minimum was found to be 1 minute, 30 seconds. The occurrence of the coal plug on number 4 sleeve appears in this average as the time elapsed to the first re-lidding. No time was recorded for the clearance of the port and the completion of the charge to the number 4 port.

In addition to the standard time taken for each observed charge, segments of the total charging operation were timed. A summary of these times appears in Table 2. The terms "return to travel" and "ready to travel" refer to a condition in which the car is moving or ready to move to some other location on the oven.

Based on the cycle time from car spotting to travel to the coal bin of 3 minutes, 30 seconds, and the hopper filling time of 1 minute, an 8 minute complete cycle time does not seem unreasonable. The 39 oven per 8 hour shift pace that has been maintained on occasion in the past, represents an average cycle time of 12.3 minutes. It appears, however, that the pacing production system may be the coke side door machine which has a planned operating cycle time of a little over 10 minutes.

5.4 Particulate Sample Collection

As a part of the observations of oven charging activities, a number of particulate samples were taken around the number 2 and 3 drop sleeves and in the free emission plume around the bottom of the charging car. The device used to obtain these samples was designed and constructed by MITRE to perform this specific sampling task. A description of the device and test results is contained in this section.

During the course of testing at the J & L facility, considerable difficulty was encountered in obtaining a particulate sample which could provide meaningful data on the physical characteristics of the emitted material. These problems gave rise to the development by

TABLE 2

OBSERVED OPERATION TIMES

Approximate Time To Fill The Hoppers In the Coal Bin	1 Minute
Ascension Pipe Cleaning Cycle	30 Seconds
Lid Removal/Complete Cycle	16 Seconds
Lid Lifting Cycle/Timed From The Sleeve Raise Until The Lid Was Replaced	8 Seconds
Lid Lifter Oscillation And Return To Travel Ready Status	9 Seconds
Slide Valve Closed To Lid Lifter Ready	32 Seconds
Drop Sleeves Down To Ready Travel	2 Minutes, 10 Seconds
Lids On, Half And Full Damper To Ready Travel	53 Seconds
Spotting Of Car For Charge Through Half And Full Damper Cycle To Coal Bin	3 Minutes, 30 Seconds

MITRE of a direct impaction particulate collection device dubbed the MITRE Carrousel. The device was configured to pass glass microscope slides through the emission duct opening. The slides, one surface of which was coated with silicon grease, collected particle samples for direct viewing and analysis under an optical microscope. Details of this device and its operation are reported in MITRE WP-10480 and the coke oven testing program final report.

A similar approach was selected for use in collecting particle samples during the observations at Weirton. The two major differences were that sample flow through the sampling device was controlled by a fan and the smaller material not deposited on the greased microscope slide was collected on a filter element through which the entire sample flow passed. A simplified schematic of the device is shown in Figure 4, and Figure 5 pictures the device in simulated use.

The intent of the device is to draw a representative sample through the first orifice in the sampling head at a velocity approximating the concentrated emission plume velocity in free air. The value of this velocity was selected based on in-duct and free space velocity measurements made during the coke oven tests at J & L and was nominally 10 ft/sec. The stream from this orifice is directly perpendicular against the greased surface of the microscope slide shown in Figure 6. The slide is held in clips in a chamber in such a way that the sample flow can pass around all four edges. The sample flow continues through an exit orifice at the rear of the chamber and

