



00031639

**A mining research contract report
DECEMBER 1983**

DEVELOPMENT OF A REMOTE COAL DUST DEPOSITION RATE MONITOR

Contract No. J0188058
Creare Products Incorporated

OFR
85-47

**BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR**

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No.
4. Title and Subtitle Development of a Remote Coal Dust Deposition Rate Monitor			5. Report Date December 1983
7. Author(s) P. W. Runstadler, Jr., P. K. Dutta, R. W. Hatfield, R. Tenenbaum			8. Performing Organization Rep. No. TR 83-1
9. Performing Organization Name and Address Create Products Incorporated Etna Road Lebanon, New Hampshire 03766			10. Project/Task/Work Unit No.
			11. Contract(G) or Grant(G) No. (C) J0188058 (G)
12. Sponsoring Organization Name and Address Office of the Assistant Director - Mining Bureau of Mines, Dept. of the Interior Washington, D.C. 20241			13. Type of Report & Period Covered Draft Final 1978-1983
			14.
15. Supplementary Notes The hardware developed under this contract utilizes measurement technology features developed under U. S. Bureau of Mines Contract No. J0188058.			
16. Abstract (Limit 200 words) <p>This report describes the design, development, and manufacture of a monitoring system to continuously monitor the buildup of float coal dust and rock dusting materials in coal mine workings. A readout and special switch module can monitor up to ten coal dust sensors, displaying the dust load directly in mg/cm^2 with a sensitivity of $0.5 \text{ mg}/\text{cm}^2$.</p> <p>The readout is a microprocessor-based unit, MSHA approved, and is rugged, portable, accurate, easy to use and read. The sensors collect dust on a disc and measure the dust loading using vibrating wire technology.</p> <p>Ten dust sensors and two readout and switch station units were built, performance tested, and calibrated. The hardware was delivered to the Bureau of Mines for further evaluation and in-mine testing.</p>			
17. Document Analysis & Descriptors			
b. Identifiers/Open-Ended Terms			
c. COSATI Field/Group			
18. Availability Statement		19. Security Class (This Report)	21. No. of Pages 122
		20. Security Class (This Page)	22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 273 (4-77)
(Formerly NTIS-35)
Department of Commerce

FOREWARD

This report was prepared by Creare Products Incorporated, Etna Road, Lebanon, New Hampshire 03766 under the U. S. Bureau of Mines Contract Number J0188058. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Bureau's Pittsburgh Research Center with Roy C. Bartholomae as the Technical Project Officer.

This report is a summary of the work undertaken over the period of September 15, 1978 to August 31, 1983 and was submitted by the authors in November 1983.

The authors wish to thank Dr. Welby Courtney and Mr. Frank Nagy of the U. S. Bureau of Mines for their cooperation, assistance and guidance to Creare Products while carrying out this program development.

Robert E. Tutwiler, Wilbur E. Kelsey, and Joyce L. Coull of Creare Products Incorporated participated in numerous test programs and preparation of this report. The authors wish to acknowledge their contributions.

CONTENTS

FOREWARD	4
CONTENTS	5
EXECUTIVE SUMMARY	7
INTRODUCTION	8
BACKGROUND AND OPERATING PRINCIPLE	12
Background	12
Operating Principle of the Dust Sensor	13
Diaphragm Deflection	13
SENSOR DESIGN, ASSEMBLY TECHNIQUE, AND TESTING	17
Transducer Design	17
Sensor Housing	20
Sensor Materials	20
Assembly Procedure	21
Transducer Construction	23
Housing Construction	24
Assembly of Transducer and Housing	24
Test Data	26
Linearity of Sensor Load Calibration	27
Calibration Tests	28
Repeatability Tests	40
Gage Comparison Tests	51
Temporal Stability Tests	51
Temperature Coefficient	57
READOUT SYSTEM	61
Magnet/Coil Assembly	61
Thermistor	61
Cable	61
Switch Module	62
Readout Unit	62
Software Readout	64
Electronic Hardware	66
Switch Module - Standard MA-2SM	66
Switch Module - Modified MA-2SM	67
Hardware - Readout Unit	67
Readout Unit Operation	68
Calibrating the Sensor	68
Using the Gage	69
Entering Preset Min/Preset Max Values	70
Check of Stored Values in the Readout Unit	71
Red and Black Keys	71
Readout Unit Stability Tests	71
DISCUSSION AND RECOMMENDATIONS FOR FUTURE DESIGN	73
Possible Design Improvements	74
REFERENCES	76
APPENDIX A - User Instruction Manual	77
APPENDIX B - Tabulated Sensor Test Results	92

ILLUSTRATIONS

Figure 1	- Coal Dust Sensor Schematic	14
Figure 2	- Coal Dust Sensor Assembly	18
Figure 3	- Basic Elements of the Vibrating Wire/Diaphragm Assembly	19
Figure 4	- Protective Canopy for Sensor	22
Figure 5a	- Calibration Results for Sensor 1	30
Figure 5b	- Calibration Results for Sensor 2	31
Figure 5c	- Calibration Results for Sensor 3	32
Figure 5d	- Calibration Results for Sensor 4	33
Figure 5e	- Calibration Results for Sensor 5	34
Figure 5f	- Calibration Results for Sensor 6	35
Figure 5g	- Calibration Results for Sensor 7	36
Figure 5h	- Calibration Results for Sensor 8	37
Figure 5i	- Calibration Results for Sensor 9	38
Figure 5j	- Calibration Results for Sensor 10	39
Figure 6a	- Repeatability Test for Sensor No. 1	41
Figure 6b	- Repeatability Test for Sensor No. 2	42
Figure 6c	- Repeatability Test for Sensor No. 3	43
Figure 6d	- Repeatability Test for Sensor No. 4	44
Figure 6e	- Repeatability Test for Sensor No. 5	45
Figure 6f	- Repeatability Test for Sensor No. 6	46
Figure 6g	- Repeatability Test for Sensor No. 7	47
Figure 6h	- Repeatability Test for Sensor No. 8	48
Figure 6i	- Repeatability Test for Sensor No. 9	49
Figure 6j	- Repeatability Test for Sensor No. 10.	50
Figure 7	- Sensor Comparison Tests (Sensors 1 thru 10)	52
Figure 8	- Temporal Stability Test (Sensors 1, 3, 4, 5, and 10)	55
Figure 9	- Temporal Stability Test with Data Plotted as a Function of Temperature (Sensors 1, 3, 4, 5, and 10).	56
Figure 10	- Measured Temperature Sensitivity for All Sensors	58
Figure 11	- Temporal Stability Tests (Sensors 2, 6, 7, 8, and 9)	60

EXECUTIVE SUMMARY

A new sensor and electronic measuring system for the accurate and prompt monitoring of dust deposition rate in mines is described in this report. The entire system is called a Coal Dust Deposition Rate Monitor. The system design permits continuous monitoring of the build up of float coal dust and only requires cleaning of the dust sensor after reasonably long time intervals. The sensor units are based upon vibrating wire technology and are insensitive to lead wire resistance, contact resistance, ground leakage, and humidity, which are frequent instrument problems encountered in the mining environment. The electronic readout unit is an MSHA approved, microprocessor-based readout system which can remotely read up to 10 sensors connected through a switch module. The readout unit is a portable, rugged, accurate, and easy to use device which reads dust loading on the sensors correctly in mg/cm^2 , or as a percentage of a predetermined dust load value.

In use, the ten sensors can be placed at various locations in an underground mine and can all be monitored with a cable terminating at a central station where the switch module is located. A portable readout unit is quickly and easily hooked up to the switch module. The readout unit weighs 8-3/4 pounds, is rugged, splash-proof, and mine worthy. Both the sensor and readout unit have passed vibration tests using military standards testing procedures.

The sensors were designed to be temperature compensated and can detect changes in dust loading as small as $0.5 \text{ mg}/\text{cm}^2$. The total range of the sensor is 0 to $500 \text{ mg}/\text{cm}^2$. In quantities of 10, the sensor unit manufacturing cost is approximately \$100/unit, including 10 feet of connecting cable.

The report describes the principal of operation of the sensors, the assembly procedures, and the results of sensor calibration, stability and repeatability tests. The details of the readout unit are also described.

Ten sensors and two readout units have been supplied to the Bureau of Mines for further evaluation.

INTRODUCTION

Coal dust explosions in mines remain a major mining occupational danger. Over the years mine explosions have been responsible for the deaths of hundreds of miners. Normally, a methane explosion, which in itself is hazardous, will precede the coal dust explosion. The methane explosion entrains coal dust which has deposited onto the floor and rib sides of the underground roadways. If the coal dust is not made sufficiently inert by incombustible stone dust, the methane explosion can develop into a violent coal dust explosion. Nagy et al [2] has determined that in a typical entry, a surface layer of float coal dust which is only 0.1 mm thick (equivalent to a coal dust mass loading of 8 mg/cm²) is sufficient to sustain and propagate a dust explosion.

In an effort to prevent coal dust explosions, the law requires that the coal dust in mine roadways be mixed with rock dust (CaCO₃) to inert the coal dust deposit. Currently safety regulations of the Mine Safety and Health Administration (MSHA) stipulate that mine dust deposits contain at least 80% rock dust in the entry and 65% rock dust elsewhere in the mine (except within 40 feet of the face or when methane is present).

The degree and frequency of rock dusting required to inert the coal dust is directly related to the deposition rate of new coal dust. In actuality, the frequency of rock dusting varies widely from mine to mine; some mines resort to stone dusting whenever the entry "looks black", while other mines possibly provide excessive dusting by using almost continuous dispersal. Courtney and Bartholomae of the U. S. Bureau of Mines* estimate that the average expense for rock dusting in coal mines in the U.S. is about 20 cents per ton of mined coal.

The most prevalent procedure used today to determine the rate of coal dust deposition is to collect and weigh dust samples that have settled onto sampling plates. This procedure usually necessitates carrying the samples from the mine to the laboratory for analysis. This method is time consuming, burdensome, and expensive; it also does not provide for a rapid indication of unsafe conditions, thereby delaying the implementation of prompt remedial measures.

This report describes the development of a new device and electronic measuring system for the accurate and prompt monitoring of dust deposition rates in mines. The ultimate

*Private communication.

objective of this development is to provide a practical tool for the monitoring of rock dusting operations in mines.

Under an earlier program, the Bureau of Mines awarded a contract to IRAD GAGE, Inc. to design, develop, and build two readouts and ten sensor devices for the remote monitoring of dust deposition rate in coal mines. At the time of the award of the contract, the main specification regarding the sensor's range and sensitivity was directed to develop a technology to sense extremely small (order of 0.01 mg/cm^2) changes of surface dust concentration. This development effort was successfully carried out and ten extremely sensitive sensors and two readout units were built and delivered to the Bureau of Mines. The use of these sensors was primarily aimed at in-mine locations which are remote and undisturbed. Dust deposition rate in such areas is not high and the small, incremental build up of dust could be conveniently observed with these highly sensitive sensors. A report describing the details of the development of these sensors has already been delivered to the Bureau [2].

This present report describes the extension of the above work and has been aimed at developing a new sensor with somewhat lower sensitivity but higher range. This new design permits continuous monitoring of the build up of coal dust; it also requires cleaning of the dust sensor only after reasonably long intervals. These new sensors are based on vibrating wire technology; the sensor generates a frequency signal, rather than a voltage or a current, and is thereby insensitive to lead wire resistance, contact resistance, ground leakage, and humidity, all of which are frequent instrument problems associated with the mining environment. A MSHA approved, microprocessor-based readout system has been developed which can read ten such sensors connected through a specially developed switch module. The portable readout box is a reliable, rugged, accurate, and easy to use device which can read the dust loading on the sensor directly in mg/cm^2 or as a percentage of a predetermined dust loading value.

The operating principle of the sensor is as follows: Dust collected on a disc deflects a diaphragm causing a change of tension in a wire thereby altering the vibration frequency of the wire. The magnetic stainless steel wire is attached to the diaphragm at one end and to a fixed end block at the other end. Mounted by the side of this wire is an electromagnetic sensor coil. A readout meter connected to this coil sends a series of AC voltage pulses of variable frequency through the sensor coil and listens for the resonance vibration of the wire. Once the resonance (or ringing) frequency is detected, the readout continues to excite the

wire at that frequency and displays the frequency (f). [Actually the readout displays the period (T) of the wire vibration ($T = \frac{1}{f}$).]

Through a specially built switch module the readout can monitor as many as ten coal dust sensors. The readout is microprocessor controlled; using suitably determined calibration factors, the dust loading on the sensor disc is displayed directly in mg/cm².

The sensor is quite sensitive and can detect changes of dust loading as small as 0.5 mg/cm². The device is also extremely sensitive to temperature changes. Therefore a unique system of automatic temperature error compensation has been incorporated into the readout. This system uses an extremely stable linear thermistor to monitor the sensor temperature and the readout incorporates this information to correct the displayed sensor reading.

In use, ten sensors placed at various locations in an underground mine can all be monitored with their cables terminating at a central station where the switch module is located. The readout box is portable and is quickly and easily hooked up to the switch module. Preprogrammed channel number and sensor calibration factors enable the operator to read each sensor directly in terms of actual dust loading in mg/cm² (or alternatively as a percentage of a predetermined loading value).

The readout box weights 8-3/4 lbs., is rugged, splash-proof, and mine worthy. Both the sensor and the readout box have passed vibration tests using MIL-STD-810C Method 514.2 and Method 516.2. However, it is important to realize that the sensor is extremely sensitive and should be used only in a stationary condition after establishing its initial stable reading.

Considerable design effort was expended to stabilize the sensor output. The transducer element parts of the sensor have been built using stainless steel materials, all of which have almost the same coefficient of thermal expansion. Temperature transient effects on the sensor readings have been significantly reduced using a dust collector disc as a thermal shield.

Finally, the construction method and parts were so designed and selected that the cost of manufacture of the sensor unit was kept at an absolute minimum. An estimate of the cost of manufacture in quantities of ten is approximately \$100 per sensor unit, including 10 feet of cable.

[It should be realized that cable cost will usually be significantly higher than the sensor cost in long distance installations.]

This report has been organized in five sections. The second section gives the background and principle of operation of the sensor. The third section describes the assembly and testing of the sensor, while the fourth section describes the details of the readout unit. A summary discussion of the present design and recommendations for future design approaches to improve this sensor system are included in the fifth section. An instruction manual for use of the sensor has been included as Appendix 1.

BACKGROUND AND OPERATING PRINCIPLE

Background

A surface layer of float coal dust that is only 0.1 mm thick (8 mg/cm^2) can propagate an explosion in a coal mine. Close monitoring of the deposition rate of coal dust and of rock dust that is used to inert the coal dust is therefore required to reduce the explosion risk.

The purpose of the current development program, the results of which are described in detail in this report, is to design and build a remote dust deposition rate metering system. Dust deposition rate sensors will be placed in return ventilation roadways or elsewhere in the mine and will be wired to a remote station where a readout meter can be used to measure the mass of the dust deposits on the sensors. This system is derived from a former development program in which a set of extremely high sensitivity dust monitors was developed for use in remote areas of mines. Ten such sensors were submitted to the Bureau of Mines in December of 1979. These sensors consisted of a thin metal diaphragm whose resonant frequency was measured; the mass of the dust deposit was obtained from the change in resonant frequency of the diaphragm as it was loaded with dust. The sensitivity of this sensor was on the order of 0.1 mg/cm^2 with a range of $0-5 \text{ mg/cm}^2$.

During the field study of these sensors it was realized that there existed a need to monitor dust deposition in normal working areas where the sensitivity could be lower (around 1 mg/cm^2) but the range should be high enough (around 500 mg/cm^2) to permit long intervals of use between cleaning of the dust from the sensor.

The current dust sensor basically consists of a stainless steel circular diaphragm clamped rigidly around its periphery. One end of a thin stainless steel wire is connected to the center of the diaphragm. After pretensioning the wire, the other end is clamped to an end block. An adjustable tensioning ring provides a means for applying a fixed tension to the diaphragm and wire. The wire is vibrated by a coil/magnet assembly mounted adjacent to the wire. The frequency of vibration depends on the tension of the wire. Dust that settles on a loading disc mounted on top of the diaphragm causes the diaphragm to deflect and, therefore, the wire tension and the wire's natural frequency of vibration to change. Measurements of the wire resonant vibration frequency are interpreted in terms of the mass of dust on the dust loading disc. A microprocessor-based vibrating wire readout scans the frequency of wire vibration and uses a pre-determined calibration factor to directly read the total mass

of dust (in mg/cm²) on the loading disc. The microprocessor technique also allows the dust load to be read as a percentage of a predetermined quantity of dust. The range of this sensor system is 500 mg/cm², with a resolution of about 0.5 mg/cm².

The major advantages of this technique over the previous vibrating diaphragm type sensor are:

- (1) The sensor has a larger range of dust loading.
- (2) The diaphragm clamping condition is less critical and cheaper to assemble.
- (3) The sensor stability and readings are much less influenced by acoustic or mechanical vibration and shock.

Ten sensors have been built and supplied to the Bureau of Mines. An estimate of the cost of production in quantities of 100 is around \$100.00 each.

Operating Principle of the Dust Sensor

The operating principle of this dust sensor is based on accurately measuring the vibration frequency of a wire clamped to a stationary end block at one end and to a deflecting diaphragm at the other end. Deflection of the diaphragm is proportional to the increase in dust load on a disc mounted on the diaphragm.

Diaphragm Deflection

Figure 1 illustrates the basic elements of the coal dust sensor transducer. AB is a 0.001 inch thick stainless steel diaphragm to which a music wire CD is clamped at the center of the disc. The other end of the wire is clamped under tension to a stationary end block D. An electromagnetic coil E both excites and listens to the vibration frequency of this wire. A disc mounted above the diaphragm collects the dust load and transfers the load to the diaphragm only near the center of the diaphragm. The deflection y of the diaphragm caused by dust loading of this central area is given by Roark [3]:

$$y = \frac{w[a^2 - r^2(1 + 2\ell nr)]}{16\pi D} \quad (1)$$

where:

$$D = \frac{Et^3}{12(1 - \nu^2)}$$

t = diaphragm thickness (in.)

r = radius of loading area (in.)

w = unit line load (pounds per inch
of circumference)
 a = radius of the diaphragm (in.)
 ν = Poisson's ratio

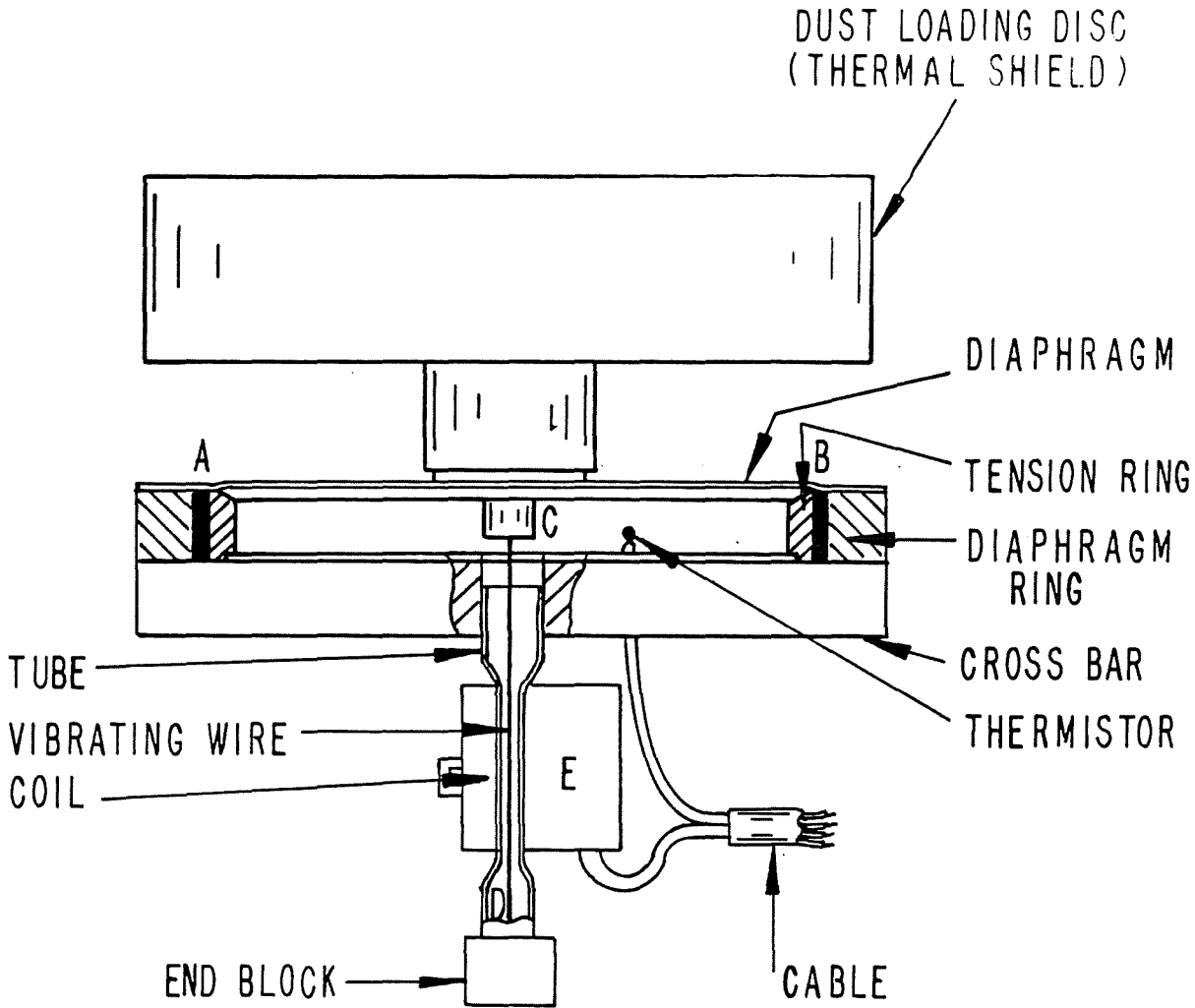


Figure 1. Coal Dust Sensor Schematic

Equation 1 shows that the deflection of the diaphragm is directly proportional to the loading on the diaphragm. As the diaphragm deflects the initial tension of the wire is reduced. In the actual embodiment of this sensor concept the

deflection of the diaphragm is extremely small (less than 0.002 in.) for the full range of dust loading and is equal to the deformation of the wire. The physical deformation of the wire changes its vibration frequency from f_0 to f_1 :

$$f_0 - f_1 = \frac{1}{2\ell_w} \frac{E_w g}{\rho} \epsilon_{w0} - \epsilon_{w1} \quad (2)$$

where:

f_0 = initial frequency of the vibrating wire

f_1 = current frequency

ℓ_w = wire length

E_w = Young's modulus of the wire material

g = acceleration due to gravity

ρ = wire material density

ϵ_{w0} = initial wire strain

ϵ_{w1} = final wire strain

It will be obvious that the disc deflection y is:

$$y = \ell_w (\epsilon_{w0} - \epsilon_{w1}).$$

The readout unit measures the current frequency in terms of wire vibration period and displays the period in microseconds. The details of the readout technique are discussed in the following section.

Readout Technique. A complete description of the readout and its method of use are given later, but briefly the unit works as follows:

A coil and magnet mounted adjacent to the wire excite the wire to vibrate at its natural resonant frequency. Following excitation, the same coil and magnet pick up a signal (by the motion of the wire in the magnetic field of the coil) which is fed to an electronic counter. The time for 100 vibrations of the wire is measured and displayed as a digital number in the period mode display of the readout. In the process of exciting the wire to its natural frequency a microprocessor-controlled excitation pulse scans a wide range of frequencies in order to select the natural frequency of the wire vibration.