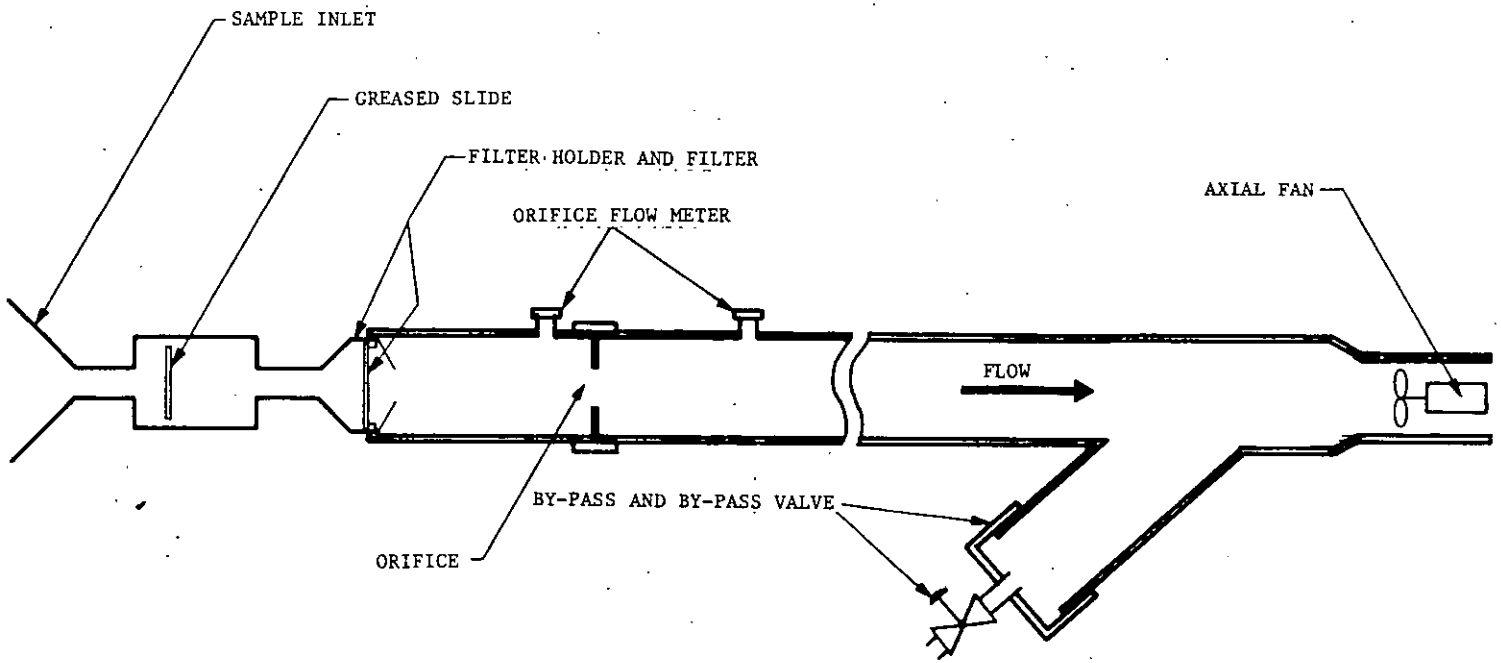

FIGURE 4
SIMPLIFIED SCHEMATIC DIAGRAM

FIGURE 5

PARTICULATE SAMPLER IN SIMULATED USE

FIGURE 6

SAMPLING HEAD

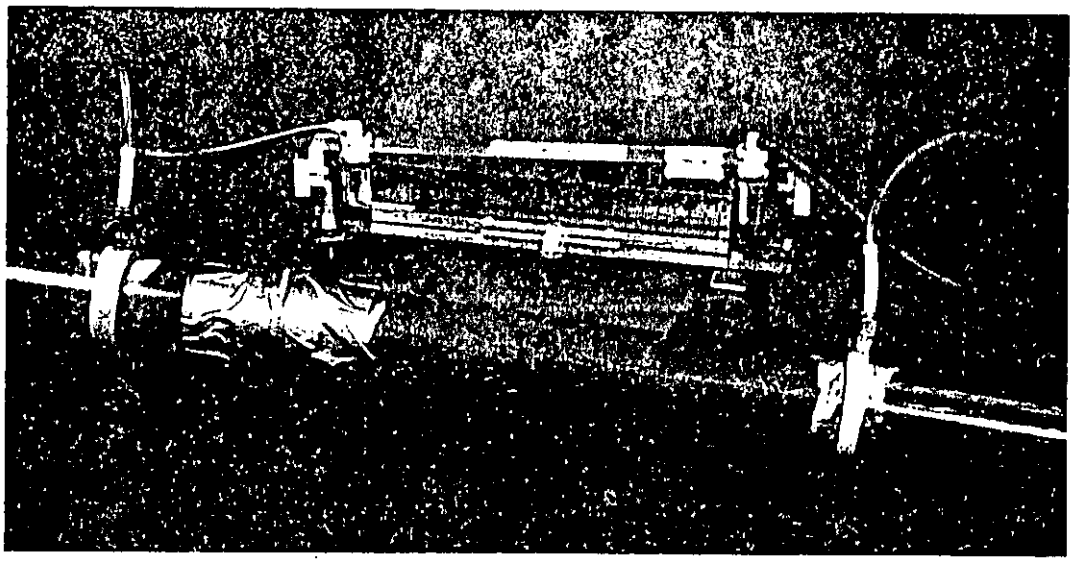

FIGURE 7

ORIFICE ASSEMBLY FOR SAMPLE FLOW MEASUREMENT

into a filter element holder. The filter element which restricts particle passage down to approximately .7 μ is pre-weighed to allow measurement of the deposited material. From the filter, the air flow passes into a 1-1/2 inch tubular passage which serves two functions; a handle extension, and a housing for an orifice flow meter (Figure 7). The flow meter provides a facility for measuring sample volume flow and thus the capability for determining sample velocity at points of interest in the system. In order to adjust the flow through the sampling system, a controllable bypass circuit is provided, as shown in Figure 8.

The following is a brief description of the samples collected based on visual observations of the greased slides, the filter elements, and the loose particulate catches. No detailed analysis of these elements has been undertaken at this time, but this brief summary will indicate the success of the sampling technique and equipment.

The material deposited on the slides was fairly uniform in size characteristics. An area of one of the greased slides is shown in Figure 9. The deposits, as expected, are concentrated in about a 3/4" circle corresponding to the inlet orifice position and size. Some of the larger particles are located on the periphery of the slide indicating some reentrainment or "particle bounce." Many of the larger particles did not adhere to the slide and were caught in the filter element. This would seem to indicate that although they

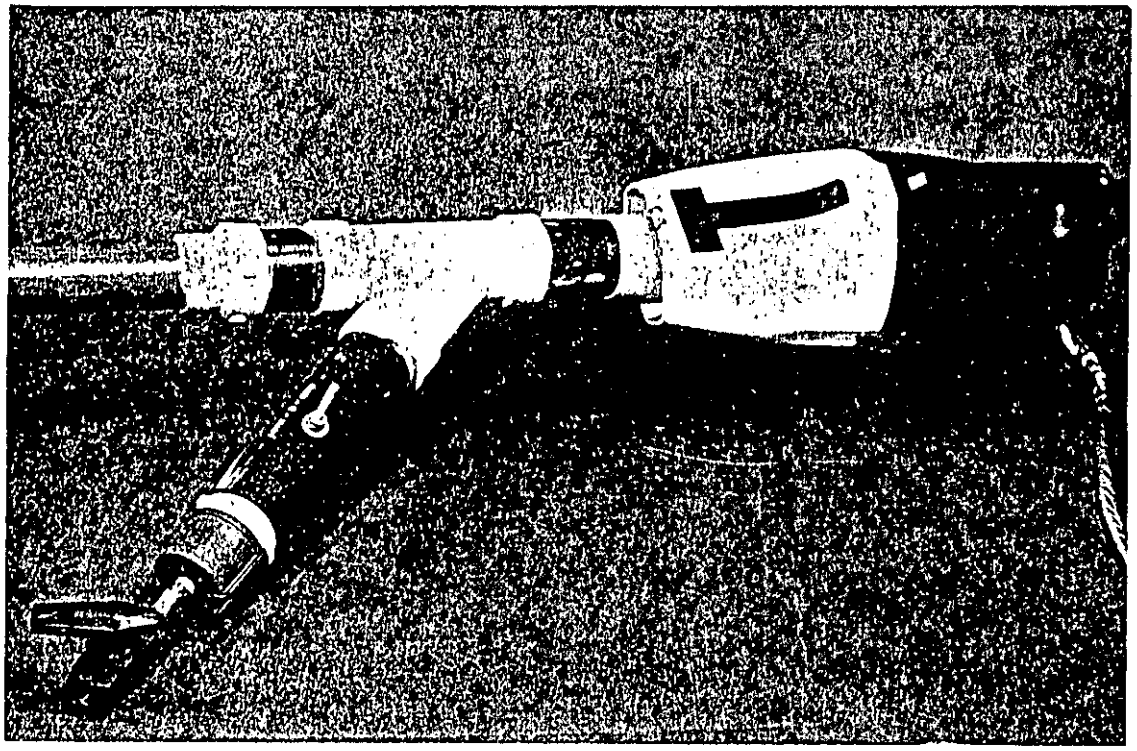

FIGURE 8

BYPASS AND FAN ARRANGEMENT

FIGURE 9

TYPICAL AREA OF GREASED SLIDE, CHARGE TO OVEN C-22 ON 3/13

impacted on the slide, their larger size and aerodynamic resistance caused them to be dislodged and blown off the greased surface.