Each dust sensing transducer is calibrated at the factory to determine its calibration factor, i.e., the amount of digit change of the period reading for a unit change in dust loading. The readout unit incorporates a computer and this computer uses the calibration factor to determine and display the dust loading on the diaphragm directly in mg/cm². Additional software instructions to the computer also permit the unit to display the dust loading as a percentage of the difference between preset maximum and minimum values of dust concentration.

(The actual electronic process taking place in the readout is complex and is generally of no interest to an operator using the dust monitor. Those interested in knowing further details of the readout technique should refer to the details of the readout given in Section 4.)

SENSOR DESIGN, ASSEMBLY TECHNIQUE, AND TESTING

The dust deposition monitoring system consists of remotely positioned dust sensing transducers connected electrically to a centrally located readout box. The sensor itself consists of three subparts: the sensing transducer, the housing, and the dust loading disc. Figure 2 depicts an assembly layout of a complete sensor.

Transducer Design

Basically the transducer consists of a highly tensioned wire which is fixed to an end block at the lower end and attached at its upper end to the center of a flexible diaphragm. The sensitivity required from this transducer design dictates the use of an extremely small diameter wire and thin diaphragm. The transducers are assembled with 0.005 in. diameter wire (2.5 in. length) and a 3.25 in. diameter metal diaphragm which is 0.001 in. thick.

The overall performance objectives of the sensor were:

- (1) The sensor should not be subject to damage by vibrations.
- (2) The sensor should be able to withstand shock loadings in transport.
- (3) The sensor should be insensitive to acoustic noise.
- (4) The gage factor, from sensor to sensor, should be as identical as possible.
- (5) The sensor should be insensitive to temperature effects, i.e., stable to changes in surrounding temperature.

The construction of transducers with nearly identical calibration gage factors required the ability to fine tune individual sensors to approximately the same tension in both the diaphragms and wires. A tension ring has been incorporated into the transducer design to permit fine adjustment of the diaphragm tension. The basic elements of the diaphragm/wire assembly are shown in Figure 3.

During the transducer assembly, the diaphragm is spot-welded to the outer flat surface of the diaphragm ring. The tension level is then adjusted by raising and lowering the tension ring in contact with the diaphragm. This is done using two fine thread set screws. This system serves to produce a well defined diaphragm diameter with reasonably uniform tension level at all positions around the circumference of the tension ring.

ITEM	DESCRIPTION	MATERIAL
1	BOTTOM END BLOCK	303 ST ST'L
2	DIAPHRAGM END BLOCK	303 ST ST'L
3	TUBE	304 ST ST'L
4	CROSS BAR	303 S/S FLAT
5	DIAPHRAGM RING	304 ST ST'L
6	TENSION RING	304 ST ST'L
7	HOUSING	PVC
8	BOTTOM COVER	P.V.C.
9	TOP COVER (NOT SHOWN)	P.V.C.
10	SM-5A COIL CABLE ASSEMBLY	
11	THERMAL SHIELD	
12	4-40 X 3/8" LG SOCKET HEAD CAP SCREWS	STAIN ST'L
13	4-40 X 1/2" LG SOCKET HEAD CAP SCREWS	STAIN ST'L
14	1/8" DIA X 1 1/2" LG DOWEL PIN (OVERSIZE .001)	H S
15	1/4"-20 X 1 1/2" LG RD HD. MACH. SCR (NOT SHOWN)	NYLON
16	LEE COMPRESSION SPRING NO. LC-024B-6	STAIN ST'L
17	RUBBER GROMMET	NEOPRENE
18	.005 DIA X 2 1/2" LG MUSIC WIRE	302 ST ST'L
19	TY WRAP	
20	YELLOW SPRING THERMISTOR NO. YS144201	
21	BELDEN CABLE NO. 8723 4 COND GRAY	
22	CAPILLARY	316 ST ST'L
23	.001 THICK X 4" DIA DIAPHRAGM	302 ST ST'L

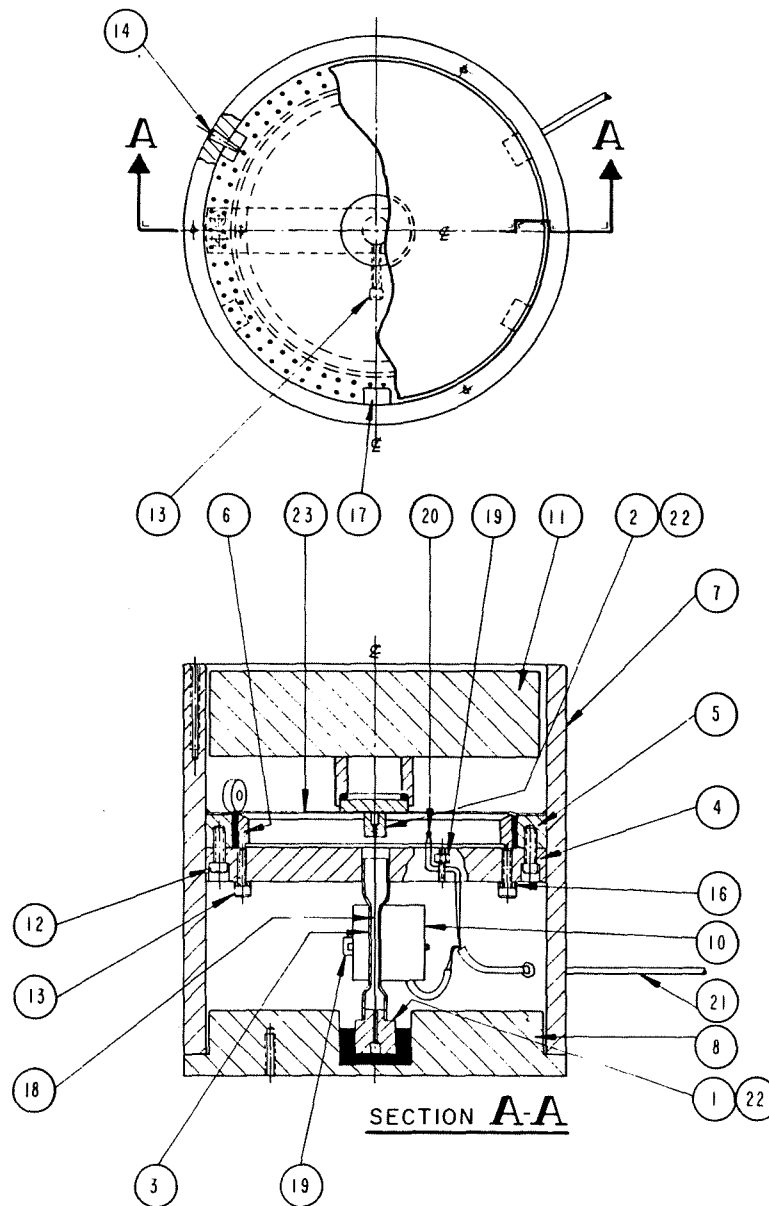


Figure 2. Coal Dust Sensor Assembly

At an early stage of the development of the sensor, it was observed that because of complex mechanical interactions, a small thermal mass of wire and diaphragm, and the mismatch of thermal expansion coefficients of various parts, the device was excessively responsive to temperature changes. A considerable design effort was undertaken to reduce this problem. One significant change was the use of parts made from stainless steel of the same thermal expansion coefficient.

A second significant change was to thermally isolate the diaphragm. The diaphragm is thin and is therefore very sensitive to thermal changes. To isolate the diaphragm from sudden temperature changes a thermal shield above the transducer diaphragm is used. The shield is made of closed cell foam specially cut to fit on the diaphragm. This shield accomplishes several functions:

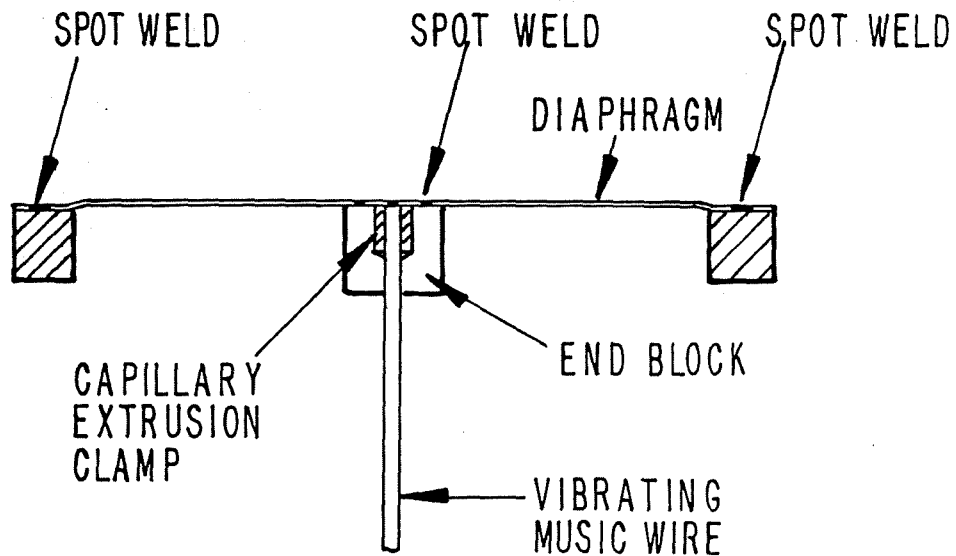


Figure 3. Basic Elements of the Vibrating Wire/
Diaphragm Assembly

- 1) The shield collects the deposited dust on its top surface (coated with aluminized mylar) and transfers the dust load to the center of the transducer diaphragm.
- 2) The shield insulates the diaphragm from sudden thermal transients.
- 3) By concentrating the load to the center of the diaphragm, the shield increases the transducer sensitivity.
- 4) The shield gives some protection for the diaphragm from falling debris, etc.

In normal use, frequent cleaning has to be done only to this removable and replaceable shield and not to the delicate diaphragm which can remain essentially undisturbed.

Sensor Housing

The following were selected as the basic requirements of the housing design for the sensor:

- 1) The vibrating wire transducer element must be well sealed from ambient coal dust. Dust deposition on the vibrating wire would be catastrophic to proper sensor performance.
- 2) The housing must protect the sensor from shock and vibration. The transducer is mounted inside the housing by resting it on isolation mounts located below the diaphragm rings and above the diaphragm. Direct access to the transducer interior is sealed and the maintenance of pressure balance above and below the diaphragm is established through a circuitous air path.

To avoid vibration or shock damage, the lower end block is encased in a J-type silastic compound. The isolation mounts, which pin the transducer in the housing, have rubber linings which aid in stability against shock and vibration. Additionally all adjustment points and joints (tension ring screws, crimped tube screws, crimped tube/crossbar and crimped tube/lower end block) are epoxied in place during the final assembly to prevent reading shifts due to shock or vibration.

Sensor Materials

The principal factors dictating the selection of materials for construction of the sensor were:

- 1) expense,
- 2) a small temperature compensation factor,
and
- 3) long-term sensor life.

The sensor must survive adverse and corrosive environmental conditions and stainless steel was selected for the construction of the transducer. To eliminate any thermal expansion mismatch, only 300-type series stainless steel was used for the transducer element components:

<u>Component</u>	<u>Stainless Steel Metal Type</u>
Diaphragm	302
Wire	302
End Block	303
Crossbar	303
Diaphragm Ring	304
Tension Ring	304
Crimped Tube	304
Cap Screws	304
Capillaries	316

The dust collector/thermal shield is a closed cell foam pad, with an aluminized mylar facing. Attached to the lower surface is a small PVC standoff ring to allow the dust collector to be located centrally on the diaphragm.

The entire housing is constructed from PVC plastic. Reflective tape has been added to the housing exterior to assist in locating sensors during field use.

A protective PVC canopy (Figure 4) has been designed to help protect the sensor from falling debris. The PVC canopy rests on three standoff rods constructed from 304 stainless steel.

Assembly Procedure

The assembly procedure for construction of the coal dust sensor is as described below. The procedure is separated into three major stages: 1) transducer construction, 2) housing construction, and 3) the assembly of the transducer and housing.

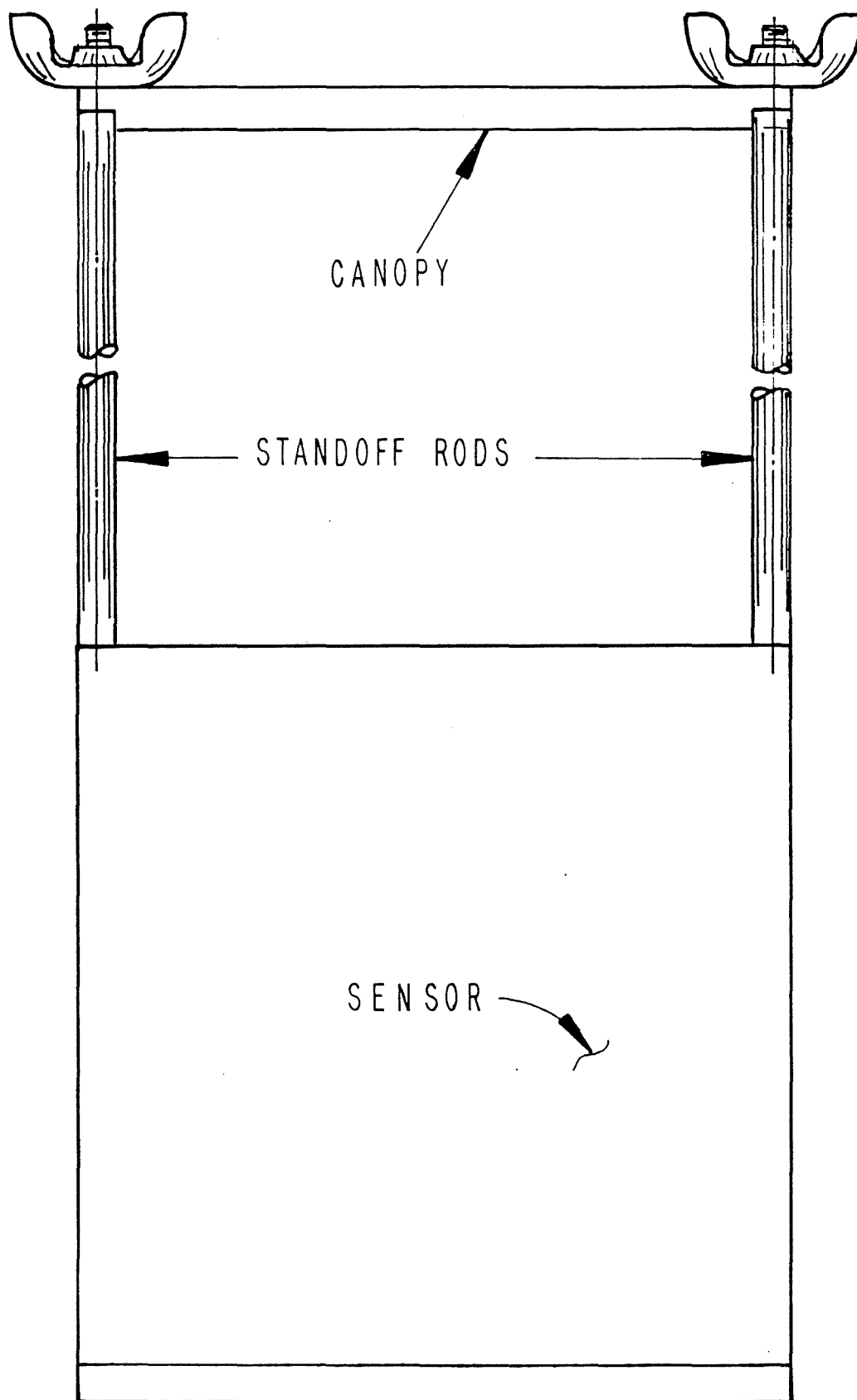


Figure 4. Protective Canopy for Sensor

Transducer Construction

The transducer is constructed as follows:

- a) A 0.001 inch thick 302 stainless steel diaphragm is tensioned in a fixture such that essentially uniform radial tension is achieved. This is accomplished by pulling radially on the diaphragm in eight directions using eight springs. The diaphragm ring is then slid under the diaphragm and alignment should be sufficient to ensure that an equal amount of diaphragm material is visible around the diaphragm ring's boundaries. The diaphragm is then spot-welded to the ring, in a welding pattern that limits diaphragm material buckling, while guaranteeing a uniform, permanent bond.
- b) The 0.005 in. diameter 302 stainless steel wire is then set, using the proprietary IRAD capillary extrusion technique, in an 0.25 in. O.D. Type 303 stainless steel end block (Figure 3). An adequate length of wire is left in place. The wire section nearest the end block is then magnetized and, using a centering fixture, the end block is spot-welded to the center of the diaphragm.
- c) The wire is then fed through the crossbar, tube, and through the lower end block. All joints are temporarily clamped, and the wire on the lower end block is then set. For both end block settings, the wire tension is maintained at about 300 gm.
- d) The tension ring is then "backed off" from the diaphragm so as not to contact it. The crossbar is permanently clamped to the diaphragm ring, and the crimp tube clamp to the crossbar is released. A weight is then hung from the lower end block to provide a fixed, known tension in the wire and the crimp tube is clamped at the crossbar junction. This procedure assures a close uniformity of wire tension for all sensors. To further adjust the transducer reading (wire/diaphragm tension), the height of the tension ring is raised or lowered by using the adjusting set screws (see Figure 2).

Housing Construction

The housing assembly is constructed from PVC plastic. Standard, stock size dimensions were used to minimize manufacturing costs.

- a) The housing outer cylinder is made from standard Schedule 40 PVC pipe. Some minor machining may be required to maintain the roundness and inner diameter specifications.
- b) The transducer rests in the housing on three compliant mounting pins (located every 120°) and is clamped by three additional compliant pins located on the bottom and top of the diaphragm ring. Each mounting pin is assembled in the identical manner; a stainless steel dowel pin is press fit into the housing tube and a thick-walled (~ 0.375 in.) soft rubber ring is then glued onto the pin. Initially, only the lower level of pins is completed; the upper pins are started into their positions, but not pushed through the cylinder wall until the transducer is added.
- c) A length of 4-conductor cable is fed through a clamp and through an entry hole in the housing tube. The cable is not clamped at this time.

The transducer and housing sections are now ready for mating and final assembly.

Assembly of Transducer and Housing

- a) Sufficient cable is fed through the housing to easily reach the transducer. An IRAD Model SM-5A standard strain gage electronic coil is attached (soldered and insulated with shrink tubing) to the red and black leads, and a thermistor is attached to the green and white leads. The ground shield is left unattached and is clipped at the cable jacket.
- b) The thermistor bead is positioned to be located in the air space between the crossbar and the diaphragm, and the thermistor wire is clamped to the 303 stainless steel crossbar using plastic tyrap. Two tyrap are used to: 1) assure the thermistor is permanently locked in position, and 2) to provide strain relief for the thermistor leads.

- c) Following attachment of the electronic coil to the cable leads, the coil is clamped to the crimp tube, surrounding the transducer wire, and a single tyrap is used to assure a permanent bond. Both the thermistor and coil are read at this time to check that the gage and thermistor are reading. A check of lead resistance assures that no shorts exist. The transducer is then lowered into the housing until the diaphragm ring rests on the three lower isolation mounts.
- d) The three upper isolation mounts are now pressed into position, clamping the transducer into its final position in the housing.
- e) The excess cable is slowly pulled out of the housing interior (through the cable entry port) until a minimal amount remains as strain relief. The cable clamp is set in the housing wall and the cable is clamped into place. Additionally, a knot is tied in the cable and the cable is drawn out of the housing until the knot contacts the housing I.D. The cable is then set to withstand a tension force of approximately 10 lb_f.
- f) The thermal shield is constructed from a closed cell foam pad covered with aluminized mylar. A small circular PVC standoff is attached to the shield center. The contact between the standoff and the diaphragm locating disk is through an o-ring glued to the inside diameter of the standoff.
- g) The sensor top is sealed from migrating coal dust by an RTV seal made between the diaphragm ring and housing inside diameter.
- h) The final bench reading is set with the thermal shield installed. The transducer is allowed to come to thermal equilibrium and the reading is achieved by adjusting the height of the tension ring via the two tension ring adjustment screws (located in the crossbar).
- i) The final sensor bench reading is now ready to be permanently set. The tension ring set screws are treated with a Loctite thread-locking adhesive, and the boundaries between crossbar and crimp tube and crimp tube and lower end block are fixed with Micro Measurements AE-10 epoxy.

- j) A final check of the sensor interior is performed, allowing sufficient time for all epoxys to cure, before the bottom cover is installed. The bottom cover serves two purposes: 1) it seals the sensor interior from migration of coal dust to the vibrating wire, and 2) the lower end block is cast in a J-type silastic to relieve the "cantilevered" wire section from possible vibration. Therefore, bottom cover installation is initiated by filling a hole in the bottom cover with J-type silastic. Before the silastic is completely cured, the bottom cover is glued to the cylinder housing such that the lower end block is buried in the silastic. (Note: the bottom cover cannot be removed without a major risk of lower end block loading and possible breakage of the vibrating wire.) The entire assembly is now allowed to cure before proceeding to final test and Q.A. procedures.
- k) Each sensor is heat cycled (5 cycles @ 140°F) and load cycled (3 cycles from 0-900 mg/cm²).
- l) Each sensor is then load calibrated (readings taken approximately every 40 mg/cm² of increased loading over three cycles). The temperature compensation factor is also determined.
- m) Sensors are permanently numbered (replacing temporary numbers installed during assembly) and the top covers added. The sensor assembly is now complete.

Test Data

Ten coal dust sensors were manufactured, tested and delivered to the Bureau of Mines. This section describes the testing performed on these sensors prior to delivery to the Bureau. The data and plots provided in this section display data for the following types of tests:

- 1) calibration tests
- 2) repeatability tests
- 3) gage-to-gage comparison tests
- 4) temporal stability tests

More than ten gages were manufactured and tested. From these gages, the best performing ten gages were selected. Prior to testing, these gages were numbered 1 through 12. In the following discussion, the ten gages selected are numbered 1 through 10.

Each gage was delivered to the Bureau with its gage number on it and each gage has its own thermal shield—which is also the dust collecting platform—and this shield was also numbered to correspond with the gage sensor number. The remainder of the parts of the sensors, i.e., the gage canopy cover and mounting bolts, etc., were designed to be interchangeable between gages. Since the thermal shield serves as a part of the gage sensing apparatus, the calibration tests, and the other tests described above, need to be performed with the thermal shield in place. Note that while the thermal shields are replaceable, whenever they are replaced the gage calibration must be repeated to include the effects of the new thermal shield.

Linearity of Sensor Load Calibration

The original calculations done on the prototype designs of the coal dust sensors show them to be quite linear; i.e., the period reading of the sensor output was very close to being a linear function of applied load (for a sensor at constant temperature). This predicted result was found to be true over a limited range of load. When a single linearizing function was put into the algorithm of the readout unit (the algorithm converts differences in measured period of wire vibration to mg/cm^2 dust reading), the precise calibration of the sensors over the full load range—i.e., 0 to $500 \text{ mg}/\text{cm}^2$ —showed the calibration curve to be slightly non-linear. The maximum difference between the actual load curve and a linear fit matching the 0 and $500 \text{ mg}/\text{cm}^2$ load points was on the order of $20 \text{ mg}/\text{cm}^2$.