One of the cleanest charges observed was made while the particulate sampler was in use. This was a charge to Oven B-13, at approximately 11:25 a.m. on 3/26/74. Examination of the slide showed a very light deposit of uniformly distributed particles. Few extremely large particles were found on the slide or on the filter holder. There was a minimal amount of loose material found in the system. One point of interest is the brownish color of the filter element as opposed to the black color of sample filters from other tests. The filter element pictured in Figure 9 had the lowest sample weight for filter deposits recorded for the seven tests.

Two of the filter elements exhibited a shiny black surface characteristic and fairly heavy sample weights. The surface of the filters as shown in Figure 10 appears to have been wiped with a rather thick liquid. The deposits show a pool like characteristic which produces the shiny surface. This is in contrast to the surface of the other four samples, example in Figure 11 , which show a large number of distinguishable particles. The only obvious differences between the two groups of charges was that there was considerably more visible fire on the two tests on which the filters with the shiny surfaces were obtained. The sampler was not operated in the direct flame but the heat may have had a polishing or melt/flow effect on the filters or it may have changed the characteristics of particulate material emitted.

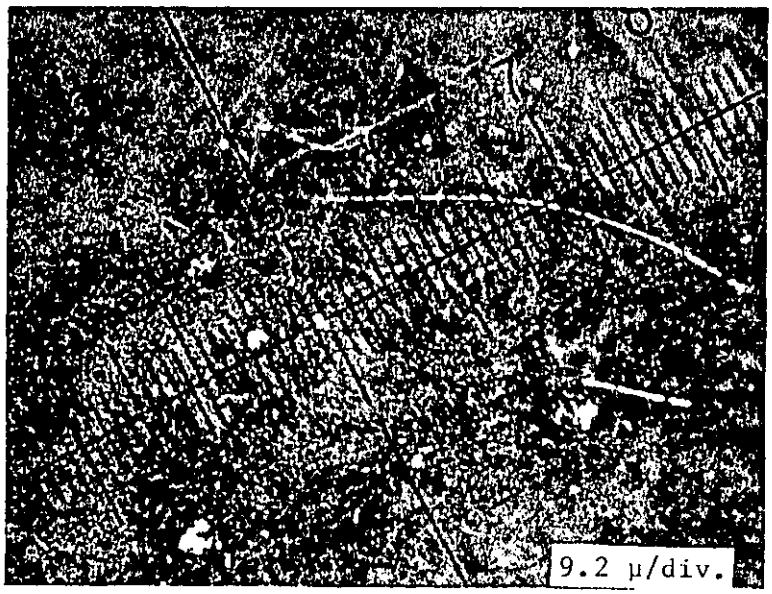

FIGURE 10

TYPICAL FILTER ELEMENT AREA, CHARGE TO OVEN B-13 ON 3/26/74

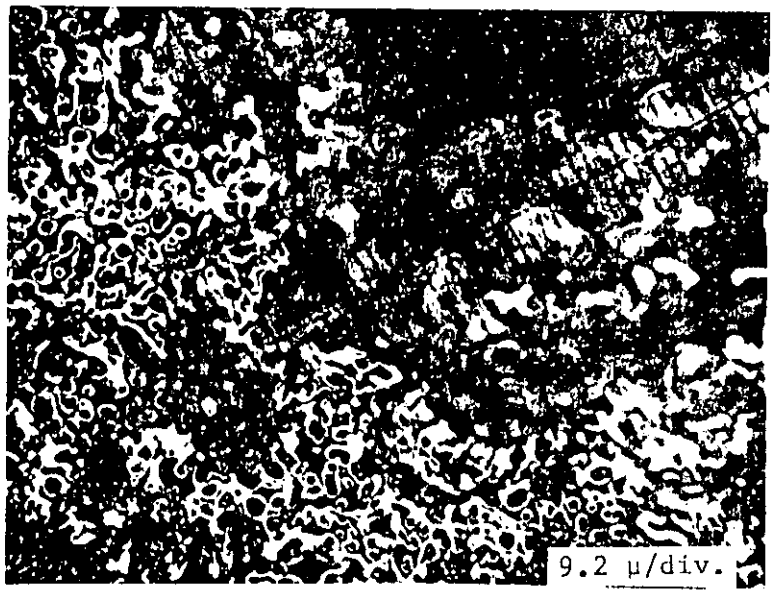

FIGURE 11

TYPICAL FILTER ELEMENT AREA, CHARGE TO OVEN C-24 ON 3/15/74

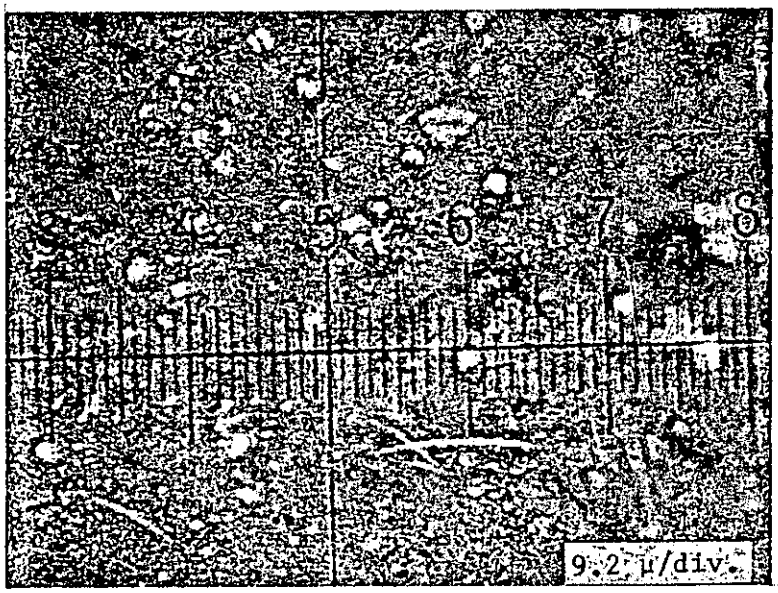

FIGURE 12

TYPICAL FILTER ELEMENT AREA, CHARGE TO OVEN A-11 ON 3/26/74

No further analysis of the samples is planned at this time, but they will be preserved should there be further interest in information which they may provide.

5.5 Gas Constituent and Concentration Measurements

During the week of 3/11/74 to 3/15/74, gas constituent and concentration data were obtained for a select group of pollutants. The pollutants measured were as follows:

Pollutant	Detector Tube Concentration Range
NO_2	0.1-50 PPM
CO	10-3000 PPM
CO	.001-.1%
CO_2	.01-10%
H_2S	1-800 PPM

The gas measurement was performed with an MSA universal tester using MSA detector tubes.

The gases were measured in the plume surrounding the drop sleeve during the charging operation, and also on the oven top during ambient conditions when a charge was not taking place near the measurement area.

The gas concentrations that were obtained proved to be inconsistent, which in turn made it difficult to draw any meaningful conclusions from them. The reasons for this difficulty were the wind conditions that prevailed at the oven top at Brown's Island coupled

with the relatively low order of emissions to be measured. These conditions contributed to a highly dispersed and rapidly dissipated emission condition.

These emission plume characteristics were in contrast to the emission plumes at Jones and Laughlin Pittsburgh Works, where the emission plumes were less dispersed and slower to dissipate. The concentrations that were obtained are as follows:

Weirton Steel

Ambient Air Data - Oven Top

NO_2	-	No Response
H_2S	-	No Response
CO_2	-	.07%
CO	-	.002%
CO	-	10 PPM

Plume Data - Drop Sleeve During 3/11/74 Charge

NO_2	-	No Response
CO_2	-	No Response
H_2S	-	25 PPM
CO	-	.01%
CO	-	50 PPM
CO	-	75 PPM
H_2S	-	5 PPM

Plume Data - Drop Sleeve During 3/12/74 Charge

H_2S	-	No Response
NO_2	-	.1 PPM
CO_2	-	.08%
CO	-	.005%
CO	-	125 PPM

Plume Data - Drop Sleeve During 3/13/74 Charge

NO_2	-	.4 PPM
CO_2	-	.3%
H_2S	-	10 PPM
CO	-	100 PPM
CO	-	.02%

Ambient Air Data - 3/11/74 (Battery Top)

NO_2	-	No Response
H_2S	-	No Response
CO_2	-	.07%
CO	-	.001-.1 - .002%
CO	-	10-3000 PPM - 10 PPM

Plume Data - 3/11/74

NO_2 - Around Drop Sleeve	-	No Response
CO_2 - Around Drop Sleeve	-	No Response
H_2S - Around Drop Sleeve	-	25 PPM
CO - Around Drop Sleeve	-	50 PPM
CO - Around Drop Sleeve Oven B-24	-	75 PPM
H_2S - Around Drop Sleeve Oven C-24	-	5 PPM

Plume Data - 3/12/74

H_2S - Around Drop Sleeve Oven C-22	-	No Response
NO_2 - Around Drop Sleeve Oven A-24	-	.1 PPM
CO_2 - Around Drop Sleeve Oven B-24	-	.08%
CO - Around Drop Sleeve Oven C-24	-	.005%
CO - Around Drop Sleeve Oven A-20	-	125 PPM

Plume Data - 3/13/74

NO_2 - Around Drop Sleeve Oven B-28	-	.4 PPM
CO_2 - Around Drop Sleeve Oven C-28	-	.3%
H_2S - Around Drop Sleeve Oven A-1	-	10 PPM
CO - Around Drop Sleeve Oven B-1	-	100 PPM
CO - Around Drop Sleeve Oven C-1	-	.02%

After careful examination of the data presented here, it was decided that no meaningful conclusions could be drawn regarding emissions produced during the charging operation. The ambient data does, however, provide some quantitative information of possible use on oven top conditions. Any application of this data should, however, take into account its short comings in quantity and the highly variable conditions.

6.0 LARRY CAR WORK HISTORY

6.1 Work and Maintenance Schedules

In discussions with supervisory personnel, we were told that no formalized arrangement for rotation of the oven equipment has been established. The philosophy which prevails is to let the shift foreman select the equipment to be used. This usually means the continual use of one car until either a malfunction occurs or the car is placed in standby to be checked by the motor inspector.

The motor inspector will generally notify the foreman the day before he intends to check the car. The foreman can then set the car out at the beginning of the shift during which the car is to be inspected. The actual time of inspection during the shift is based on the inspector's work load. In conversations with the "greasers," we were told that they normally grease the car on a daily basis while it is in operation. This is usually accomplished during periods when the car is in the coal bin being filled. The daily greasing is confined to 36 hand fittings and operation of the central lubrication system.

In addition, the greasers try to catch each car out of service at least once a week to check all machinery requiring lubrication. This complete check requires from 1-1/2 to 2 hours and includes such items as the checking, cleaning, and lubricating of semi-exposed gearing and other hard to reach rotating machinery. The hydraulic systems are also checked at this time.

One fact which allows flexibility in scheduling is that the electrical department is responsible for all maintenance and repair work on oven machinery. They have the capability within their shop

to handle all but the heaviest mechanical repair jobs. It is their responsibility to coordinate work on those jobs for which they require assistance. This seems to provide prompt attention to problems as they arise and centralizes the responsibility for their resolutions. This arrangement is in contrast to the situation which existed at J & L in which the foreman or car supervisor was responsible for coordination of the various craft shops needed for a repair job, such as millwrights, riggers, electrical, line and wire, pipe fitters, etc. The crafts in turn would then schedule work priorities based on minimization of production disruption. In some instances, this caused delays when one craft was not available and other work could not proceed until their segment of the job was complete.

6.2 Significant Events

As a part of the observation activity, a compilation of significant events such as breakdowns causing loss of production, was undertaken. We were told that no formalized reporting system on specific events is established, but that information of this type could be obtained from operating supervisors based on their personal recollections and notes. This approach was pursued through informal talks with these individuals.

The conversations disclosed only two occasions during which production was lost because of larry car problems. The first occasion involved the loss of 4 to 6 hours of production when one of the cars became immobilized over an open port. This resulted in damage to drop sleeve hydraulic systems and one ascension pipe cleaner and

associated control system. Analysis of the event indicated that the following sequence of events may have occurred.

1. At the end of a charge, the operator observed an unusually heavy concentration of flame from around one drop sleeve.

2. He reacted in a proper manner by attempting to move the car away from the flaming port. In his attempt to clear the car for motion, the operator accidentally pushed the ascension pipe cleaner actuating button. The cleaner extended and became wedged between ascension pipes as the car moved.

3. The operator stopped the car when he realized what had happened, but its proximity to the open flaming port caused considerable damage before the lid could be replaced.

Some portion of the cleaner assembly had to be cut away before the car could be moved off the oven. In addition, the second car was undergoing maintenance at that time and was not ready for immediate service. Work necessary to get the standby car into service was rushed to completion and production was resumed with certain functions being operated manually in the bypass mode.

The car which had burned was repaired to a point where it could perform production charging in approximately 8 to 10 hours. Several of its functions would have had to be operated in the bypass mode and the damaged ascension pipe cleaner was inoperable.