It was determined that a second order parabolic curve fitting linearizing algorithm could match the measured load characteristic to within $\pm 1 \text{ mg}/\text{cm}^2$. Further, one of the two calibration constants required for a second order curve fit could be kept constant for all sensors. Therefore, only one load calibration constant needed to be specified for each sensor. This being the case, it was then still possible to use the faceplate/keyboard layout originally designed for the readout, since the input of calibration data for each sensor would only require one load calibration constant.

This approach worked well and the results of using a second order curve fit algorithm within the readout to linearize the sensor calibration curves can be judged by examination of the calibration data as presented below.

Each type of test performed on the gages is described in detail below and an interpretation of the data is given.

Calibration Tests

Each gage was independently calibrated to obtain a calibration factor for that gage. The determination of the "calibration factor" was made in the following way:

- 1) With the gage under stable temperature conditions, the CURRENT PERIOD reading was recorded for successive loads from 0 to greater than full load. The load concentration values used in these tests ranged from 0 to 611 mg/cm² (500 mg/cm² = full load). The loads were obtained by placing a concentrated and known weight in the center of the thermal shield and dividing the weight by the area of the thermal shield to compute the load concentration in mg/cm².
- 2) For each load concentration, the CURRENT PERIOD of wire vibration of the sensor was recorded.
- 3) The calibration factor (=a) was computed from the best straightline fit through the data between zero load concentration and maximum load concentration.

With the calibration factor determined for each gage as described above, this GAGE FACTOR was entered into the readout unit for each gage.* Then a series of calibration tests were run on each gage as follows:

- 1) Each gage was brought to thermal equilibrium condition by the monitoring of the temperature on each gage as determined by the temperature reading on the readout.
- 2) The gage was initialized for INITIAL PERIOD (and also for INITIAL TEMPERATURE which is automatically entered with the INITIAL PERIOD.
- 3) Successive and increasing load concentrations were then applied between 0 and 611 mg/cm². At each load concentration value, the DUST LOAD in mg/cm² was read from the readout and the actual load concentration as recorded.

*A description of the Coal Dust Sensor Readout Unit and how to use it to initialize data and read coal dust sensor loadings is given in Section 4.

- 4) The gage load was returned to zero load and the load DUST LOAD recorded.
- 5) The above procedure was repeated for a total of three successive calibration cycles. The data from these tests are displayed on figures 5a through 5j, which display a plot of measured load concentration as a function of actual load concentration applied to the sensor. A 45° solid line is shown on each figure to give the expected locus of data points for exact correspondence between measured and actual load concentration values. In most of these plots, a single data point "circle" is shown to represent the data for the three separate test cycles; in some cases, two or more data "circles" are shown if the spread in measured values for the three test cycles is sufficiently large.

The main conclusions to be drawn from these data are that the sensors are very repeatable and that the accuracy is good. The repeatability for the gages is slightly greater than the $\pm 1 \text{ mg/cm}^2$ which was the target objective of this development.