The second event occurred when an interlock switch on the ascension pipe cleaner failed causing the ram to be extended prematurely. The extended ram contacted the overhead trolly track as the unit swung down to the operating position. Power was lost and a portion of the

"hot rails" was badly damaged. It required approximately 1/2 hour to resolve the problem and resume production. The standby car could not operate until the hot rail was cleared.

6.3 Operator Performance

The larry car operator performance at Weirton seemed to be of a highly consistent level. This can be attributed to the fact that the Brown's Island Battery is highly automated, and the larry car operators' performance is limited to the task of driving and spotting the larry car, and operating the charging/aspirating mechanisms with the aid of automated control circuitry. The fact that the car is automated leaves relatively few decisions to the individual discretion of the driver, since he follows a predescribed charging scheme formatted by the oven superintendent.

6.4 Future Modifications

As far as MITRE could ascertain from its experiences on the oven and conversations with battery personnel, the Brown's Island Battery is being modified in every area that seems to need further design and planning. At the present time, attention is being given to three specific areas; leaking ascension pipe caps, level sensing in the charging car hoppers, and increased aspiration in the collecting main system.

Experimentation is currently taking place concerning the ascension pipe caps in order to discover new methods of reducing the emissions that occur immediately after the charging operation. Various materials and seating configurations are being implemented experimentally on the oven, and are being observed during normal operating conditions so as to determine the advantages and disadvantages of each.

The Brown's Island Battery is also working on a method for sensing the coal level in the larry car coal hopper. The reason for this is to signal the larry car operator when all coal has been discharged through the drop sleeve into the oven. Prior to this, the larry car operator had been using his own judgement as to the emptiness of the hopper, or allowing the automatic charging cycle to initiate slide valve closure. As a result, the slide plate valve is left open for an undetermined amount of time after the coal discharge is complete. It is this undetermined period of time that allows charging emissions to escape to the atmosphere via the open slide plate and coking stack. The Brown's Island personnel feel that a reduction in charging emissions would be accomplished if the slide plates were closed immediately following the emptying of coal, and as a result, are presently devoting attention to this problem. During the week of March 24th, the electrical department was experimenting with a current sensing device attached to the drive motor of the screw that feeds coal to the drop sleeve during the charging operation. Theoretically, when the screw feed cylinder of the larry car is free of coal, the operating load of the motor, which is normally 15-20 amps during the coal feeding sequence, is decreased by 2-4 amps. This reduction could be sensed by the current sensing device. This drop in the current load could then be used as a signal for the larry car operator to close the slide plate valve, thus closing the charging emission escape route.

Experiments are also under way concerning oven aspiration and steam ejector operation. Different ascension pipe plumbing configurations are being considered and tried experimentally on the oven during normal charging conditions.

APPENDIX I

LARRY CAR OBSERVATION LOGS

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/11/74
TIME: 3:40
OVEN: C-22

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.			PS					
30 SEC.		MF		MF		MF		
45 SEC.				LF		LF		
1 MIN.		L		F		F		
1 MIN. 15 SEC.			MS→F	F	MS	F		
1 MIN. 30 SEC.			MS	F	MS	F		
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:50							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS
.01 Concentration of CO.
Reading Taken at #2
Drop Sleave

REMARKS:

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/11/74
TIME: 3:55
OVEN: A-24

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.			SPF	MBL		F+MBL		
30 SEC.				M		FL		
45 SEC.				L		L		
1 MIN.				F		F		
1 MIN. 15 SEC.	LPF		LS		MS			
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:35							

↑ = INCREASING
S = STACK
L = LIGHT FLOW
BL = BLACK

↓ DECREASING
HP = HOPPER
M = MEDIUM FLOW
Y = YELLOW

→ CHANGING TO
F = FIRE
H = HEAVY FLOW
P = PUFFY

WEATHER:

MANUAL GAS 25 PPM of H_2S at #2 Drop Sleeve

REMARKS:

THE MITRE
MCF 2495 12/73

RLB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/11/74
TIME: 4:10
OVEN: B-24

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.			SP	LF		LF		
30 SEC.		L		LF		LF		
45 SEC.				LF↓		LFP		
1 MIN.		L→M	LS	F	L→SF	F		
1 MIN. 15 SEC.								
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:32							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS 75 PPM of CO at #2
Drop Sleeve

REMARKS:

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 2:10
OVEN: B-20

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.				M		MF		
30 SEC.				LF		F		
45 SEC.				LF		F		
1 MIN.		M		M	LS	L		
1 MIN. 15 SEC.			MS	F	MS	F		
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:35							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER: Dry Bulb 46 RH 70%
Strong North Wind

MANUAL GAS

REMARKS:

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 2:22
OVEN: C-20

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.				M→H		MF		
30 SEC.				M		F		
45 SEC.		L		LF↑		F↑		
1 MIN.					MS			
1 MIN. 15 SEC.			FS		FS			
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:38							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: MITRE particulate test run.

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 2:35
OVEN: A-22

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			SP					
15 SEC.				M		M→LF		
30 SEC.				M		LF		
45 SEC.				M		FP		
1 MIN.				M↑		MF		F
1 MIN. 15 SEC.			MS		MS			
1 MIN. 30 SEC.				F		F		F
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:44							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

THE MITRE
MCF 2495 12/73

RLS
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 2:47
OVEN: B-22

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			SP					
15 SEC.		F		L→MF		L→MF		
30 SEC.		FP		LFP		LFP		
45 SEC.		LFP		LFP				
1 MIN.		F↑		L↓F↑		L↓F↑		
1 MIN. 15 SEC.					MS		HP P	
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:35							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER: _____

MANUAL GAS _____

REMARKS: _____

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 2:58
OVEN: C-22

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			SP					
15 SEC.				M		MF		
30 SEC.				M		LF		
45 SEC.				MY		F		
1 MIN.				L→M		F		
1 MIN. 15 SEC.			MS+HP		MS+HP			
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:34							

↑ = INCREASING
S = STACK
L = LIGHT FLOW
BL = BLACK

↓ DECREASING
HP = HOPPER
M = MEDIUM FLOW
Y = YELLOW

→ CHANGING TO
F = FIRE
H = HEAVY FLOW
P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

MITRE
MCF 2495 12/73

RWB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 3:10
OVEN: A-24

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.								
30 SEC.								
45 SEC.								
1 MIN.								
1 MIN. 15 SEC.								
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:30							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS .1 PPM Reading NO_2 On #2 Drop Sleeve

REMARKS: Routine of larry operator seems variable. When the larry car came on the spot he half-dampered instead of waiting until the charge was complete.