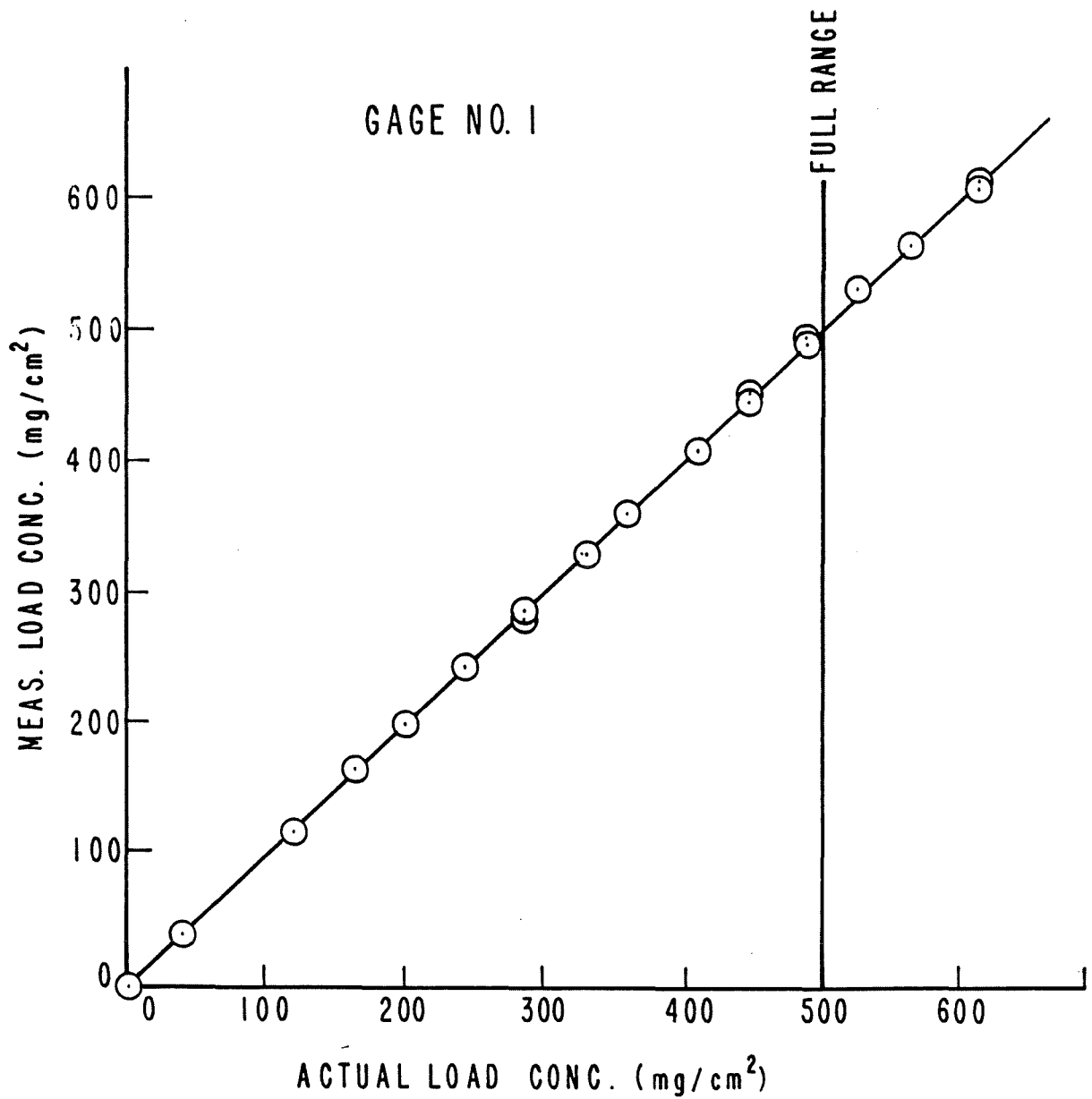


Figure 5a. Calibration Results for Sensor No. 1

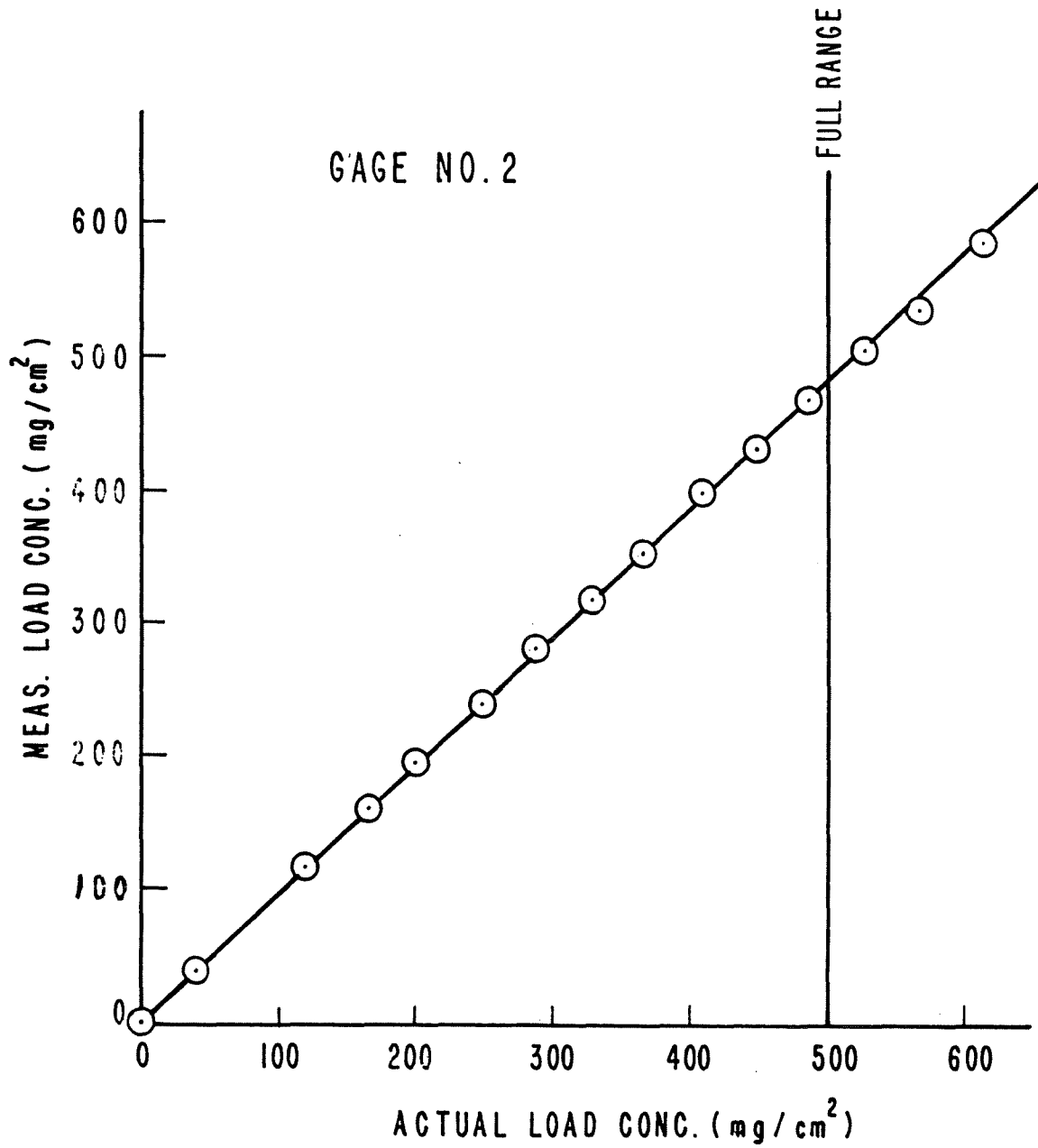


Figure 5b. Calibration Results for Sensor No. 2

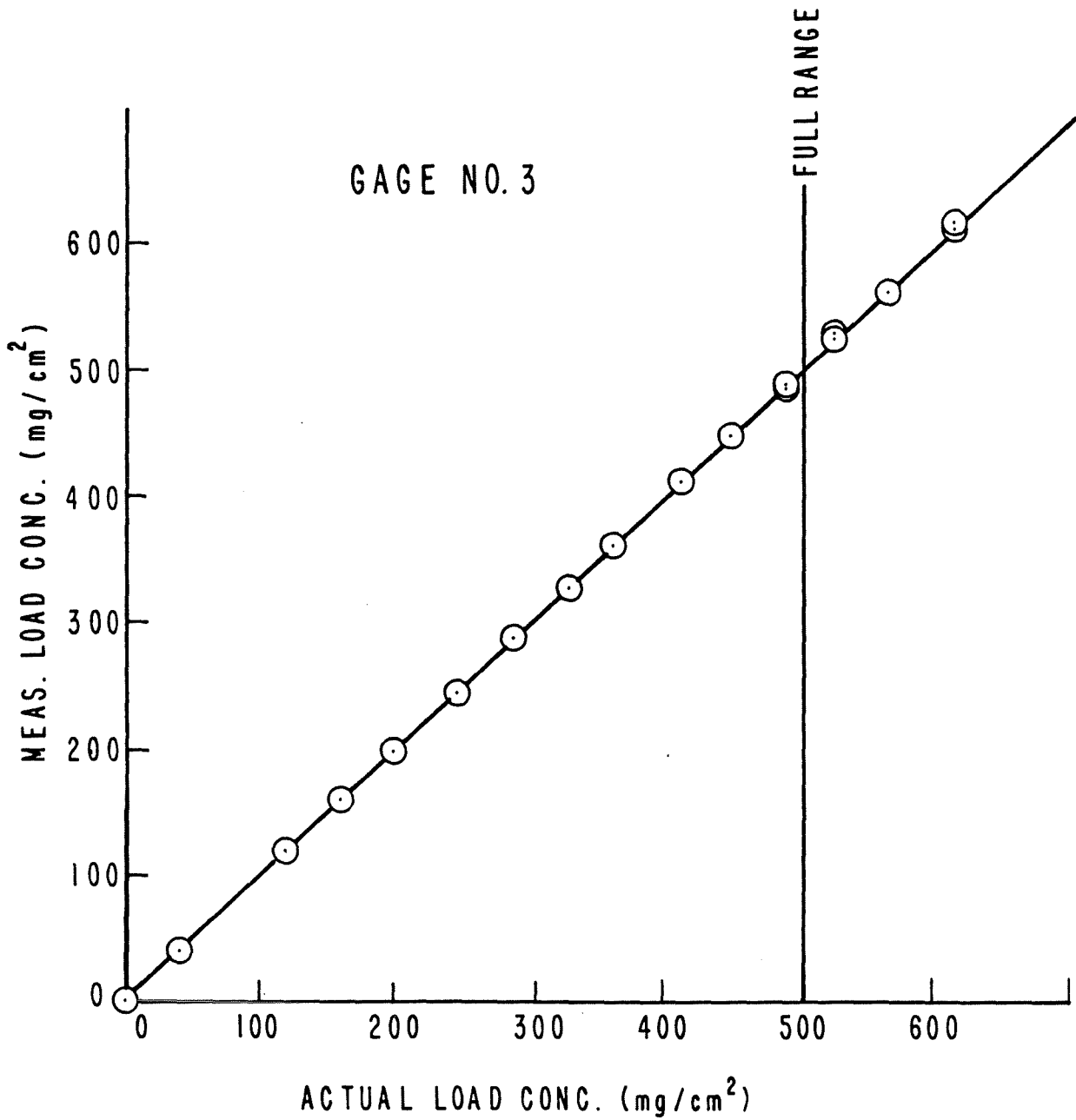


Figure 5c. Calibration Results for Sensor No. 3

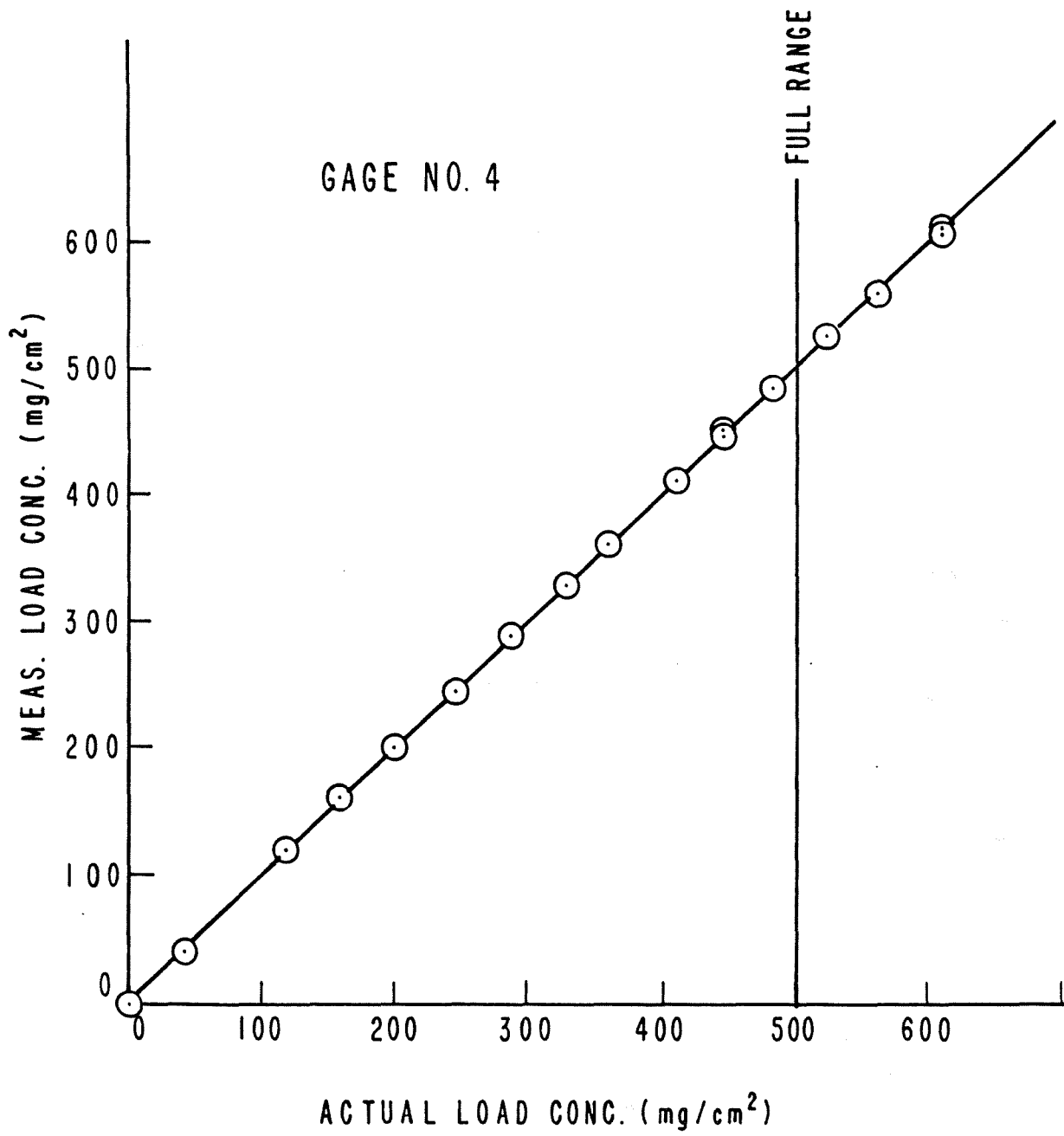


Figure 5d. Calibration Results for Sensor No. 4

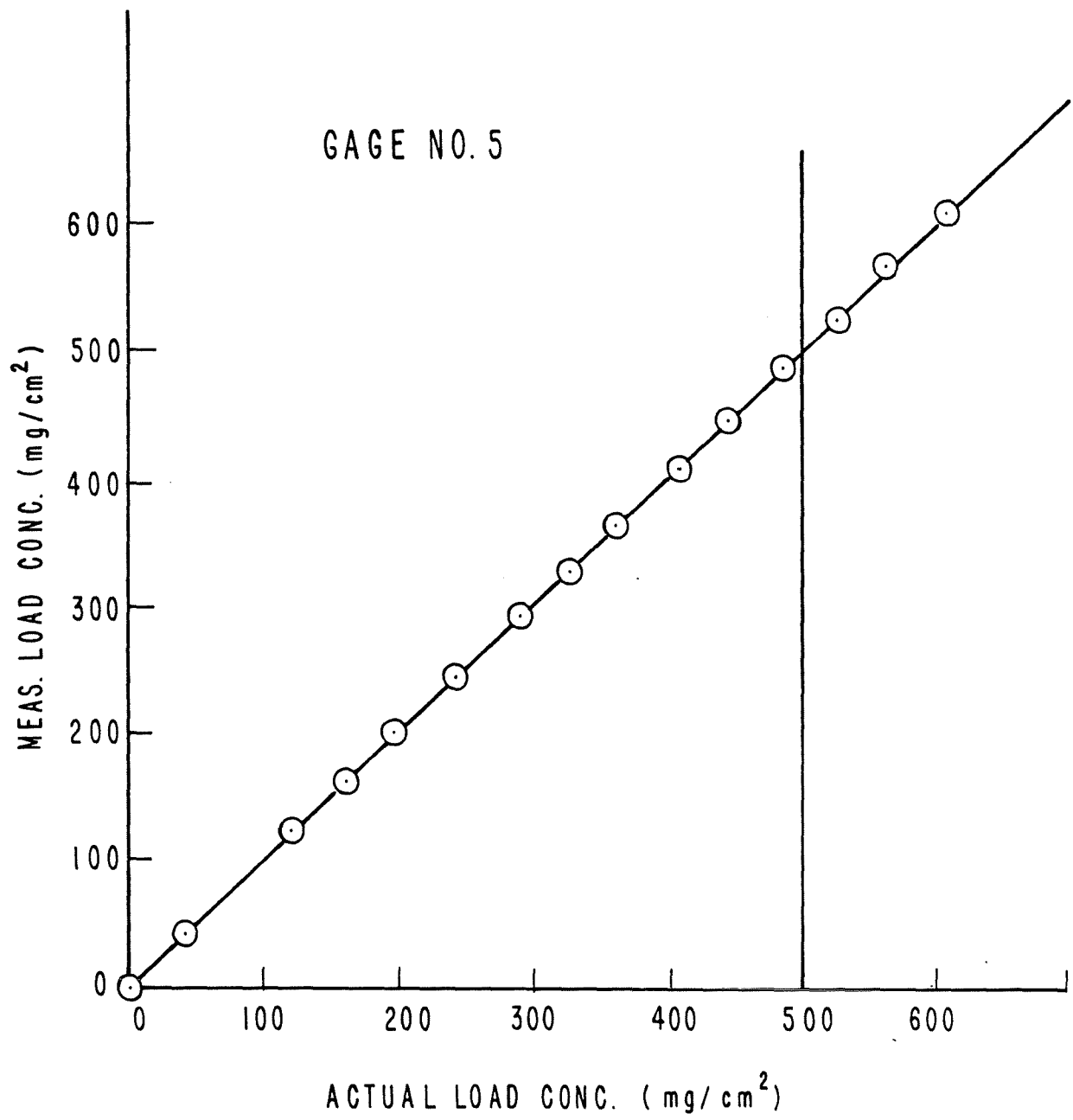


Figure 5e. Calibration Results for Sensor No. 5

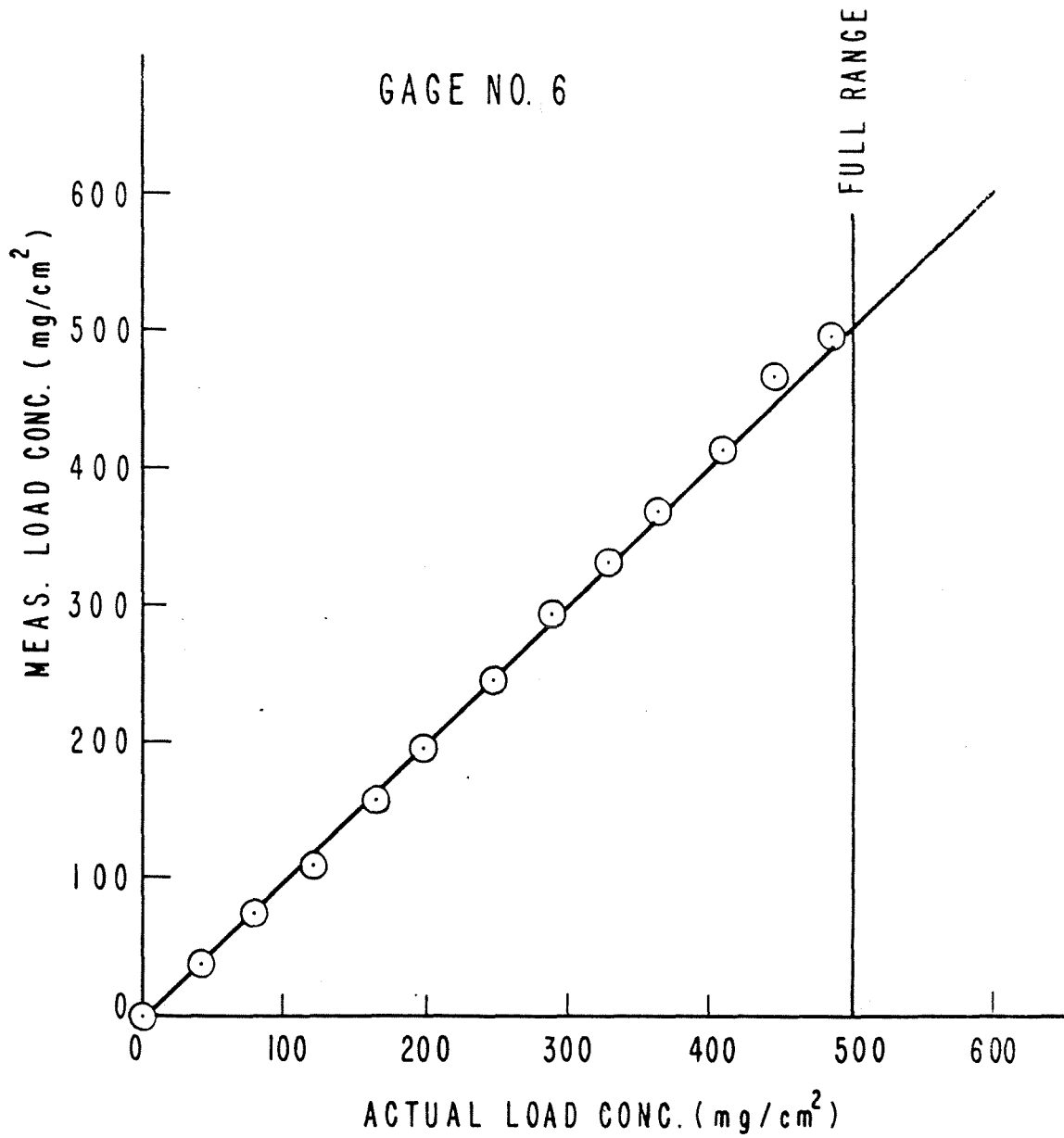


Figure 5f. Calibration Results for Sensor No. 6

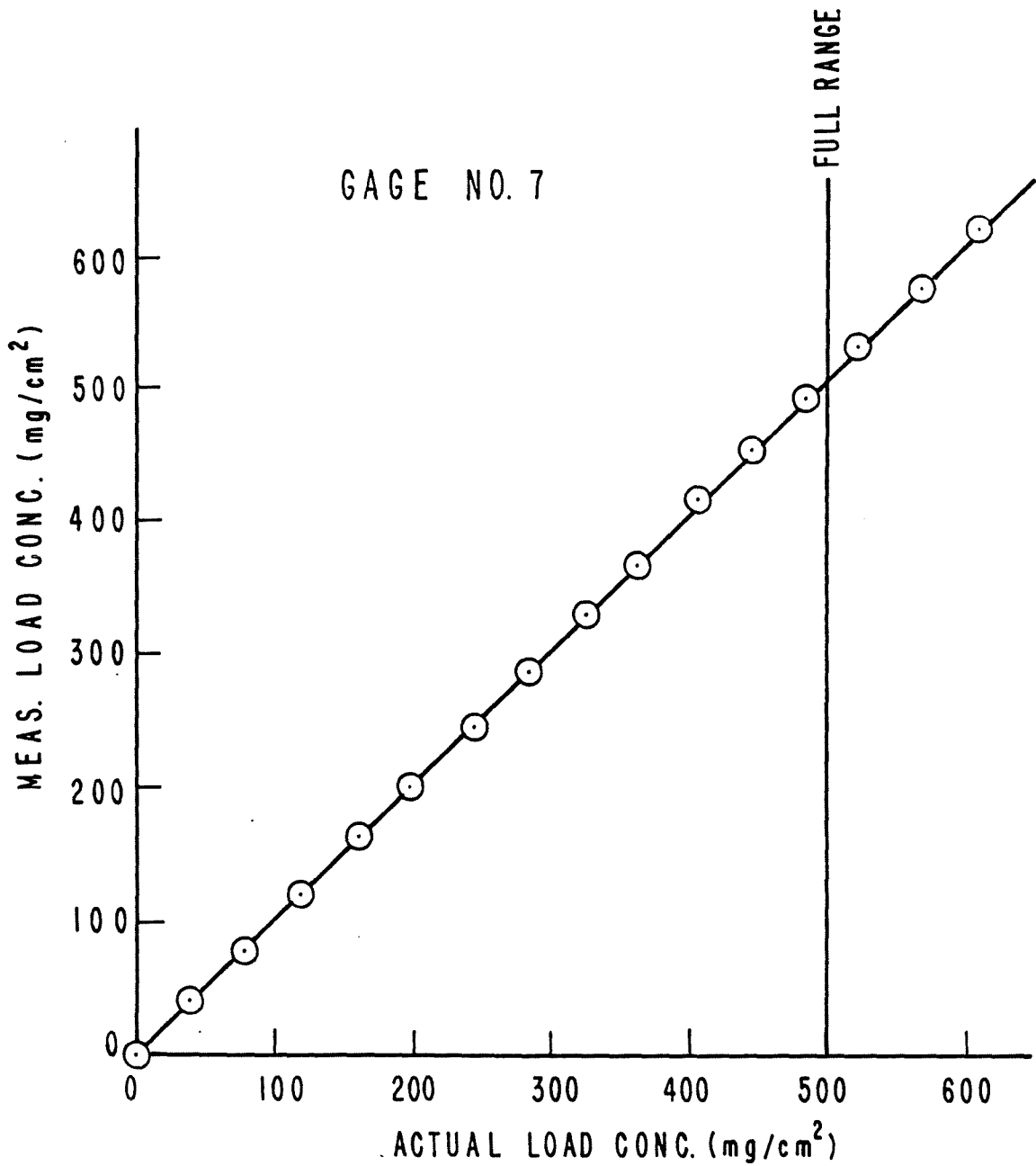


Figure 5g. Calibration Results for Sensor No. 7

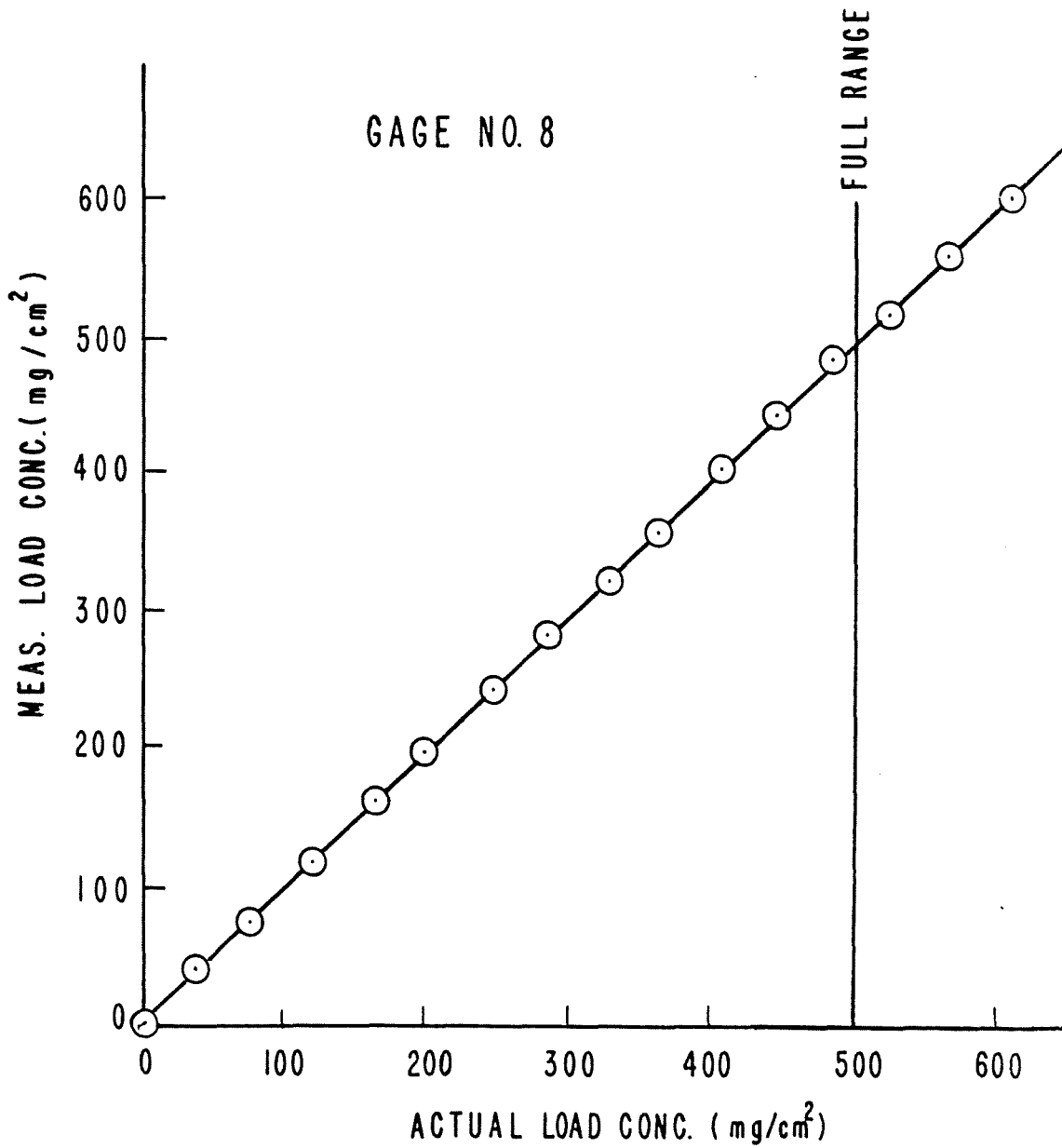


Figure 5h. Calibration Results for Sensor No. 8

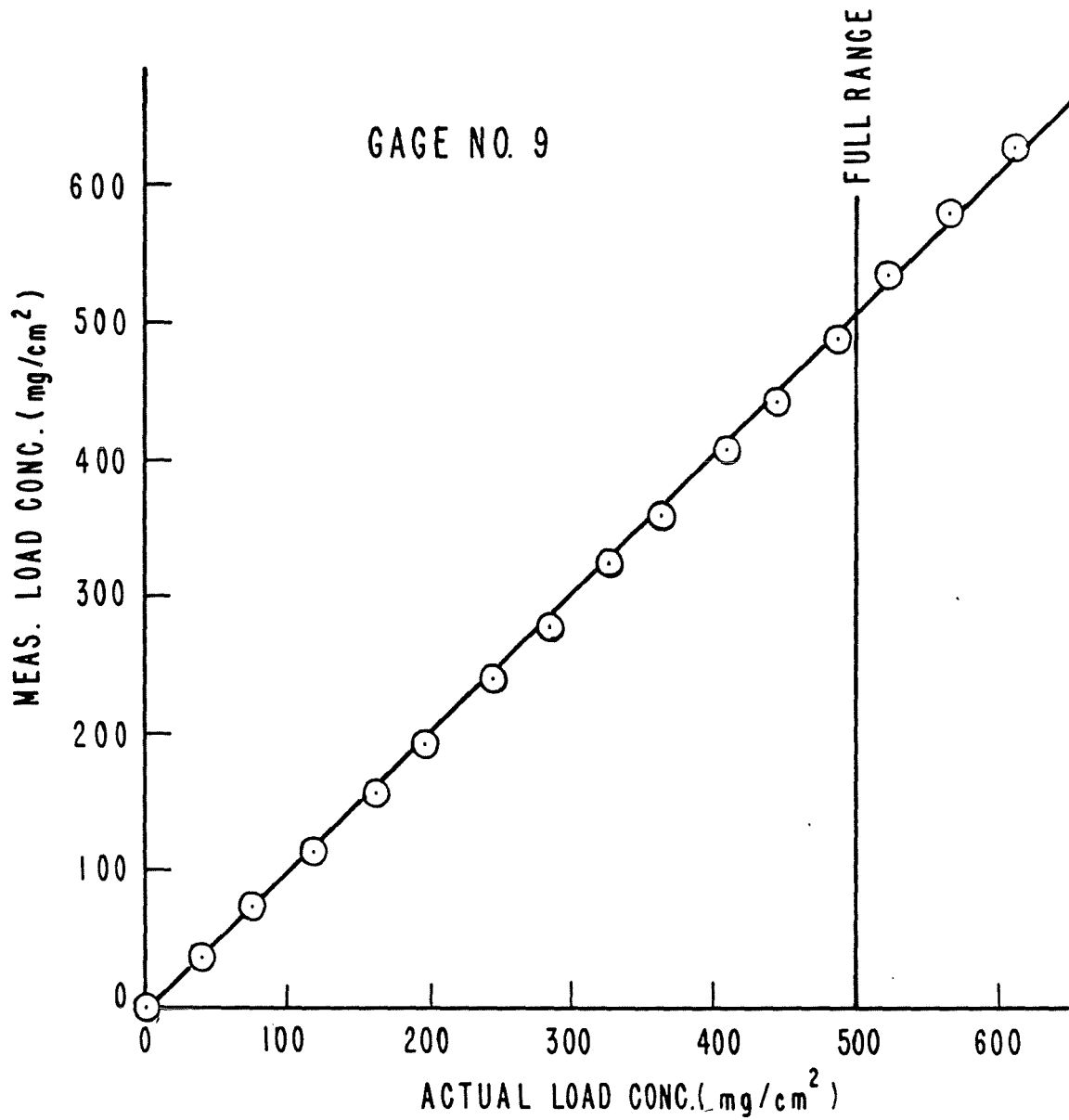


Figure 5i. Calibration Results for Sensor No. 9

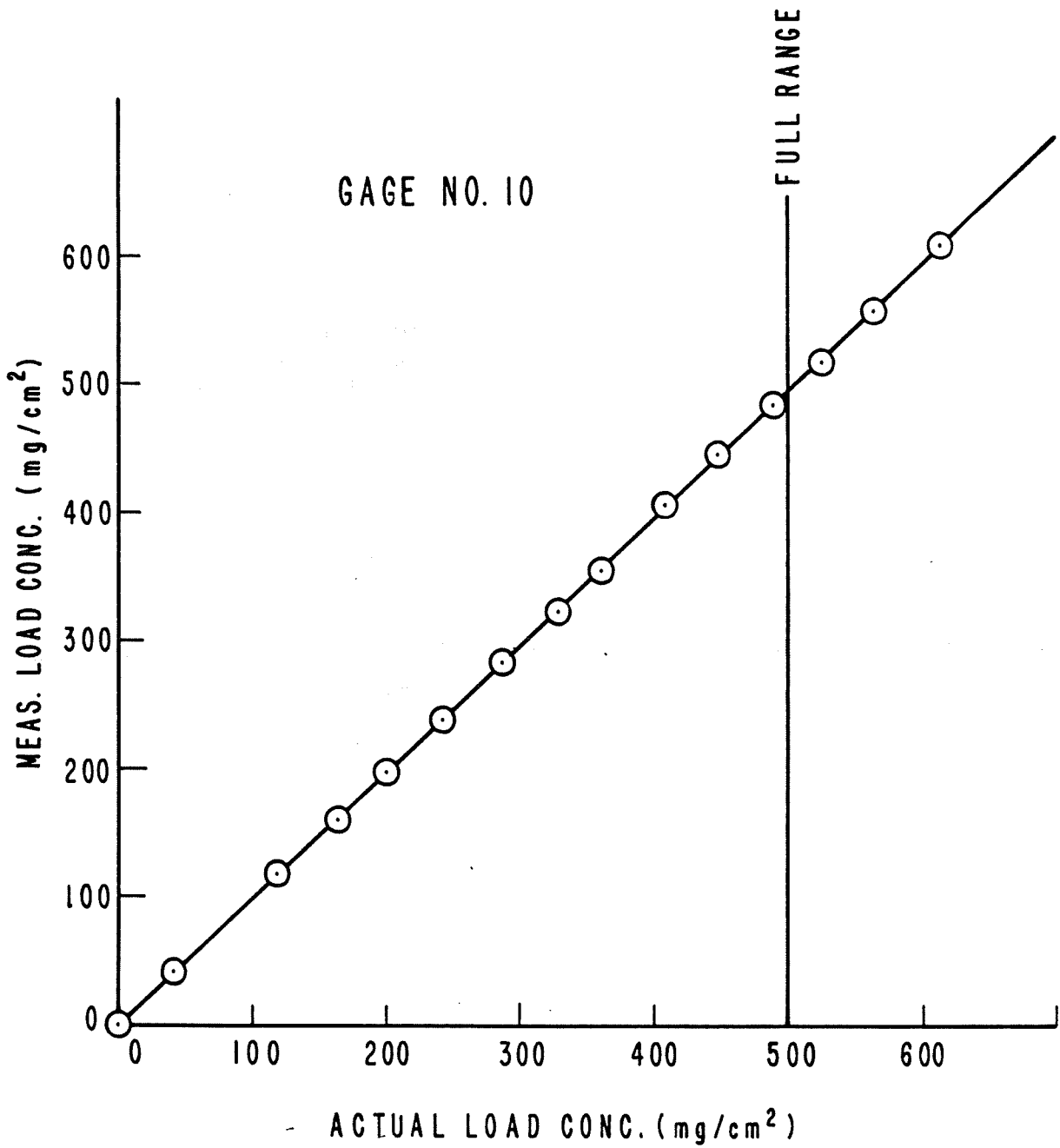


Figure 5j. Calibration Results for Sensor No. 10

Repeatability Tests

A series of tests were performed on each gage to check the "repeatability" of the gage to read the same DUST LOAD for successive applications of the same load to the sensor. Three different loads were applied to the gage and were:

- 0 mg/cm²
- 243 mg/cm² (approx. mid-range)
- 485 mg/cm² (approx. full-range)

These tests were performed as follows:

1) Using the same GAGE FACTOR determined and used in the calibration tests, each gage was brought to temperature equilibrium and then successively loaded and unloaded a total of eight times between 0 and 243 mg/cm². The GAGE PERIOD (and temperature) was initialized at the start of this series of tests.

2) The above procedure, including both period and temperature initialization, was then repeated for 485 mg/cm².

The series of figures showing the data for these tests, labeled "Repeatability Tests", are given for each gage in figures 6a through 6j. Each gage figure shows the series of eight tests at 0, 243, and 485 mg/cm². A solid line showing the actual load concentration applied to each sensor at each of these two load levels is shown in the figure.

In examining these data, the following conclusions are reached. The data are quite repeatable for these series of tests, being usually on the order of ± 2 mg/cm² or less around the actual dust load value. The value of the DUST LOAD reading compared to the actual load concentration value is also consistent with the calibration data obtained for each sensor in the calibration tests described previously.

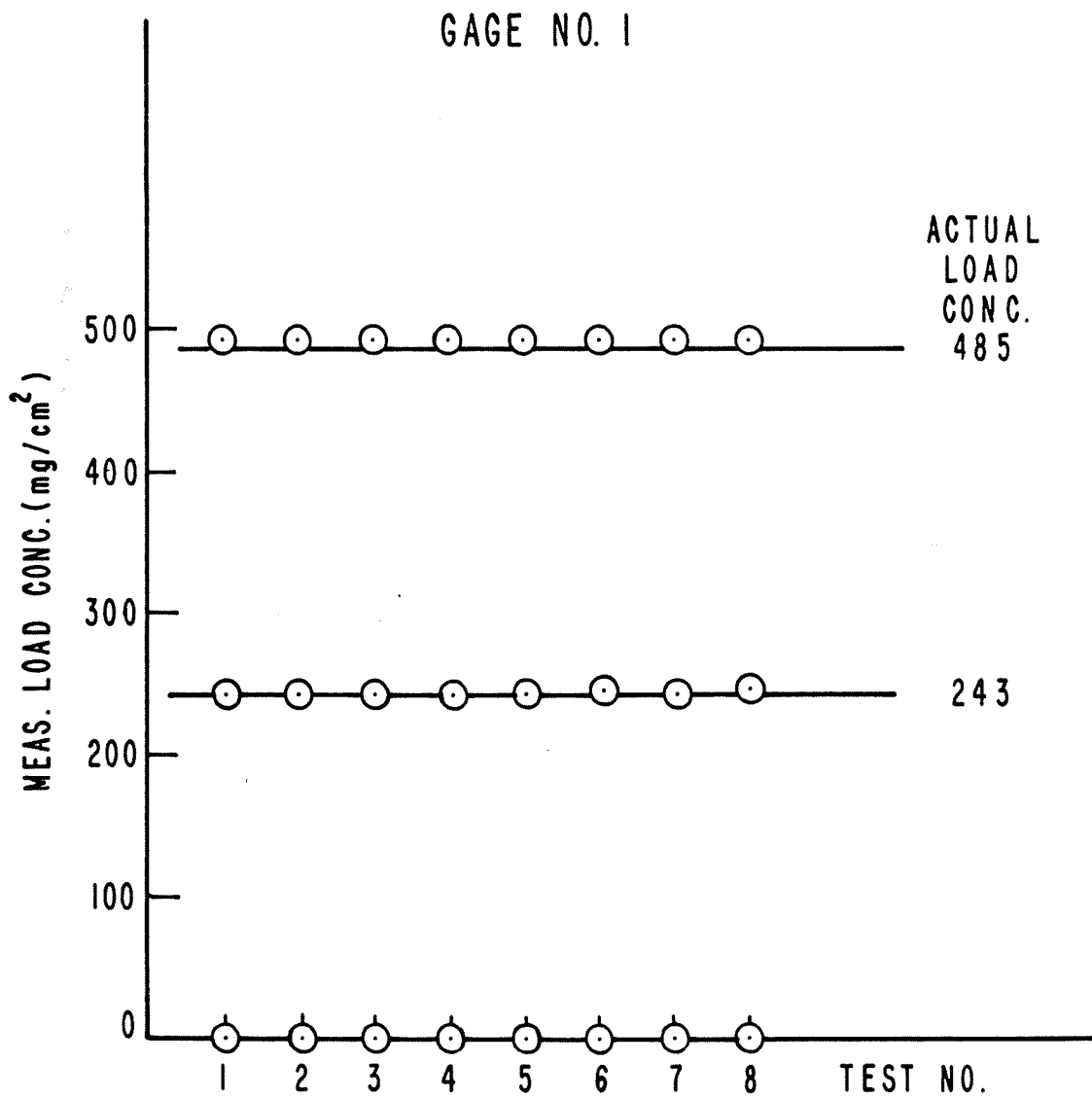


Figure 6a. Repeatability Test for Sensor No. 1

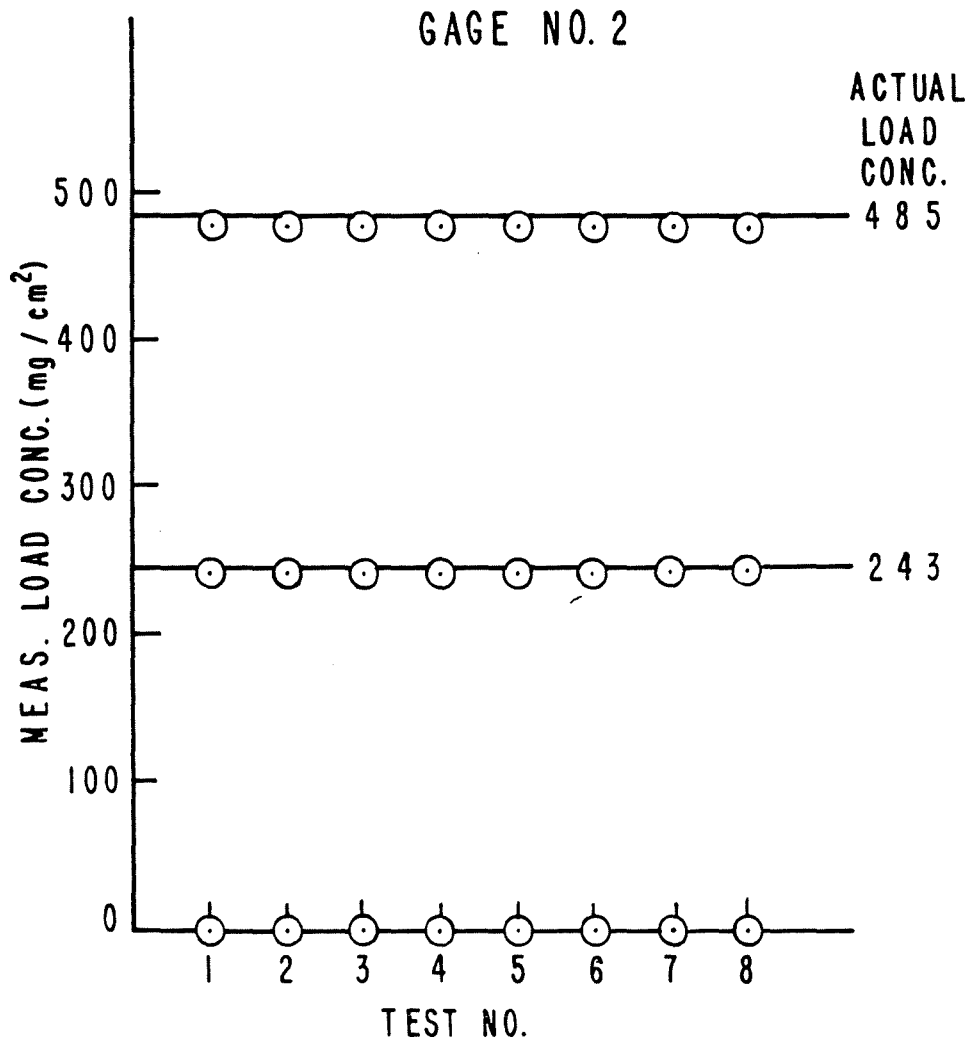


Figure 6b. Repeatability Test for Sensor No. 2

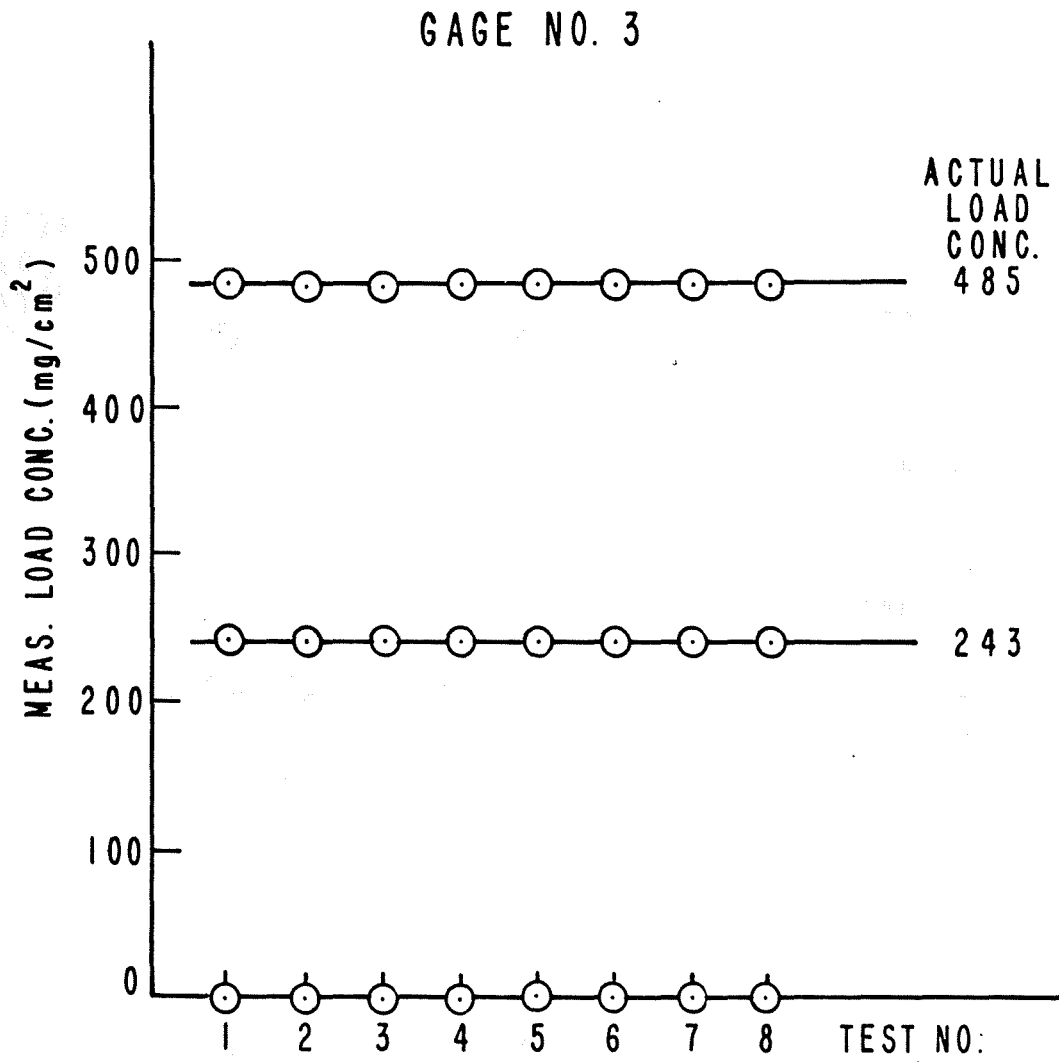


Figure 6c. Repeatability Test for Sensor No. 3

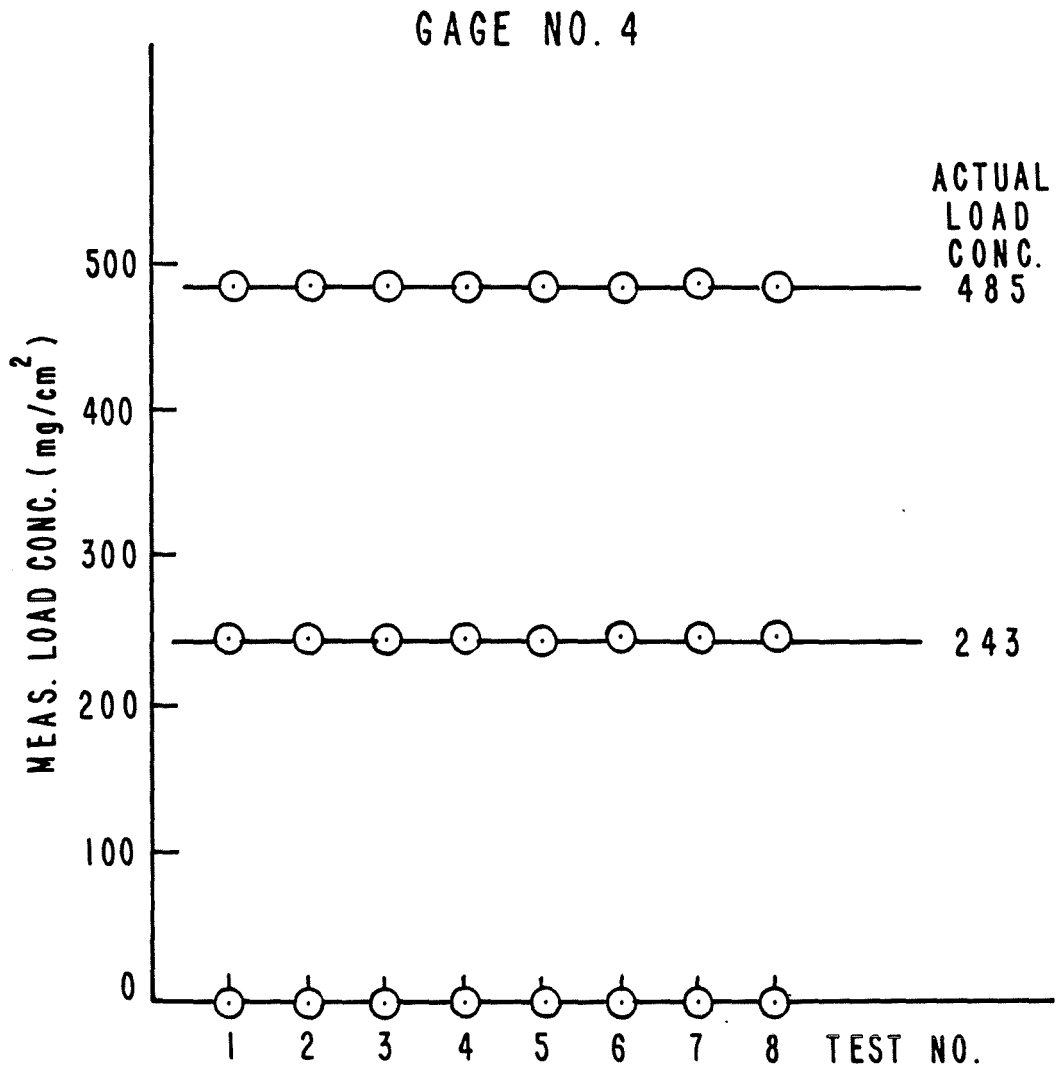


Figure 6d. Repeatability Test for Sensor No. 4

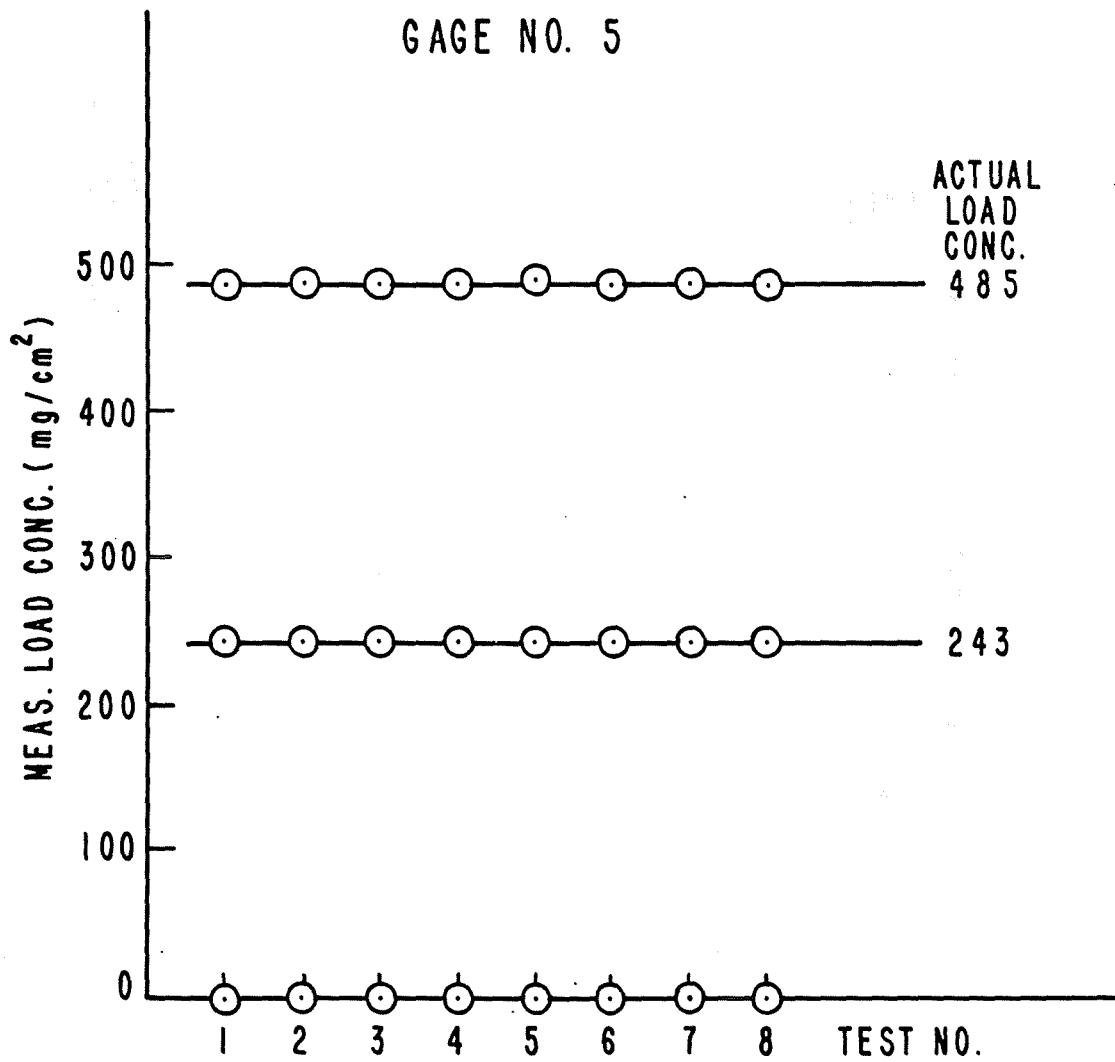


Figure 6e. Repeatability Test for Sensor No. 5

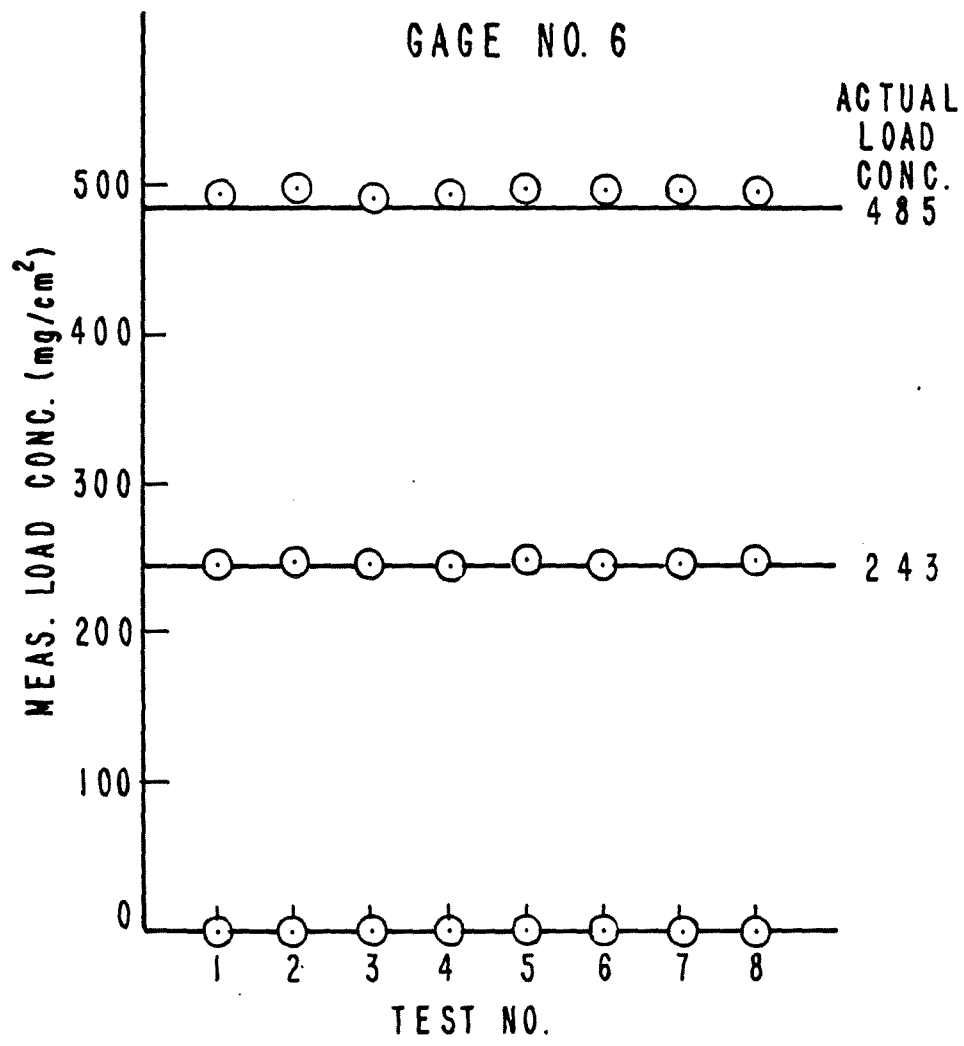


Figure 6f. Repeatability Test for Sensor No. 6

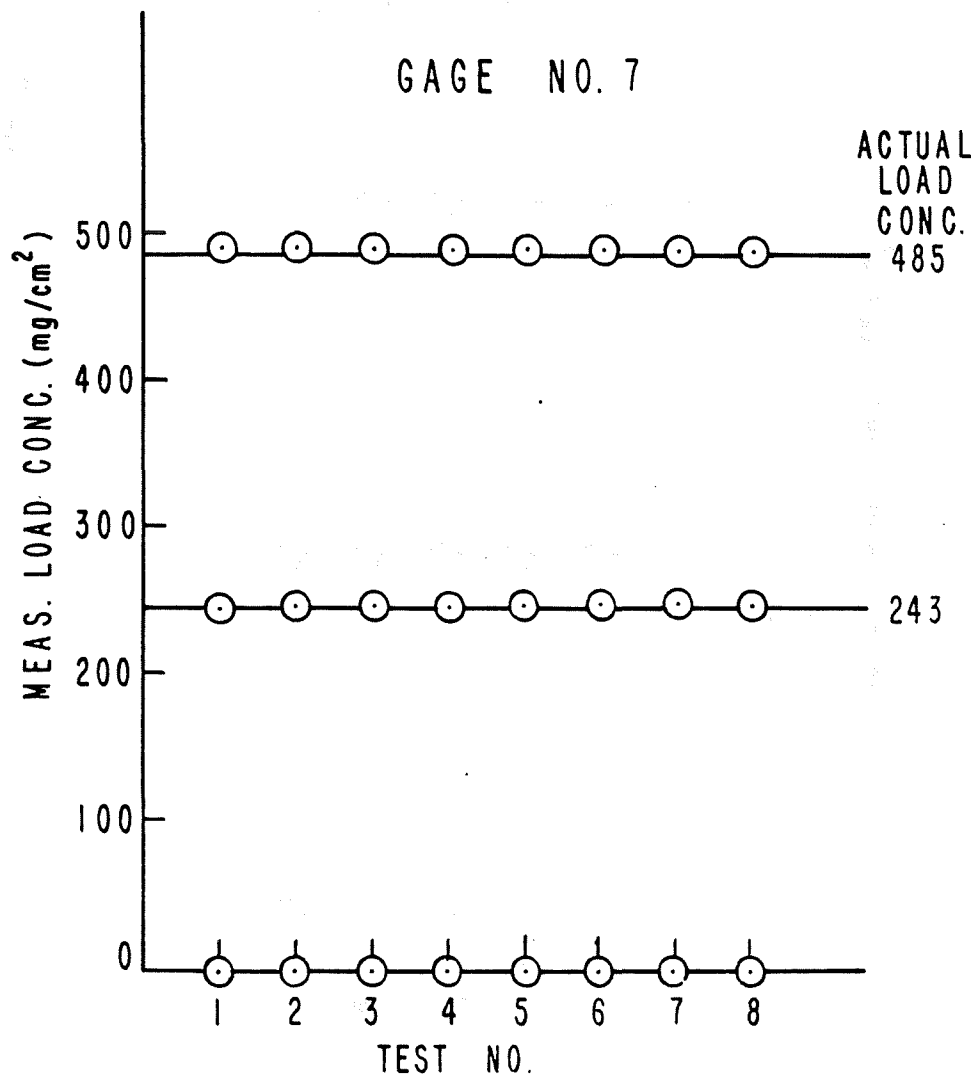


Figure 6g. Repeatability Test for Sensor No. 7

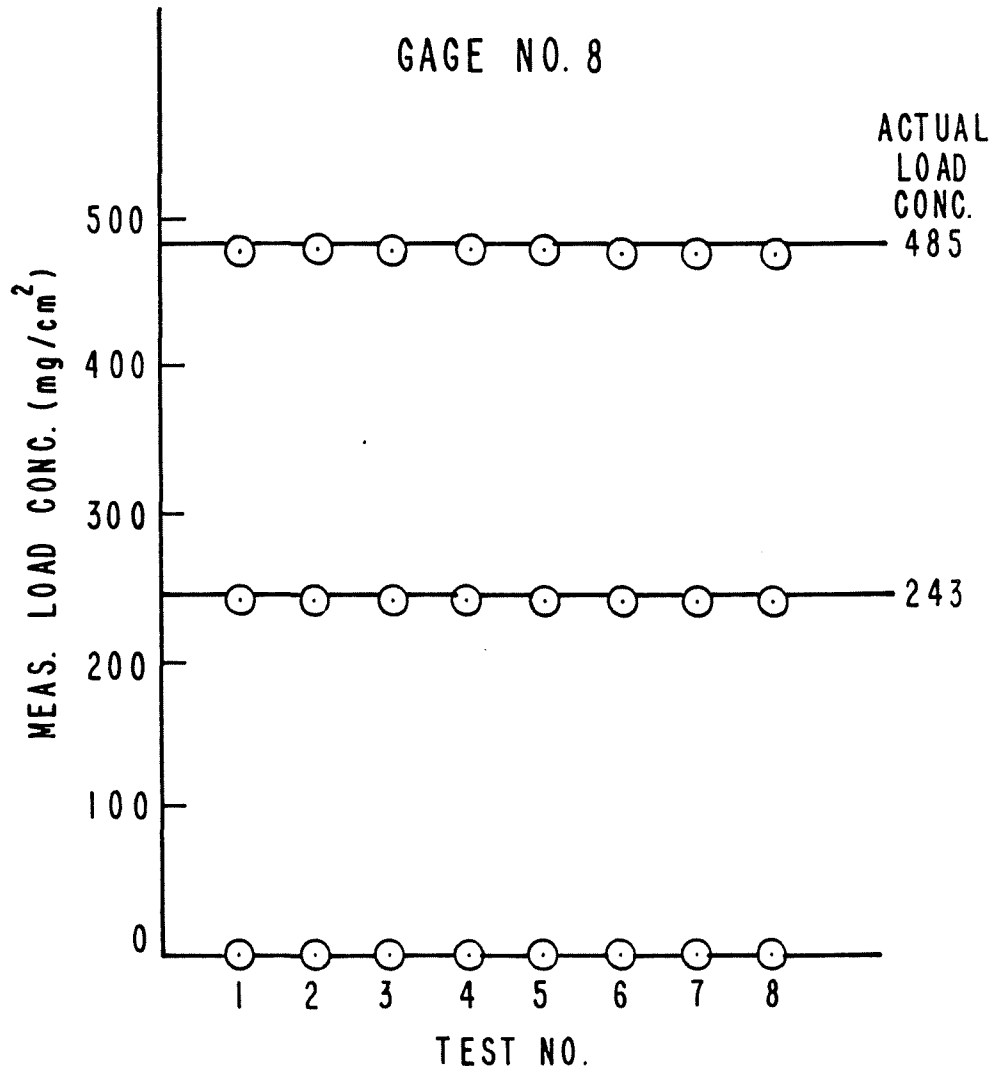


Figure 6h. Repeatability Test for Sensor No. 8

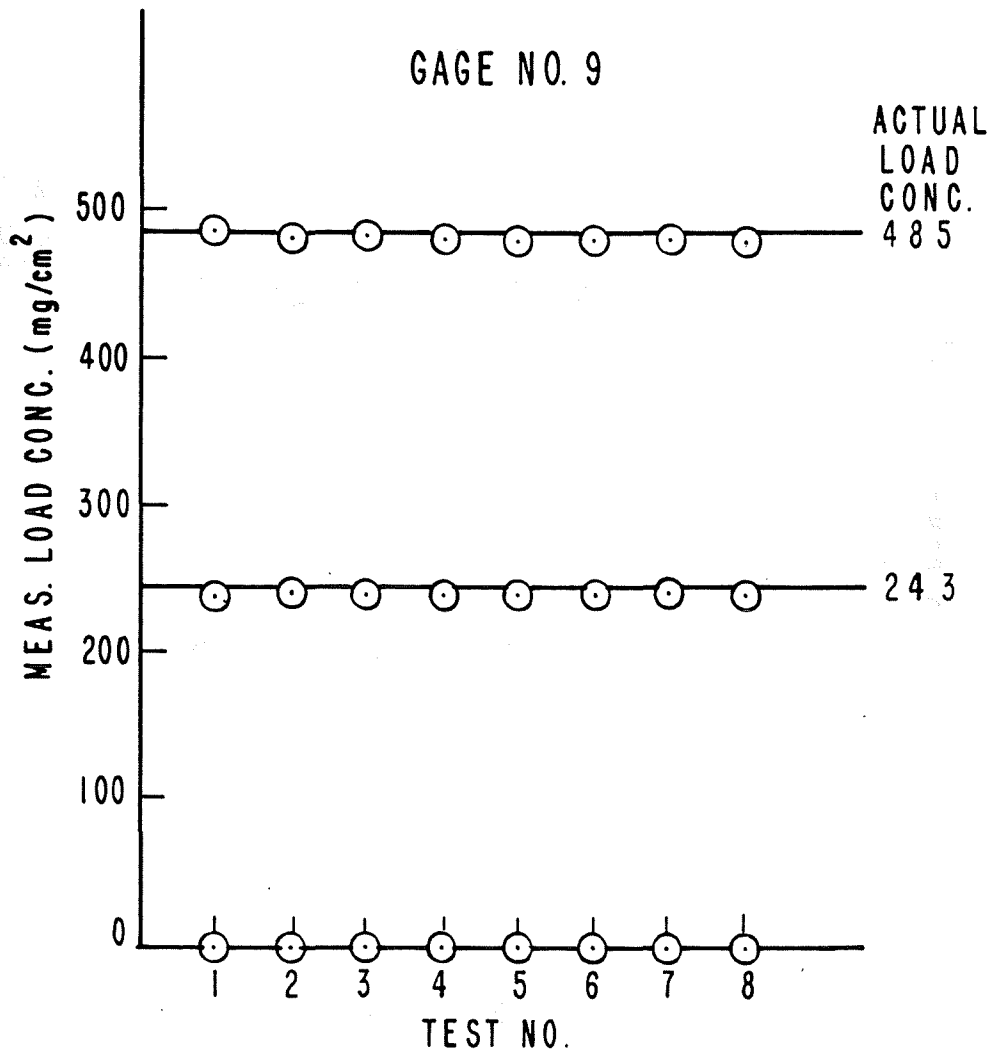


Figure 6i. Repeatability Test for Sensor No. 9

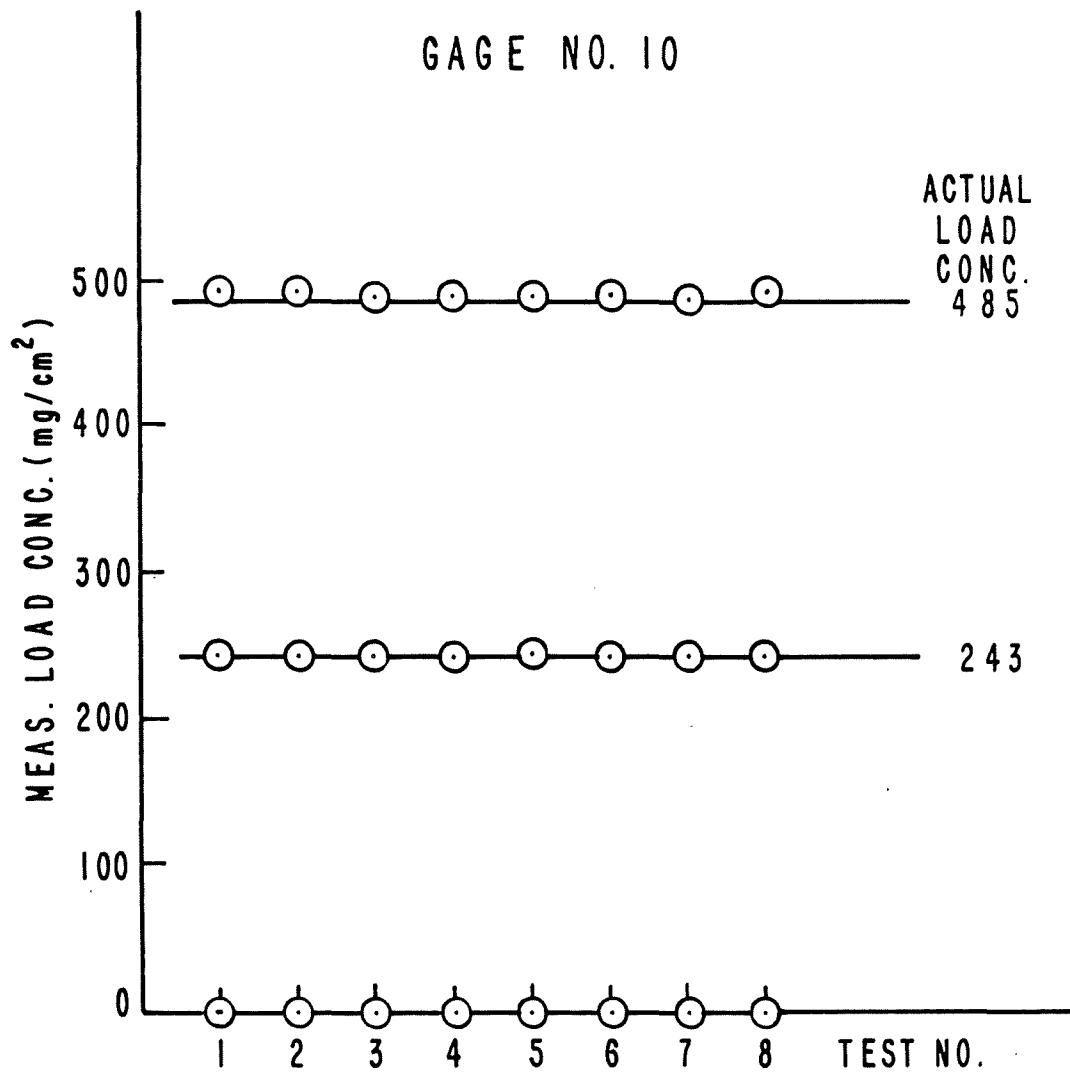


Figure 6j. Repeatability Test for Sensor No. 10

Gage Comparison Tests

Using the same GAGE FACTOR obtained and used in the calibration check tests, each gage was loaded and its reading read using the same load weights. The purpose of these tests was to compare each gage against each other gage in a so-called "nose-to-nose" comparison. Using identical load concentrations, each sensor should read the same load concentration value if it has been properly calibrated. The data for this "nose-to-nose" comparison test are displayed in Figure 7.

The results of this comparison test are favorable for these gages. Each gage agrees well with the calibration data obtained for that gage and each gage is in close agreement with the actual load concentration value used for the test. The difference in DUST LOAD reading between the gages is small, being on the order of $\pm 3 \text{ mg/cm}^2$. In the use of these dust sensors in a mine, it is the change in DUST LOAD readings which is of principal value, not the absolute accuracy of the gage per se. However, as the data in these figures show, the change in load concentration, for properly calibrated gages, is accurate, as is the absolute value of load concentration.

Temporal Stability Tests

Temporal stability tests were done in order to look at the long-term stability of DUST LOAD readings taken under load. In performing these tests, each gage was loaded with a known, concentrated weight equivalent to approximately $75\text{-}80 \text{ mg/cm}^2$ (the loads being slightly different for each gage). These tests were performed in the following way:

- 1) The same GAGE FACTOR, as determined and used in the calibration check test, was used for each gage. At the start of the test on Day 1, the gage was initialized for period (and temperature) at 0 load.

- 2) A known and constant load concentration was then placed on each gage and the corresponding DUST LOAD reading was recorded.

- 3) The gages were left in a room subjected to the normal variations in temperature during the summer.

- 4) The gages were checked periodically. DUST LOAD readings were recorded without disturbing the gage or the load. For each gage, the time of day, DUST LOAD reading, and CURRENT PERIOD and CURRENT TEMPERATURE were recorded. The tests were continued over a time span of several days.