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 3:28
OVEN: B-24

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LSP					
15 SEC.				LFP		M		F
30 SEC.				M		F		
45 SEC.		F		L		F		
1 MIN.								
1 MIN. 15 SEC.			SP	F	MS	F		
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:32							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Half damper after charge, then unlid, then full damper. Vibrators were used as a demonstration for new larry operator.

THE MITRE
MCF 2495 12/73

RWB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 3:38
OVEN: C-24

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			SP					
15 SEC.				M		MFP		
30 SEC.				LFP		LFP		
45 SEC.				LFP		LFP		
1 MIN.				L↓FP		L↓FP		
1 MIN. 15 SEC.			LS	L	LS			
1 MIN. 30 SEC.			MS		MS			
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:43							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS .005% CO at #2 Drop Sleeve

REMARKS: Regular sequence after charge. The overall charge looked very good, with very light smoke from the stacks.

The MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 3:59
OVEN: A-26

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LSP					
15 SEC.				LF		LF		
30 SEC.				LF↑		LF↑		
45 SEC.				L↓F		L↓F		
1 MIN.		M			MS		L HP P	
1 MIN. 15 SEC.								
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:35							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS 125 PPM CO at #2 Drop Sleeve

REMARKS: Normal sequence after charge. End of charge looked cleaner than usual.

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/12/74
TIME: 4:32
OVEN: C-26

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.				L		LFP		
30 SEC.				LFP		LFP		
45 SEC.				L↓		L↓		
1 MIN.				LF		LF		
1 MIN. 15 SEC.			MS					
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Long wait before charge. Electrical Department looked over the bottom of the car but did nothing.

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/13/74
TIME: 5:02
OVEN: C-1

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			SP					
15 SEC.				L		L		
30 SEC.				L		LF		
45 SEC.				LFP		LFP		
1 MIN.				L↓		L↓FP		
1 MIN. 15 SEC.	MH	FL↓M	MS	M	MS			
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS .02% CO at #2 Drop Sleeve

REMARKS: 4:10 complete cycle

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 10:25
OVEN: A-20

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE		MF		M				
15 SEC.				M↑		M↑		
30 SEC.		F		H		MF		L
45 SEC.		M		H		MF		L
1 MIN.		M	M	M	M	M↑F		L
1 MIN. 15 SEC.		F	M↓	L	M↓	F		L
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:45							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: An ascension pipe lid did not come down, and as a result, the smoke at the drop sleeves was worse than usual. Smoke from stacks stopped quicker than usual. Car was run in the manual mode.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 10:55
OVEN: C-20

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			SP					
15 SEC.				FM		MF		
30 SEC.				FM		M↑F		
45 SEC.				FM↓		M↓F		
1 MIN.		M		FM		LF↑		
1 MIN. 15 SEC.	M			HF↑		LF		
1 MIN. 30 SEC.			SM↑			MF		
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:43							

↑ = INCREASING
S = STACK
L = LIGHT FLOW
BL = BLACK

↓ DECREASING
HP = HOPPER
M = MEDIUM FLOW
Y = YELLOW

→ CHANGING TO
F = FIRE
H = HEAVY FLOW
P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 11:15
OVEN: A-22

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MP					
15 SEC.				MB		MB		
30 SEC.				M↑		M↑		L
45 SEC.				M↑		M↑		L
1 MIN.		L		M↑		M↑		L↓
1 MIN. 15 SEC.		L	M	M↓	SH	M		
1 MIN. 30 SEC.		L		L↓	SM	HY		L
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:42							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 11:30
OVEN: B-22

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE				MF		MF		LF
15 SEC.				L		LF		F
30 SEC.						LFP		LP
45 SEC.						F↑		F↑
1 MIN.		L	L	L	M	F↑		LFP
1 MIN. 15 SEC.		L↓	L	M↑	M↓	HF		FL↓
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:47							

↑ = INCREASING
S = STACK
L = LIGHT FLOW
BL = BLACK

↓ DECREASING
HP = HOPPER
M = MEDIUM FLOW
Y = YELLOW

→ CHANGING TO
F = FIRE
H = HEAVY FLOW
P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: MITRE particulate test run. Heavy fire on Number 3 Drop Sleeve

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 11:40
OVEN: C-22

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MP					
15 SEC.				MB		MBF		FP
30 SEC.				M↑H		MF		F
45 SEC.				M		LF		
1 MIN.				L		F↑		F
1 MIN. 15 SEC.		L	M	M	M	M		FL
1 MIN. 30 SEC.		L	M	F	M			
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:37							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 11:52
OVEN: A-24

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			SMP					
15 SEC.						FLB		
30 SEC.				MB		FL		
45 SEC.	P			L		LFP		
1 MIN.				M↑	MS	F	P	
1 MIN. 15 SEC.		L	LS	FL	MS			L↑
1 MIN. 30 SEC.						MF		
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:38							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 12:10
OVEN: B-24

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LSP					
15 SEC.		F		FM		M↑		
30 SEC.				H				
45 SEC.				FM		HY		
1 MIN.				M↓		M↓		M
1 MIN. 15 SEC.			SM↑	M	SM↑	M		L
1 MIN. 30 SEC.			SM↓		SM			
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:38							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 12:21
OVEN: C-24

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			SP					
15 SEC.				MF		MF		
30 SEC.				MF		MF		
45 SEC.				LF		LF		
1 MIN.			M↑	M	M↑HP	MF		L
1 MIN. 15 SEC.		L	H	H		F	P	L
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:38							

↑ - INCREASING
S - STACK
L - LIGHT FLOW
BL - BLACK
↓ DECREASING
HP - HOPPER
M - MEDIUM FLOW
Y - YELLOW
→ CHANGING TO
F - FIRE
H - HEAVY FLOW
P - PUFFY

WEATHER:

MANUAL GAS

REMARKS: MITRE Particulate Test Run

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 12:39
OVEN: A-26

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			SP					
15 SEC.				M↑		M↑		
30 SEC.				M		M→H		
45 SEC.		L		M		H		
1 MIN.		L		M		H		
1 MIN. 15 SEC.				MY		MY		
1 MIN. 30 SEC.	H↑		SM	L	SM	L		L
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:39							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

The MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 12:54
OVEN: B-26

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LSP					
15 SEC.		F		M		LF		
30 SEC.		FP		M		LF		
45 SEC.				M↑		F		
1 MIN.				F		FP		
1 MIN. 15 SEC.			MS		MS↑		HP P	
1 MIN. 30 SEC.			M↑	F	M	F		
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Patching door jam.