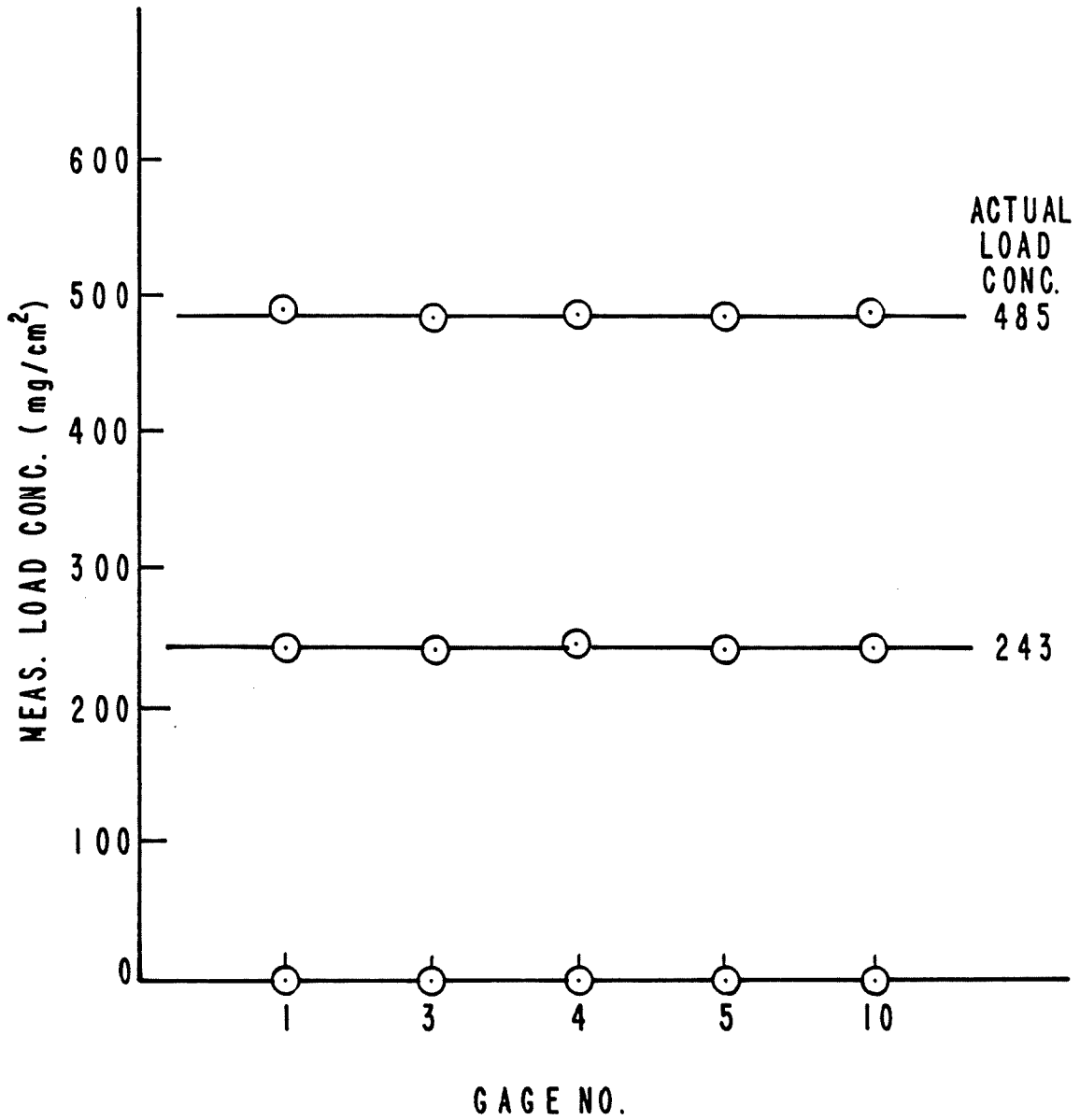


Figure 7. Sensor Comparison Tests (Sensors 1 through 10)

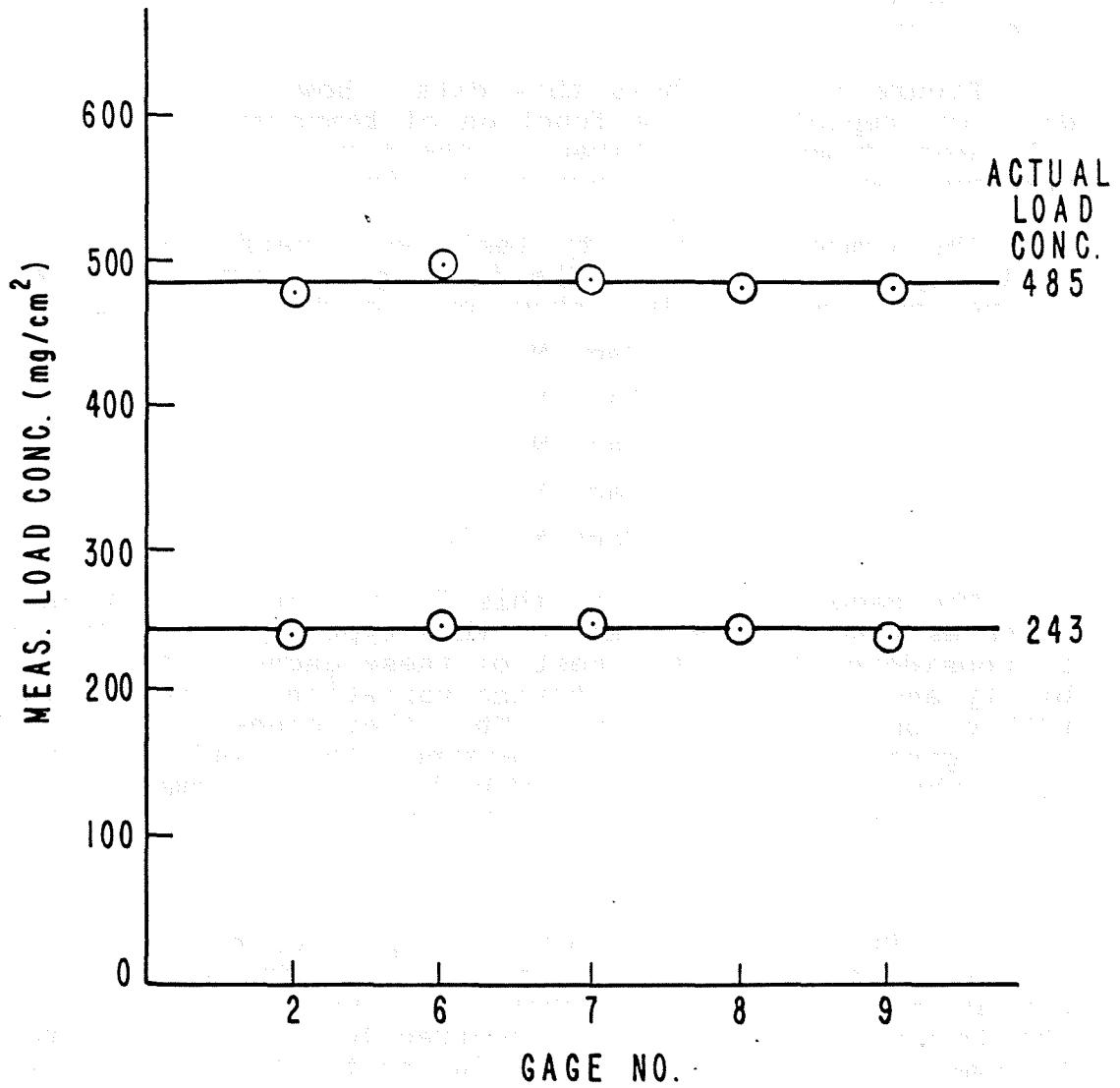


Figure 7 (con't). Sensor Comparison Tests
(Sensors 1 through 10)

The data for these temporal tests are plotted as a function of time in Figure 8. On this figure, for each gage, a solid line is drawn that corresponds to the actual load concentration placed upon the gage. This figure also shows the variations in recorded temperature of the gages during the several days of testing.

Figure 9 also shows this data. However, this time the data are replotted as a function of temperature of each gage (the gage temperature taken at the time of taking DUST LOAD readings) and not as a function of time.

The temporal stability tests were performed separately on two groups of gages. The first group comprised the following gages and the data shown on Figures 8 and 9:

- Gage No. 1
- Gage No. 3
- Gage No. 4
- Gage No. 5
- Gage No. 10

The gages as tested in this first group did not have results as stable as desired for this type of test. Gage No. 3 is considered to be the best of these gages in terms of stability and repeatability, having variations in monitored DUST LOAD of only several mg/cm². The other gages, however, showed a greater variation in readings than would be expected from the calibration, repeatability, and comparison test data. It was suspected that this was the result of at least several factors:

- 1) During the three-day test period, none of the gages really reached temperature equilibrium. The gages were left out in an open research laboratory room and were subject to the temperature variations incurred by relatively large environmental temperature swings during the hot days of summer; the temperature started out on the low side and increased continuously during the day. The highest temperature was reported around 7 p.m. on day 2 with a temperature of approximately 30°C (86°F). If the gages did reach equilibrium in temperature, they would then provide the same DUST LOAD reading at a repeated temperature. Careful experiments, done during the development of these gages, showed that each sensor had a defined, consistent, and repeatable single temperature characteristic if the gages were always read when they were in equilibrium. However, if the gages were undergoing a thermal transient, different parts of the gages were at different temperatures and the reading of the gage departs

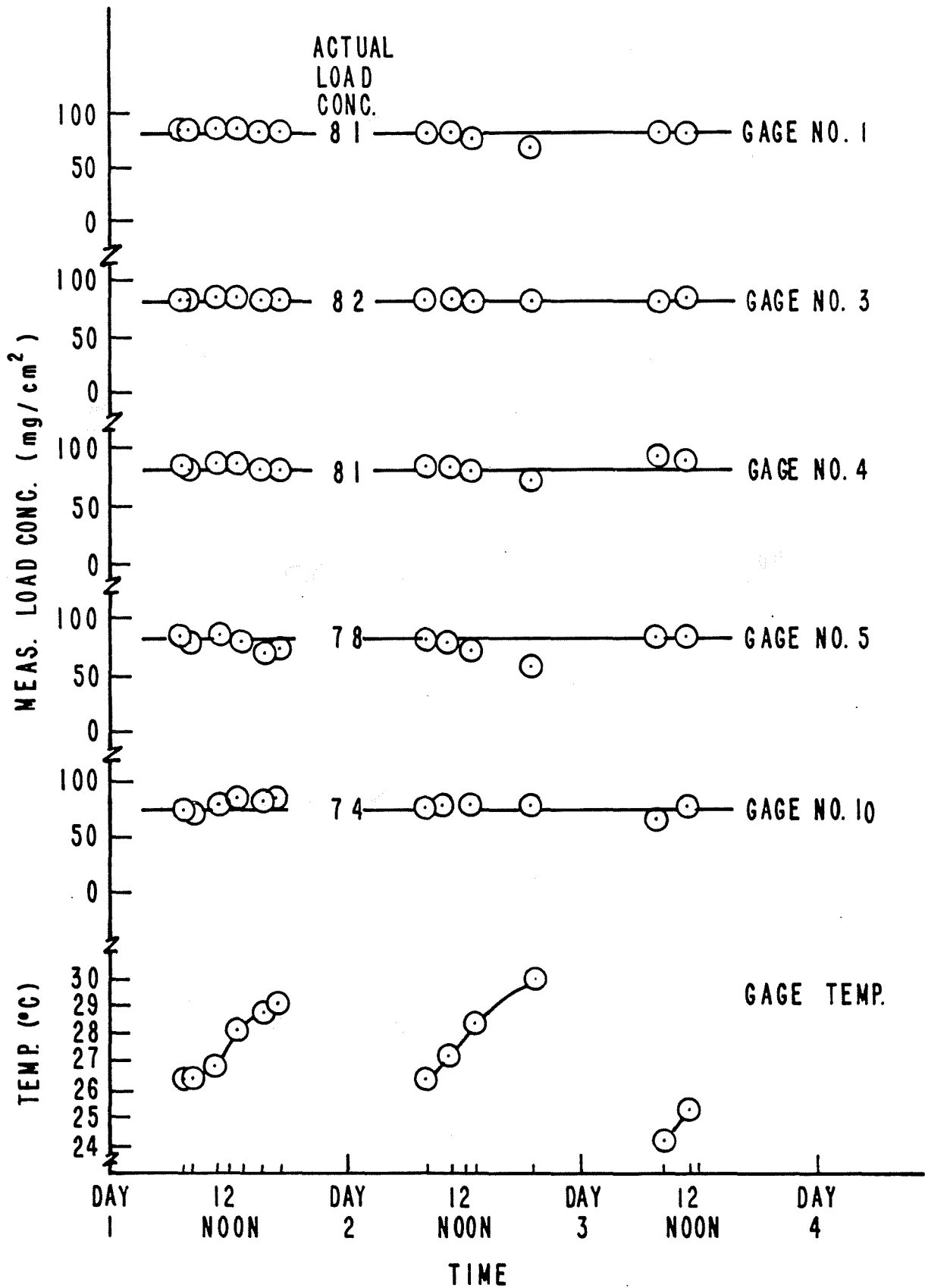


Figure 8. Temporal Stability Test (Sensors 1, 3, 4, 5, and 10)

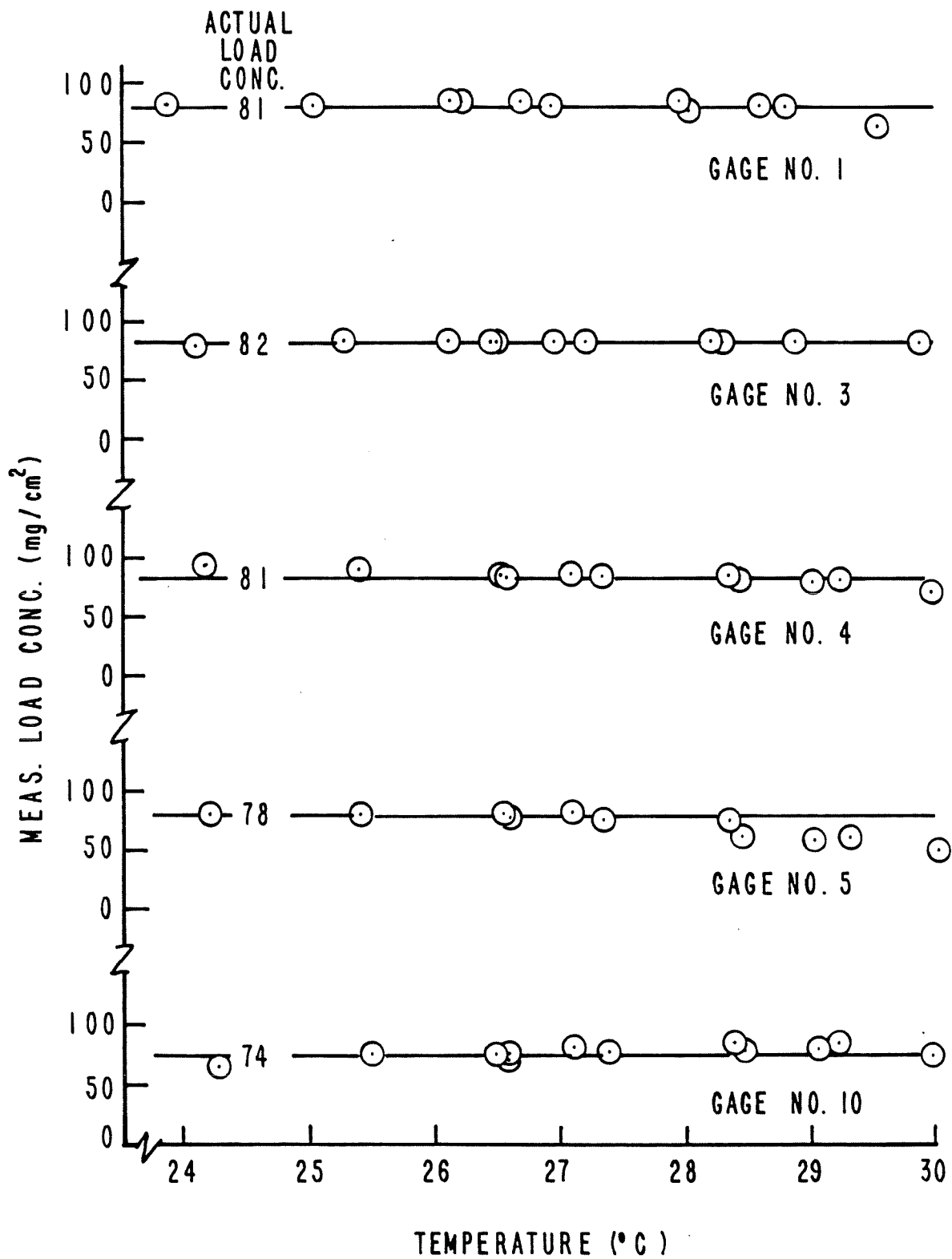


Figure 9. Temporal Stability Test with Data Plotted as a Function of Temperature (Sensors 1, 3, 4, 5, and 10)

from the thermal characteristic determined under equilibrium conditions; the gage did, however, return to the equilibrium thermal characteristic as soon as thermal equilibrium prevailed.