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 1:36
OVEN: C-26

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LSP					
15 SEC.				L		MF		
30 SEC.				LPF		LPF		
45 SEC.				L		LF		
1 MIN.						F		
1 MIN. 15 SEC.		F	LS	L	M↑S	L		
1 MIN. 30 SEC.				L		L		
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:37							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Very clean charge. Good coordination demonstrated between larry car and pusher car. Leveling bar went in on signal from larry car.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/15/74
TIME: 1:52
OVEN: A-28

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.				L		LF		
30 SEC.						FP		
45 SEC.			L			FL		
1 MIN.			L		M	FL		
1 MIN. 15 SEC.			L		L↓	L		
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:33							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Very good charge

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 9:58
OVEN: B-9

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LSP			LFP		
15 SEC.				LFP		LF↓		
30 SEC.				LF↓				
45 SEC.								
1 MIN.								
1 MIN. 15 SEC.	M	F	MSMHP		MS	F		F
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Fairly clean charge. Very little smoke during middle of charge. Hopper smoke.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 10:08
OVEN: C-9

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2.		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LSP					
15 SEC.				LFP		FP		
30 SEC.				L↑FP		FP		
45 SEC.				L↓		FP		
1 MIN.								
1 MIN. 15 SEC.			MS	F↓	MS	F↓		
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: End of charge was very clean, with very little smoke around drop sleeves. Stack smoke was unusually light.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 10:23
OVEN: A-11

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			HSP					
15 SEC.				MF		MF		
30 SEC.				M↓FP		M↓FP		
45 SEC.				MF		MF		
1 MIN.				LF↓		LF↓		
1 MIN. 15 SEC.		F	MS↑	F	MS↑	F		
1 MIN. 30 SEC.	L		LHP		LHP			
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: MITRE particulate test run. End of charge had more smoke than usual.

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 10:45
OVEN: B-11

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LSP					
15 SEC.				LFP		FP		
30 SEC.				LFP		LFP		
45 SEC.				FP		FP		
1 MIN.								
1 MIN. 15 SEC.		F	MS	F	MS	F		F
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Lid lifter on Number 4 drop sleeve did not operate, the lid was removed manually by the lidman. A one minute loss is realized if lid-lifter doesn't work. Relidding operation was normal.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 10:54
OVEN: C-11

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP					
15 SEC.				L↓FP		L↓FP		
30 SEC.				LFP		LFP		
45 SEC.								
1 MIN.				LFP		LFP		
1 MIN. 15 SEC.	LHP	F	LHPMS		MS	F		
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	Not Recorded							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Takes approximately 15-20 seconds to move off spot, check lids, and re-spot. Smoke was heavier than usual on number two stack.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 11:07
OVEN: A-13

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			HSP					
15 SEC.		FP		MFP		FP		
30 SEC.		F		MF		F		
45 SEC.				MF		F		
1 MIN.		F	MS	F	MS	F		
1 MIN. 15 SEC.				F		F		
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:38							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Lid operation satisfactory, larry car appeared to be mis-spotted.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 11:20
OVEN: B-13

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP					
15 SEC.				MF		MF		
30 SEC.				LFP		LFP		
45 SEC.				L↓F↓		L↓F↓		
1 MIN.								
1 MIN. 15 SEC.			MS↑	M	MS↑			
1 MIN. 30 SEC.						F		
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:45							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: MITRE particulate test run. Charge looked fairly clean. Light flow from stacks. Number two drop sleeve seemed to hold a negative pressure for most of the charge.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 11:33
OVEN: C-13

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LSP					
15 SEC.				M		M		
30 SEC.				M		M		
45 SEC.				LFP		LFP		
1 MIN.				HYP				
1 MIN. 15 SEC.			MS		MS			
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:45							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Lid lifter operation satisfactory, but larry man checked lids. Car re-spotted poorly, drop sleeves misaligned. Poor seal on number one drop sleeve appeared to have caused poor suction on number one and two ports.

MITRE
MCF 2495 12/73

BWB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 11:53
OVEN: A-15

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP					
15 SEC.		MF		MF		MF		MF
30 SEC.		F		MF		MF		FP
45 SEC.				M		M		
1 MIN.		LF		LF		LF		
1 MIN. 15 SEC.				F	MS	F		F
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Ascension pipe lid did not come down in the automatic cycle, closed manually by lid man. This caused a delay of about one minute. Car leaked badly around all sleeves.

THE MITRE
MCF 2495 12/73

RWB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 1:24
OVEN: A-19

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MS					
15 SEC.				LFP		LFP		
30 SEC.				L↓FP		L↓FP		
45 SEC.								
1 MIN.				L↓FP		L↓FP		
1 MIN. 15 SEC.	L			L↑F		M↑F		
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:38							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 1:39
OVEN: B-19

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LPS					
15 SEC.		F		L↑F		L↑F		F
30 SEC.		F		LF		LF		
45 SEC.		F		LF		LF		F
1 MIN.			MS	F	MS	F		
1 MIN. 15 SEC.								
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Larry car appeared to be misaligned on the charging ports. A lot of smoke and fire at the beginning of the charge. Drop sleeves were tilted. Number two and number four lids were cocked and burning.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 1:54
OVEN: C-19

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP					
15 SEC.		M↑F		M↑F		M↑F		
30 SEC.		F		MF		MF		
45 SEC.				L↓F		L↓F		
1 MIN.		F↓		F↓		F↓		
1 MIN. 15 SEC.		M		LF		LF		H
1 MIN. 30 SEC.		F						F
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:43							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Number one and four drop sleeves had heavy smoke. Car was spotted okay.

THE MITRE
MCF 2495 12/73

BNB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 2:18
OVEN: A-21

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			HSP	HP		HP		
15 SEC.		F↓		FP		FP		
30 SEC.		FP		MF		MF		
45 SEC.				LF		LF		
1 MIN.			MS	F	MS	F		F
1 MIN. 15 SEC.								
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:38							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: MITRE particulate test run. Operation was ahead of schedule and larry car was detained in coal bin.