2) Each of the gages has, in fact, a slightly different temperature characteristic. In the initial development of these sensors, the effect of temperature on the behavior of the sensor reading was most disturbing and posed a fundamental problem. The design of the gage proceeded with the objective of having the sensor be unaffected by temperature changes. In the final testing of the sensors, this was found not to be true. It was also found that the temperature coefficient of each sensor was not the same. The temperature coefficient of the gages was determined by measuring the CURRENT PERIOD reading for each sensor under constant load conditions (0 Load) while the temperature was changed over a range between 19°C and 25°C. The data for the sensors, as each gage was mechanically adjusted to obtain a nearly uniform temperature coefficient, is shown in Figure 10. The measured temperature coefficient for each gage is the slope of the curves in Figure 10 (CURRENT PERIOD reading units/°C). The final data shown in Figure 10 was obtained by careful adjustment of each sensor to yield approximately the same temperature coefficient (i.e., the same slope of the reading versus temperature curve) so that a constant temperature coefficient could be used within the readout to correct readings for temperature variations. The data shows that the temperature coefficients for these sensors varied as follows:

Temperature Coefficient (CURRENT PERIOD Units Per °C)

Range (all sensors)	58-68 units/°C
Average	62 units/°C
Standard Deviation	3.4 units/°C (± 6%)

The readout unit incorporates only a single temperature coefficient algorithm to correct the readings caused by temperature changes (the design of the readout faceplate did not allow for a temperature correction factor to be input for each sensor and thus the temperature correction algorithm used within the readout needs a common correction to all of the gages). Figure 11 (which is a replot of the temporal stability data as a function of temperature before the correction for temperature changes was made in the readout) displays this effect. For example, gage no. 10 and gage no. 4 show the DUST LOAD reading slowly rising with temperature or slightly falling with temperature, respectively.

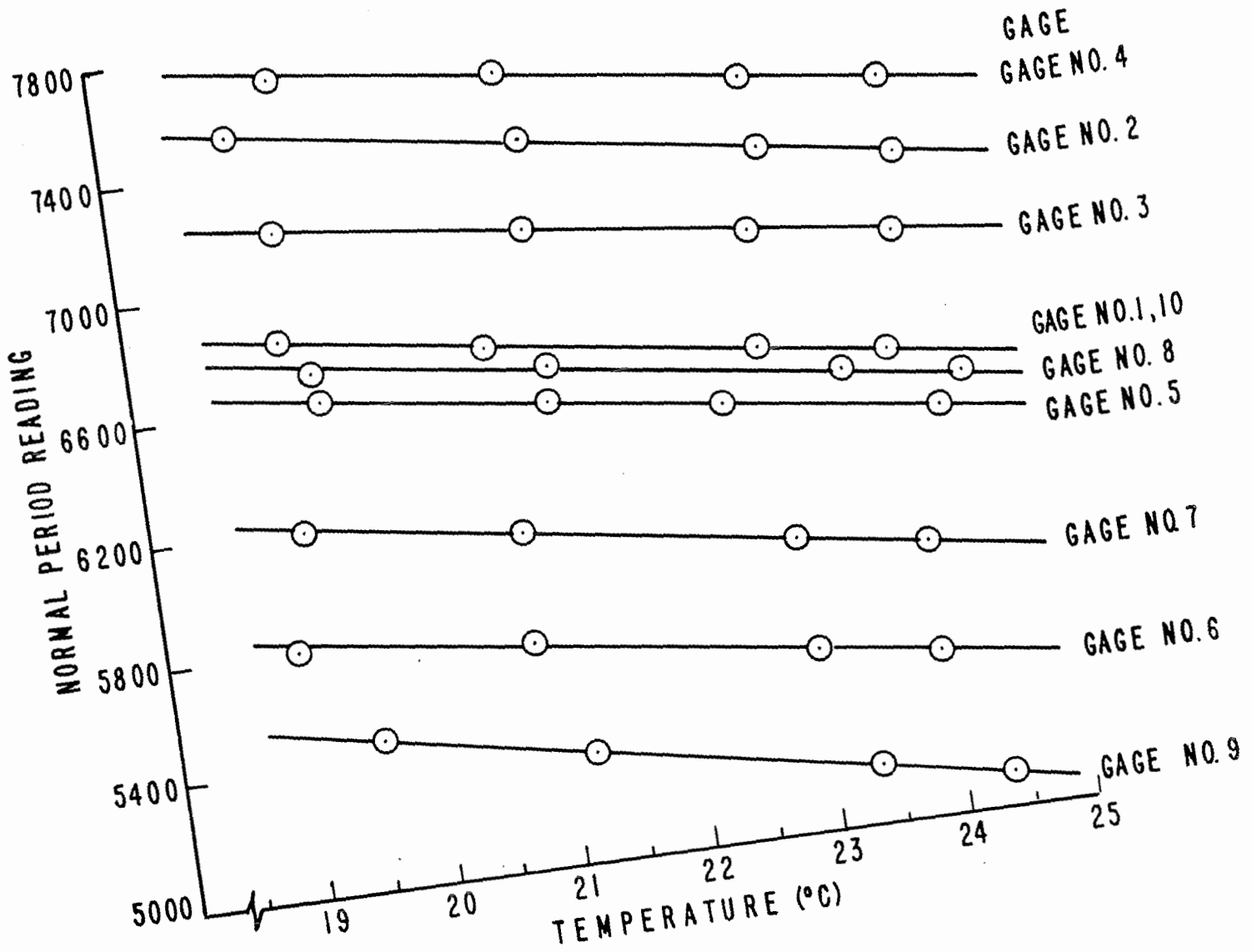


Figure 10. Measured Temperature Sensitivity For All Sensors

By fine mechanical tuning, the gages were brought as close to a constant value of temperature characteristic as seemed reasonable. If the gages were then kept in an insulated enclosure during these tests, to significantly reduce the amount of environmental temperature change and hence temperature transient effects, there was much less of a variation of gage readings over an extended time period. The data shown in figure 11 are for the following gages which were tested after all gages were fine tuned as described above.

Gage No. 2

Gage No. 6

Gage No. 7

Gage No. 8

Gage No. 9

These data indicate a much more stable and constant set of readings for each of the above gages over a period of approximately two weeks. The temperature variations measured within the insulated enclosure are also shown at the bottom of this figure.

Tabulated data for all of these calibration, repeatability, comparison, and temporal stability tests are given in Appendix B.

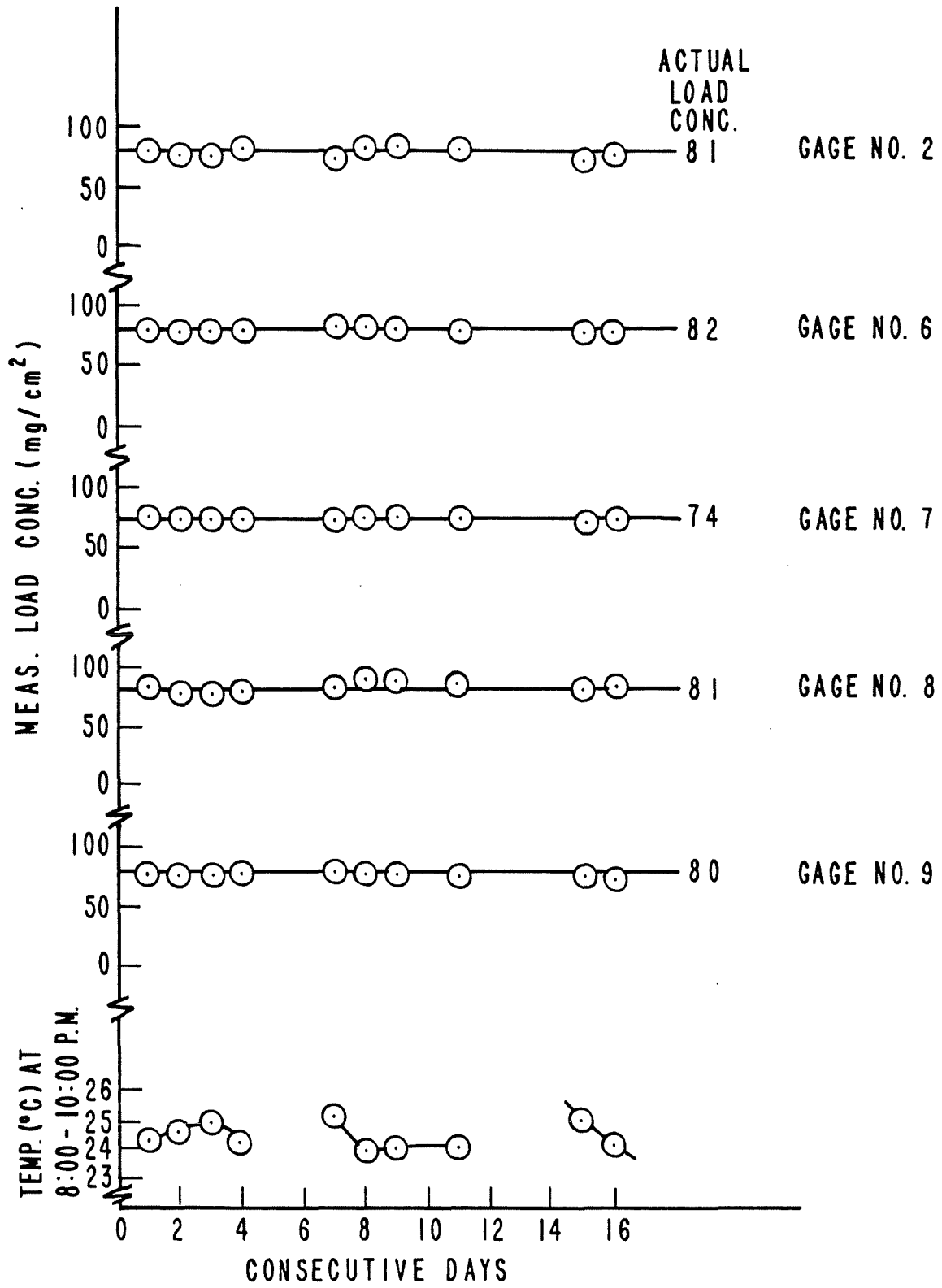


Figure 11. Temporal Stability Tests

READOUT SYSTEM

The readout system consists of the following components:

- 1) magnet/coil assembly (part of the sensor)
- 2) temperature measurement circuitry,
- 3) cable,
- 4) switch module, and
- 5) readout unit.

Magnet/Coil Assembly

The purpose of the magnet coil assembly is to both pluck and read the vibrating wire element. The assembly is sealed in an epoxy (Hysol casting compound #C9-4215*) cast with a slot designed to match the crimped section of the tube around the vibrating wire. The assembly consists of two bobbins with a special Simco bar magnet piece in each coil and a cross-connecting pole piece to each of the two bobbins. The winding on the bobbin is made with #40 gauge enameled wire to a final resistance of approximately 70 ohms. The two lead wires and the coil assembly are soldered to two leads of 4-conductor signal transmission cable which connects the unit to a switch module.

Thermistor

Each dust sensor has a YSI Thermilinear Precision Thermistor Model 44201** for sensing the diaphragm temperature. The output of the thermistor is part of a bridge circuit in the switch module, whose output is fed into the readout box for automatic temperature correction of the dust reading. Each of these thermistors has a range from 0° to 100°C with an accuracy of $\pm 0.15^\circ\text{C}$.

Cable

Each sensor has been manufactured with a 10 foot length of Belden #8451 4-conductor cable. Because the signal is frequency modulated, cable lengths up to 5000 feet can be used in these sensors without reading errors being caused by low voltage signals.

*Manufactured by Emerson & Cuming, Inc.,
Walpole, Massachusetts

**Manufactured by Yellow Springs Instrument Co., Inc.,
Yellow Springs, Ohio

Switch Module

The switch module is a standard (modified) IRAD Gage 20-channel unit, housed in a splash-proof box. The leads for the gage coil (black and red) are connected to Channels 0-9. The leads for the thermistor (green and white) are connected to Channels 10 - 19. The pattern of connection is shown in the Instruction Manual (Appendix A).

Readout Unit

The readout unit is connected to the switch module via a 6-conductor cable. The faceplate has two blocks of membrane type, color-coded keys for operation of the readout unit. Detailed instructions for the operation of the readout are given in Appendix A. Up to ten dust sensors hooked up to the switch module can be read by this readout unit by keying in the proper channel.

The red keys are used to enter the gage parameters for each channel. The black keys are used to read the gage once the gage parameters have been stored.

The readout measures the period of the frequency of the vibrating wire in the sensor and the temperature indicated by a thermistor in the sensor and uses these values and a programmable calibration factor to calibrate and display dust loads in mg/cm^2 or as a percentage of presettable limits. Initial readings, calibration factors, and high and low limits are stored for each channel in a non-volatile memory.

The readout is powered by a sealed 10V nickel cadmium battery pack which has a continuous "ON" life of three hours. Low battery indication first occurs when the battery life is down to half an hour. After the batteries have reached a lower power level, the readout will automatically shut off and cannot be turned back on until the batteries are recharged. This is done to prevent a total discharge of the battery pack.

The front panel provides terminals for battery charging and switch module connection. The unit's batteries are recharged by connecting the charger to a 110 V, 60 Hz source for sixteen hours.

The "user friendly" LCD display shows several messages. With the unit switched on, the readout box automatically does an internal check of its system and displays 'READY'. When the desired channel key (black key number) is pressed, the display shows dust loading in mg/cm^2 . Pressing of the dust load key will display dust load in % preset of a predetermined range. The unit is shut off by pressing the 'OFF' key.

A display of 'NO GAGE' means either that the sensor is not hooked up, or the sensor leads are disconnected, or the leads are broken. A message of "LOCK LOST" means insufficient transducer signal to make a reading. "LOW BATTERY" means low battery voltage.

"PARM ERROR" means incorrect initialization procedures have been entered into the unit. The readout needs to be initialized to read the dust loading directly or to express the dust loading in terms of a percentage of the difference between minimum and maximum dust loading settings.

If R = current period reading of the sensor,
 R_0 = initial period reading,
 α = temperature response coefficient of the gage,
 t_0 = temperature at the time of calibration in °C,
 t = current temperature in °C, and
 K = load calibration factor of the sensor

then, the total dust loading, L , in mg/cm² is given by

$$L = K [R + (t - t_0) - R_0] \text{ mg/cm}^2$$

and if

P_{\min} = preset minimum dust loading in mg/cm²
 P_{\max} = preset maximum dust loading in mg/cm²

then

$$\% \text{ Preset} = \frac{\text{current dust loading} - P_{\min}}{P_{\max} - P_{\min}} \times 100$$

The electronic circuitry of the readout comprises two circuit boards: the computer board, and a peripheral circuit board. The computer board contains an Intel 8085 microprocessor, 6K of ROM*, 2K of battery backed RAM**, 24 I/O ports and decoding circuits. The peripheral board has on it a 16-character 5 x 7 dot matrix liquid crystal display (LCD) and its drive circuitry, three nineteen bit programmable timers on a single chip, the membrane keyboard matrix, drivers for powering and controlling the switch module and plucking the gage, and an amplifier circuit for conditioning the return signal from the gage via the switch module. Also on the peripheral board is the 'power-on' circuit with automatic low battery shutoff, the low battery detection circuit, a buzzer that sounds each time a key is pressed, and some additional gates used for decoding and the enabling of different functions.

*ROM - Read only memory.

**RAM - Random access memory.

Software Readout

The readout system software was written in 8085 assembly language and resides in ROM on the microcomputer board. It is modular in that it is broken up into short, self-contained subroutines that call other subroutines. All variables are stored in a non-volatile memory. Some of the routines are discussed below.

- START - Accessed by the reset pulse when power is first turned on, this routine initializes printers and other parameters and displays 'READY' on the LCD.
- RSERV - This is the main program loop. The processor scans the keyboard to detect if a key is pressed. If a key is pressed, its value is decoded and a parsing routine calls one of seventeen ACTION routines. When the ACTION routine is complete, the program returns to the beginning of RSERV.
- ACT 0 - Do nothing.
- ACT 1 - Select the proper gage - read gage - display PERIOD.
- ACT 2 - Select gage - read gage - read thermistor - display mg/cm².
- ACT 3 - Select gage - read gage - read thermistor - display % PRESET.
- ACT 4 - Select the channel indicated by the pressed digit key and display channel number. Act 2 is then called.
- ACT 5 - Display the stored calibration factor for the selected channel.
- ACT 6 - Display the stored initial reading for the selected channel.
- ACT 7 - Display the Preset Maximum value for the selected channel.
- ACT 8 - Display the Preset Minimum value for the selected channel.
- ACT 9 - Turn unit off.

- ACT A - Enter the three digits selected by the keypad into the input register (INR). This is used for entering new values for CAL, PMAX, PMIN.
- ACT B - Assign INR to the variable representing the calibration factor for the selected channel.
INR CAL(I)
- ACT C - Enter the four digits selected by the keypad into INR. This is used for entering new values for INIT (the initial value).
- ACT D - INR INITR (I)
- ACT E - INR PMAXR (I)
- ACT F - INR PMINR (I)
- ACT 10 - Jump to START.
- ACT 11 - Same as ACT 1 except that no unit label is displayed. This is used for storing the current gage period as an initial value.
- SEARCH - This is the routine that reads the vibrating wire gage. First it passes the channel number to SMSELECT which turns on the selected channel in the switch module. It then passes a frequency from a table (PLRTBL) to the routine PLUCK which excites the gage at that frequency for 64 cycles. LISTEN is then called to monitor the return signal for ringing. If there is no ringing, the next frequency in PLKTBL is passed to PLUCK and the process is repeated until ringing is detected and its frequency is measurable. SRCHEND then passes the measured frequency to PLUCK so that the gage is excited at its resonant frequency and LISTEN then measures and stores the measured period of frequency in GAGE.

- READTEMP - The routine that reads the gage thermistor first passes the selected channel number to SMSELECT which turns on the selected channel in the modified switch module. The SM output is a square wave whose frequency is a linear function of temperature in that 1 Hz represents 0.01°C. (Thus 5000 Hz represents 50.00°C). READTEMP then calls LISTEN which returns the period of the gage frequency in GAGE.
- TEMPMATH - This routine calculates the thermistor temperature from the period stored in GAGE.
- ACT2MATH - Calculate the dust loading in mg/cm² using the current gage period and temperature and the stored initial period and temperature, and calibration factor.

$$L = K [R + (t - t_0) - R_0]$$

- ACT3MATH - Calculate the dust loading in terms of % Preset.

$$\% \text{ PRESET} = \frac{\text{LOAD} + \text{PMIN}}{\text{PMAX} - \text{PMIN}} \times 100$$

In addition to the above routines there are other routines that drive the display, check the battery level, perform arithmetic functions, and other housekeeping routines.

Electronic Hardware

Switch Module - Standard MA-2SM

The switch module connects one of ten gages to the Coal Dust Sensor readout. The gage code is passed in a synchronous serial mode to the SM over the DATA line. The D.CLOCK signal loads each bit of data into the decoding circuit on each rising edge. The decoding circuit enables one of the ten channels. There are two multiplexing circuits. The PLUCK multiplexer is turned on during the pluck. This high current circuit passes the excitation signal to the gage. The LISTEN multiplexer passes the low amplitude signal set up by the ringing wire to an amplifier whose differential output returns to the Coal Dust Sensor readout via the GAGE leads.

Switch Module - Modified MA-2SM

This MA-2SM is modified for use with thermistors. Since the thermistors do not need to be plucked, the PLUCK multiplexer is never enabled. The amplifier circuit of the standard MA-2SM is replaced by a voltage to frequency converter circuit whose input is a bridge, one leg of which is the thermistor selected by the LISTEN multiplexer. The frequency output represents temperature with the relation: 1 Hz = 0.01°C.

Hardware - Readout Unit

Single Board Computer (SBC)

The Central Processor Unit (CPU) is an 8085 microprocessor with a 4 MHz crystal. The 8255 I/O device is configured as an 8-bit input port and an 8-bit output port for interfacing with the keypad routine on the peripheral board. An additional 4 output lines are individually used to derive the D.CLOCK and DATA signals to the switch module, enable the PLUCK, and turn off the power supply. One of the remaining 4 input lines is used to monitor the low battery detection circuit.