THE MITRE
MCF 2495 12/73

RB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 3:09
OVEN: A-23

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			HPP					
15 SEC.		MF		MF		MF		
30 SEC.		MF		MF		MF		
45 SEC.		M↓FP		M↓P		M↓P		
1 MIN.	M		MS	FP	MS	F		
1 MIN. 15 SEC.				F		F		
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Heavy smoke at start of charge, car appeared to be properly spotted. More smoke from drop sleeves than usual.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 3:20
OVEN: B-23

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			LPS					
15 SEC.		MFP↓		MF		MF		
30 SEC.				L↑F		L↑F		
45 SEC.				FP		FP		
1 MIN.				LFP		LFP		
1 MIN. 15 SEC.			MS	F	MS	F		F
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:41							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Larry operator is still checking to make sure lids are off. Car appears to be off spot, sleeves are tilted.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 3:33
OVEN: C-23

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP					
15 SEC.				MFP		MFP		
30 SEC.				MF		MF		
45 SEC.								
1 MIN.						F+		
1 MIN. 15 SEC.		LP			MS			
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:42							

↑ = INCREASING
S = STACK
L = LIGHT FLOW
BL = BLACK

↓ DECREASING
HP = HOPPER
M = MEDIUM FLOW
Y = YELLOW

→ CHANGING TO
F = FIRE
H = HEAVY FLOW
P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Good negative aspiration observed on number two and number three drop sleeves, fire was being drawn in. Drop sleeve alignment appears to be better the first time they are lowered rather than the second time.

The MITRE
MCF 2495 12/73

RJB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 4:02
OVEN: A-25

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.		F		F		F		
30 SEC.		F		F		F		
45 SEC.		F		F		F		F
1 MIN.		F		F		F		F
1 MIN. 15 SEC.		F		F		F		F
1 MIN. 30 SEC.		F		F		F		F
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	Not Recorded							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: First charge of new shift, suction appeared to be malfunctioning, although the lid man disagreed. Much more fire than usual in the drop sleeves.

MITRE
MCF 2495 12/73

RB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 4:19
OVEN: B-25

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE								
15 SEC.		MFP		MFP		MFP		
30 SEC.		L↓FP		L↓FP		L↓FP		
45 SEC.								
1 MIN.				F↓		F↓		
1 MIN. 15 SEC.			LS		MS			
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:39							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Good charge.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/26/74
TIME: 4:34
OVEN: C-25

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP					
15 SEC.				FP		FP		F↓
30 SEC.		F↓		LFP		LFP		
45 SEC.				F↓		F↓		
1 MIN.						F		
1 MIN. 15 SEC.				MP				
1 MIN. 30 SEC.		L		F	L	F		
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:39							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS:

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/27/74
TIME: 3:34
OVEN: A-25

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP					
15 SEC.				LFP		LFP		
30 SEC.				L↓FP		L↓FP		
45 SEC.				FP		FP		
1 MIN.		M		F		F		
1 MIN. 15 SEC.	HP		MS		MS			
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:40							

↑ = INCREASING
S = STACK
L = LIGHT FLOW
BL = BLACK

↓ DECREASING
HP = HOPPER
M = MEDIUM FLOW
Y = YELLOW

→ CHANGING TO
F = FIRE
H = HEAVY FLOW
P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Coke side ascension pipe lid failed to close. Lid man closed it manually.

THE MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/27/74
TIME: 3:43
OVEN: B-25

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP	M↑				
15 SEC.		M		MFP		MFP		
30 SEC.		MFP		MFP		MFP		
45 SEC.		F↓		M↓FP		M↓P		
1 MIN.		LFP		LFP		LFP		
1 MIN. 15 SEC.			MS		MS		L	
1 MIN. 30 SEC.				FP		FP		
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:42							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: More smoke than usual at the beginning of the charge. Smoke especially heavy on drop sleeves one, two, and three. Charge seemed normal toward the end.

THE MITRE
MCF 2495 12/73

RWB
OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/27/74
TIME: 4:06
OVEN: C-25

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP					
15 SEC.				MF		MF		L
30 SEC.		L		L↑FP		L↑FP		
45 SEC.				LF		LF		
1 MIN.		M		F		F		
1 MIN. 15 SEC.				F		F		
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:41							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: It appeared that all hoppers and stacks puffed back at the end of the charge.

MITRE
MCF 2495 12/73

OBSERVER

LARRY CAR OBSERVATION LOG

COMPANY: National Steel
PLANT: Weirton Steel
BATTERY: Brown's Island

DATE: 3/28/74
TIME: 2:54
OVEN: A-27

	PUSHER SIDE		CENTER		CENTER		COKE SIDE	
	1		2		3		4	
	HOPPER	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER/ STACK	DROP SLEEVE	HOPPER	DROP SLEEVE
CHARGE			MSP					
15 SEC.				L↑		L		
30 SEC.				MF		LF		
45 SEC.				LFP		LFP		
1 MIN.		F		LF		LF		
1 MIN. 15 SEC.			MS		MS			
1 MIN. 30 SEC.								
1 MIN. 45 SEC.								
2 MIN.								
2 MIN. 15 SEC.								
2 MIN. 30 SEC.								
2 MIN. 45 SEC.								
3 MIN.								
END OF CHARGE								
LID REPLACED								
TOTAL CHARGING TIME	1:38							

↑ = INCREASING ↓ DECREASING → CHANGING TO
S = STACK HP = HOPPER F = FIRE.
L = LIGHT FLOW M = MEDIUM FLOW H = HEAVY FLOW
BL = BLACK Y = YELLOW P = PUFFY

WEATHER:

MANUAL GAS

REMARKS: Sleeve up to lid at eight seconds. Eight to nine seconds to rotate.

MITRE
MCF 2495 12/73

OBSERVER

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

1. REPORT NO. EPA-650/2-74-062-a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Coke Oven Charging Emission Control Test Program--Supplemental Observations		5. REPORT DATE September 1974
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.W. Bee and R.W. Spewak		8. PERFORMING ORGANIZATION REPORT NO. MTR-6684
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Mitre Corporation Westgate Research Park McLean, Virginia 22101		10. PROGRAM ELEMENT NO. 1AB013; ROAP 21AFF-004
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15. SUPPLEMENTARY NOTES		

16. ABSTRACT The report compares operational information for two coke charging cars operating to reduce charging emissions from the Brown's Island battery of National Steel's Weirton Steel Division with that for a larry car developed jointly by the American Iron and Steel Institute (AISI) and the U.S. EPA. A direct comparison is made in areas where similarities between the two designs are strong; in areas with contrasting features or procedures, their success is reported relative to design intent and EPA objectives. Both designs have had reasonably good success both in automation of oven controls and in improving operator environment. Both represent substantial improvements in emission control: although the AISI/EPA car appears to be more capable of sealing emissions during the charge, it is less consistent than the Weirton car in overall emission control. Facts presented by the report originated in three areas: a desciption of the Weirton coking system, including oven configuration, larry car operation, and general coke oven charging procedures; observation of the two Weirton larry cars during coal charging operation; and interviews with coke plant personnel responsible for operating the larry cars.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Iron and Steel Industry	Stationary Sources	11F
Coke	Emission Observations	21D
Metallurgical Fuels	Operability Assessment	
Coking	Larry Car	11H
Charging		

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