The system software resides in 6K of 2716 ROM and all variables are stored in a TC5516 2K CMOS RAM with battery backup.

The data and address busses as well as the I/O lines and interrupt lines are connected to the peripheral board via four ribbon cables.

Peripheral Circuit

- KEYPAD - This is a machine type membrane keypad mounted on the readout front panel. The vertical elements are driven by the 8-bit output port and the horizontal elements are read by the 8-bit input port.

- LCD - This is a 16 channel 5 x 7 dot matrix display. The drive circuit scans a CMOS RAM which contains the dot on-off data. The RAM data is entered from the SBC.

- POWER SUPPLY - Derived from a 10V battery pack, this circuit generates plus and minus 5V. There are two low battery detectors. The one with the higher threshold is connected to one of the input ports and causes 'LOW BATTERY' to be displayed when it goes on. The other, with the lower threshold, turns off the circuit when it goes high.
- TIMER - The 8353 timer has three sixteen bit programmable timers. They are used to generate the pluck frequencies and to measure the period of the gage signal.
- SM INTERFACE - This circuit is used to amplify the D. CLOCK, DATA, and PLUCK signals going to the switch module. The amplifier shapes the return signal from the SM into a square wave pulse train, the missing edges of which interrupt the processor and force it to read the contents of the 8353 timer on the fly.

Readout Unit Operation

Appendix A contains the coal dust sensor operating and instruction manual. The instruction manual describes how to hook up the gages to the switch module and how to hook the switch module to the readout unit. The manual also gives the description of the keyboard operation. We designed the readout to operate with a minimum of user prior knowledge. Below is described, in a "step-by-step" manner, how to calibrate a sensor and how to operate the readout to obtain DUST LOAD readings.

Calibrating The Sensor

1) After a sensor is coupled to the switch module and the switch module is coupled to the readout unit (as described in the manual), make sure the sensor is at temperature equilibrium by following these steps:

- a) Turn the readout unit ON.
- b) Press the CHANNEL key.
- c) Press the CURRENT PERIOD key.
- d) Monitor the temperature reading, making sure the sensor temperature stabilizes (< than 0.5°C/hour should be satisfactory).

Notice that the CURRENT PERIOD reading will alternate the display between the CURRENT PERIOD reading and the CURRENT TEMPERATURE reading.

2) With zero load on the sensor, record the CURRENT PERIOD reading.

3) Calibration can be obtained USING a simple two-point calibration procedure. Load the sensor with a known weight, centered on the sensor, that produces an equivalent load concentration approximately equal to the maximum range of the gage ($\approx 500 \text{ mg/cm}^2$).

4) Divide the Δ load (i.e., the maximum concentration in mg/cm^2) by the Δ Period readings (the "maximum" load Period - "zero" load Period). The result is equal to the Gage Factor:

$$\text{Gage Factor} = \Delta \text{ Load} / \Delta \text{ Period}$$

where:

$$\Delta \text{ Load} = \text{"maximum" Load} - \text{"zero" Load}$$

$$\Delta \text{ Period} = \text{"maximum" Load Period} - \text{"zero" Load Period}$$

5) If other than a two-point load calibration is required, then the calibration should be carried out with multiple load concentration values and a least squares straightline fit applied to the data. The Gage Factor is then equal to the slope of the curve of load concentration (mg/cm^2) versus Gage Period readings.

Using The Gage

1) Knowing the Gage Factor, enter the Gage Factor into the readout unit for the Channel to which the gage is coupled. This is done as follows:

- a) Switch the readout unit ON.
- b) Press the CHANNEL key.
- c) Press the GAGE FACTOR key.
- d) Press the desired digit keys equal to the Gage Factor value.
- e) Press GAGE FACTOR key (again).
- f) Press ENTER key.

2) Initialize the sensor (establish zero Dust Load corresponding to the current or present gage loading) by pressing the INITIAL PERIOD key, followed by pressing the CURRENT

PERIOD key. (This enters the Current Period and Current Temperature.) The initial value is then stored in the readout unit by pressing the INITIAL PERIOD key (again) and then pressing the ENTER key.

3) The DUST LOAD reading is obtained by pressing the DUST LOAD key. Remember that the DUST LOAD key displays either mg/cm^2 or % Preset. The LCD display on the readout unit alternates between these two outputs each time the key is pressed.

Entering Preset Min/Preset Max Values

A range of DUST LOAD for the sensor can be entered into the readout unit to automatically calculate the percent of dust load range that is presently sensed by the current load on the sensor. In order to do this, follow these steps:

- 1) Select the Preset Min value equal to the value of the lower limit of the preset range you wish to use. To store this preset min value, first press the PRESET MIN key.
- 2) Press the digit keys that will enter the new value of Preset Min.
- 3) Store the new value in the readout unit by pressing the PRESET MIN key, followed by pressing the ENTER key.
- 4) The LCD display will show the message "PMIN STORED".
- 5) A check can be made that the preset min value has indeed been stored in the readout by pressing the PRESET MIN key and observing the LCD display.
- 6) To store the new value of the upper limit of the preset range, press the PRESET MAX key.
- 7) Press the digit keys corresponding to the new preset max value.
- 8) Press the PRESET MAX key (again) and then press the ENTER key. The LCD display will show the message PMAX STORED.
- 9) To display the preset max value you have just entered, press the PRESET MAX key and the LCD display will show the value entered.

Having selected the Preset Min and Preset Max values and having entered them into the readout unit, the readout will display the % Preset value by pressing the DUST LOAD key (in the % Preset mode).

Check of Stored Values In The Readout Unit

At any time, the variables:

Preset Min
Preset Max
Initial Period
Gage Factor

that are currently stored in the readout unit on any channel can be obtained as follows:

- 1) Turn the readout unit ON.
- 2) Select the appropriate channel by pressing the appropriate CHANNEL key.
- 3) Then press the appropriate key corresponding to one of the four values (see above) which are to be read.

Red and Black Keys

The keys on the readout unit are grouped into a "red" block of keys and a "black" block of keys.

The "black" block of keys are used to read DUST LOAD readings once the Initialization data and Gage Factor data have been entered into the readout unit. Only the "black" keys need to be used for this purpose.

The "red" block of keys are used to initialize the readout unit and to enter Gage Factors for each of the channels. How to initialize channels and how to enter Gage Factors for sensors have been described above. The specific procedures to enter parameters for a channel—i.e., the pressing of the appropriate parameter keys twice followed by the pressing of the ENTER key (following the procedures described above) have been specifically designed to eliminate errors and/or accidental erasure of stored parameters.

Readout Unit Stability Tests

Late in this project development, after five sensors had been delivered to the Bureau of Mines for testing, data taken on these sensors by the Bureau indicated that problems with stability of readings sometimes occurred. The details of how

these tests were conducted are under control of the Bureau, but there was concern that some of the non-stable readings taken on the sensors could be related to the electronics of the readout. In order to provide data to determine whether this was true, some extensive tests were undertaken to determine the temporal stability of the readout itself.

These tests were performed as follows:

The coal dust sensor readout unit was connected to a 1000 psi IRAD Gage PWS vibrating wire piezometer placed in 4 inches of water (hydraulic head) for a period of one month. Simultaneously, readings were taken by an IRAD Gage MB-6LU readout unit. Data was taken at least once a day, and sometimes three to four times a day, for over a period of one month. Because the 1000 psi vibrating wire piezometer is known to be extremely stable with a very small temperature correction factor, the readings from this gage should be stable over the time period studied. This was found to be true as determined from readings with the MB-6 readout. Readings with the coal dust readout unit also showed long-term stability of readings, with no large excursions of measured data as indicated in the Bureau of Mines' tests.

From these studies it was concluded that the coal dust sensor readout unit is indeed stable and was not likely to be the cause of the sometimes unstable sensor measurements recorded by the Bureau of Mines in their tests of the coal dust sensors.

DISCUSSION AND RECOMMENDATIONS FOR FUTURE DESIGN

Ten coal dust sensors, a remote switch station, and two coal dust sensor readout units were designed, tested, and delivered to the Bureau of Mines. This coal dust monitoring system meets the original project objectives of monitoring sensitivity and range, being able to resolve dust loading changes as small as 0.5 mg/cm^2 over a full range of dust loading from 0 to better than 500 mg/cm^2 . The sensors have proven to be rugged, splash-proof, and have passed the vibration testing standards called for in the contract specifications.

However, it is important to appreciate that these sensors are extremely sensitive devices. While they are reasonably rugged, they should be used and handled with care. Monitoring should be performed only when the sensors are in a stationary condition and environmental temperature conditions have stabilized. Automatic compensation for temperature changes has been provided in the readout unit data reduction algorithms, but the sensors will only perform correctly when they are at a uniform temperature. Sudden environmental temperature changes (on the order of several degrees Fahrenheit) will produce non-uniform temperature distribution of the sensor component parts, leading to erroneous dust loading readings. Our experience has been that temperature changes, as measured by the internal thermistor device within the sensor, should not be more than 0.5°C per hour for accurate reliable readings.

The sensor incorporates a dust loading platform/thermal shield which is an important feature of the sensor design. This approach has helped achieve the performance characteristics as given in this report. This thermal shield provides:

- 1) a dust loading platform which can be easily removed from the sensor when the sensor needs to be cleaned,
- 2) a dust loading platform that concentrates the dust load to the center of the sensor measuring diaphragm, thereby helping to average non-uniformities of dust loading distribution over the thermal shield surface, and
- 3) provides a thermal shield between the sensitive sensor diaphragm and fluctuations in environmental temperature, thereby leading to improved thermal stability of the sensor readings.

It is important to remember that whenever the thermal shield/dust loading platform is removed (for cleaning or otherwise) the sensor GAGE FACTOR (calibration factor) should be rechecked (see Section 4 for instructions on how this is done).

Part of the design objectives was to produce a coal dust sensor that not only met technical performance specifications but could be built at minimal cost. We presently estimate labor and material costs to give a unit manufacturing cost of approximately \$100 per unit (including 10 feet of connector cable) when the sensor units are manufactured in quantities of 10. Cost estimates for a complete system, as installed in a mine, should also account for the cost of connecting cables (between sensors and remote switch station or between remote switch station and readout unit) which may be significant, if long distance installations are required or desired.

Possible Design Improvements

One of the major factors in the current construction and adjustment of the sensors is the physical performance of the thin, circular, metal diaphragm that comprises the "spring" element of the sensor. If additional sensors are to be built, we believe it would be advantageous to consider the replacement of the present circular metal diaphragm with a metal strip that would act as a beam spring. Such a beam "spring" would have the features of being easier to manufacture, assemble, and adjust and possibly could also be designed to be less sensitive to environmental temperature changes than is the sealed circular membrane of the present design.

Upon completion of the testing of the sensors and readout units, and delivery of the complete monitoring system to the Bureau, the Bureau undertook tests which indicated that the electronic readout unit was at times subject to erratic operation under conditions of high relative humidity. The readout unit was designed to be hermetically sealed (a membrane key panel type faceplate was specifically used to allow this to be done). However, the readout units were disassembled and assembled several times prior to delivery to the Bureau with the result that the hermetic seal was not in place during the Bureau's testing. While an appropriate hermetic seal, as designed, should be sufficient to permit operation of the unit under high humidity conditions, a modification to these seals may be required in future use of this system.

The present faceplate layout of the readout unit does not allow for a separate input of individual temperature coefficients for each sensor. Instead, the sensors must be "fine tuned" by mechanical adjustment to bring the temperature sensitivity of each unit close to a constant value. This constant value is then used as an internal input to the mathematical algorithms within the readout unit which then corrects dust loading readings as a result of temperature changes. Future readout designs should preferably permit the separate input of temperature coefficients for each sensor, in the same way as the GAGE FACTOR for each sensor is now done, so that tailored temperature corrections for each individual sensor can be provided. This would provide two advantages: 1) each sensor would not have to be "fine tuned" to bring it into agreement with a fixed value of temperature coefficient, thereby reducing manufacturing costs, and 2) the use of individual temperature coefficients for each sensor would provide a more accurate correction for temperature changes, since it is impractical to bring each sensor to exactly the same value of temperature coefficient.

REFERENCES

1. Dutta, P. K., Tenenbaum, R., and Hawkes, I.; Remote Readout Coal Dust Deposition Rate Monitor; Technical Report TR79-5, Prepared for the U. S. Dept. of the Interior, U. S. Bureau of Mines, Contract No. J0188058, December 1979.
2. Nagy, J., Mitchell, D. W., and Kawenski, E. M.; Float Coal Hazard in Mines; A Progress Report, U. S. Bureau of Mines RI 6581, 1965.
3. Roark, R. J. and Young, W. C.; Formulas for Stress and Strain; McGraw Hill Publishing Co., 1965.

APPENDIX A. USER INSTRUCTION MANUAL

INSTRUCTION MANUAL
COAL DUST SENSOR
MODEL CDS

CONTENTS

1.	INTRODUCTION	79
2.	SYSTEM COMPONENTS	80
	2.1 Principle of Operation	80
	2.2 Readout	80
	2.3 Readout Keyboard Operation	81
	2.4 Switch Module	82
	2.5 Sensors	82
3.	SYSTEM ASSEMBLY	84
4.	SYSTEM INITIALIZATION	85
5.	PRESET MIN/PRESET MAX	86
6.	FIELD READINGS	87
	APPENDIX 1 - Determination of Dust Load for Wire Period	
	APPENDIX 2 - Gage Factor Listing	

1. INTRODUCTION

This manual describes the operation of a coal dust deposition rate measurement system. The prototype system has been developed under U. S. Bureau of Mines Contract No. J0188058 for the in-situ measurements of deposited coal dust concentrations up to 500 mg/cm^2 , with a resolution of 1 mg/cm^2 . The system components referred to in this manual are (1) the readout, (2) switch module, (3) sensors, and (4) connecting cables. The following sections of this manual provide instructions on the system assembly and the readout unit initialization and operation.

2. SYSTEM COMPONENTS

2.1 Principle of Operation

Each coal dust sensor has a tensioned stainless steel wire connected to a flexible stainless steel diaphragm. To reduce thermal effects, a "thermal shield" (constructed from closed cell foam) is mounted on the center of the diaphragm. Dust particles settle on the shield which, in turn, transfers the dust load to the steel diaphragm thus reducing the tension stress level of the stainless steel wire. The readout unit measures the period of the natural resonant vibration frequency of the stainless steel wire and also the gage temperature. These values are processed along with previously stored values of initial period, temperature, and gage factor to calculate and display dust loading in mg/cm^2 .^{*} Minimum and maximum dust load preset values can also be stored so that the reading can be shown in terms of % PRESET, i.e., change in dust load expressed as a percent of the change in dust load between the minimum and maximum preset values.

2.2 Readout

The readout can monitor up to ten coal dust sensors connected through a modified 20-channel switch module. The switch module is connected to the readout via a 6-conductor cable.

The readout software is programmed to display the average of the previous six consecutive readings, progressively dropping the earliest reading and adding the newest reading to the six values. This requires that a minimum of six readings be permitted, at a constant load level, prior to reading and recording the displayed value.

The readout is powered by nickel-cadmium batteries which have a continuous on-life of three hours. A low battery indication first occurs when the battery life is down to approximately 30 minutes. After the batteries have reached a lower level, the readout will automatically shut off and cannot be turned back on until the batteries are recharged. This is done to prevent a total discharge of the battery pack. Stored parameter values are in a separate memory powered by a second battery, however, and are therefore protected from loss due to power drain on the main battery pack. The Ni-Cd batteries are recharged by connecting the charger for sixteen hours. [Note: Taking readings while the charger is plugged into the main lines is likely to cause erroneous readings.]

^{*}See Appendix 1.

2.3 Readout Keyboard Operation

There are two blocks of keys. The red keys are used to enter the gage parameters (initial data) for each channel. The black keys are used to read the gage once the gage parameters have been entered and stored.

ON/CHAN - This key is used to turn the unit on. If the unit is already on, this key followed by a digit key will select a new channel defined by the digit key.

OFF - Used to turn the unit off, this key is under software control. In use, if the system crashes (does not respond to any key), the unit can be turned off by pressing the small button switch below the charger jack.

DUST LOAD - Used to read dust concentration. Each time the key is pressed, the display alternates between mg/cm² and % PRESET.

PRESET MIN - Used to display the stored value of the lower preset limit (mg/cm²). To store a new preset value, press the PRESET MIN key followed by the digit keys that enter the new value (in mg/cm²). This new value is then stored by pressing the PRESET MIN key followed by the ENTER key. The display will show PMIN STORED.

PRESET MAX - Used to display the stored value of the higher preset limit (mg/cm²). To store the new value, press the PRESET MAX key followed by the digit keys for a new value (in mg/cm²) and then by the PRESET MAX AND ENTER keys as described above.

GAGE FACTOR - Displays the stored gage factor. To enter a new value, the GAGE FACTOR key is pressed followed by the desired digit keys and then by the GAGE FACTOR and ENTER keys.

CURRENT PERIOD - This key causes the gage to be read and the period of its frequency displayed. The least significant digit represents 0.05 microseconds. The digits displayed are the least significant four digits of a five digit number whose most significant digit is always 1.

INITIAL PERIOD - Displays the stored initial reading. To store a new value, the INITIAL PERIOD key is pressed followed by the desired digit keys or by the CURRENT PERIOD key (enters the current gage period). The new value is then stored by pressing the INITIAL PERIOD key and then the ENTER key.

ENTER - The use of this key in storing new parameters has been described above. When this key is hit out of sequence, it initializes the readout to the state right after it is turned on, displaying 'READY'.

2.4 Switch Module

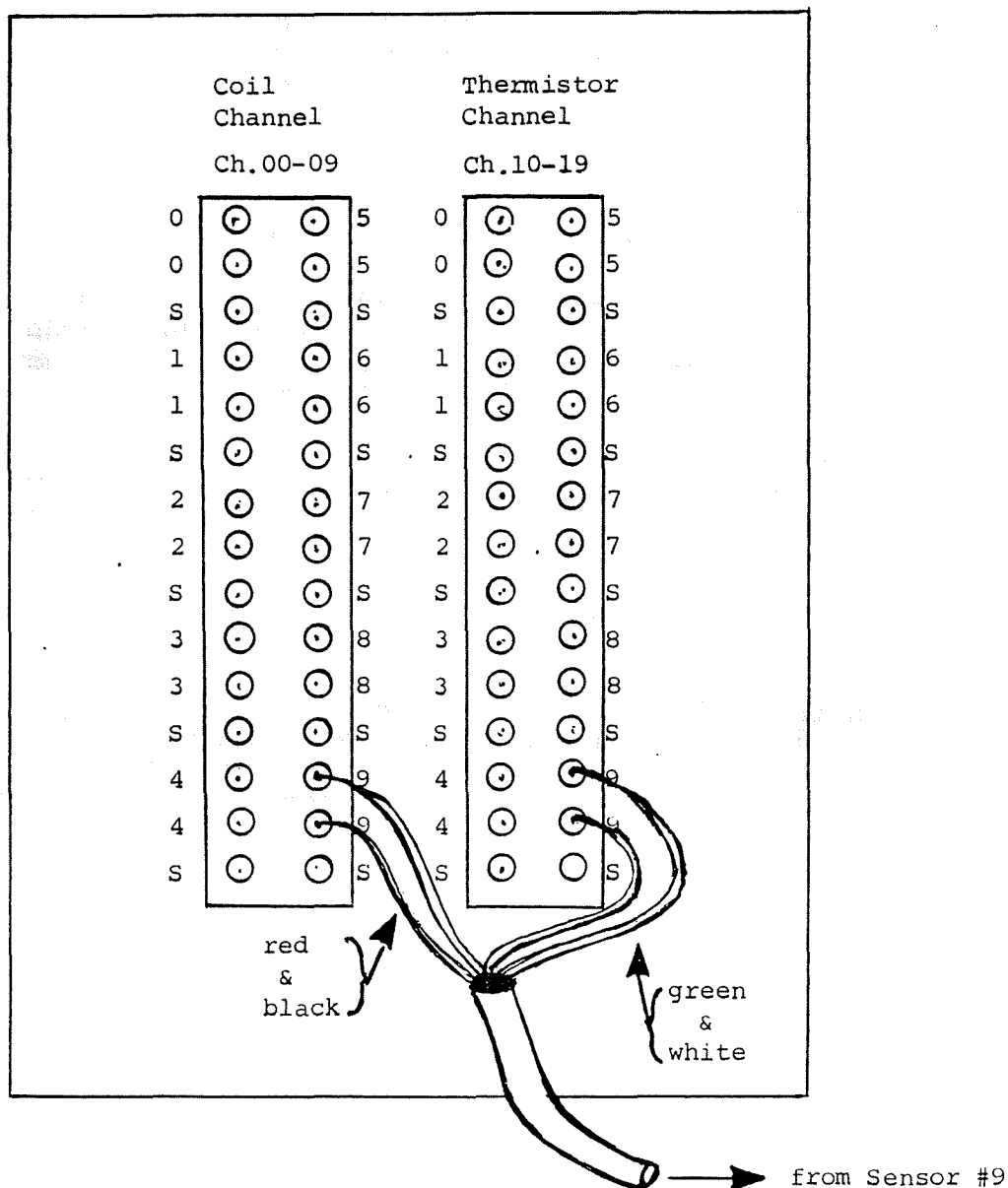
The coal dust sensor switch module is a modified standard IRAD GAGE 20-channel unit. The leads of the gage coil from each sensor (red and black) are connected to Channels 0-9. The leads for the thermistor (green and white) are connected to the corresponding Channels 10-19 (see Figure 1). The shield lead from each sensor is a common ground and can be connected to an 'S' terminal on either side of the switch module.

2.5 Sensors

The coal dust sensors consist of a tensioned stainless steel vibrating wire fixed at one end to a stationary end block and connected at the other end to a flexible, stainless steel diaphragm. The wire cavity is sealed from the outside environment to protect the vibrating wire from contamination by dust particles. A "thermal shield" (mylar-coated closed cell foam) disk is provided with each sensor to negate the influences of varying thermal environments.

Each sensor comes with a 4-conductor shielded cable. The red and black leads are connected to the gage coil. The coil plucks the vibrating wire and monitors the resonant frequencies which are transmitted to the readout where an electronic counting circuit measures and displays the wire period. The green and white leads are connected to a thermistor in the interior of the sensor and are used to measure the gage temperature.

Chs. 00-09 - Coil Leads (Red and Black) from Sensor.
 Chs. 10-19 - Thermistor Leads (Green and White) from Sensor.



Example: Channel 9

Connect red and black leads to terminals #9 (two terminals, labelled "9" under Ch. 00-09, either lead to either terminal).

Connect green and white leads to terminals #19 (two terminals, labelled "9" under Ch. 10-19, either lead to either terminal).

Shield lead is a common ground and can be used on either side.

Figure 1. Coal Dust Sensor Switch Module

3. SYSTEM ASSEMBLY

This dust monitor system is shipped as individual components and components are packed tightly to isolate them from shock loads received during shipping. Upon receipt, remove the sensors, switch module, readout, and connecting cables from the packing materials, and connect as outlined below:

- 1) Remove the protective cover lid* from each sensor by unscrewing the three 6-32 thumb screws.
- 2) Check that the thermal shield is centrally located on the centralizing PVC disk at the diaphragm center. [Caution: Handle gently, as the sensor diaphragms are sensitive, delicate components.]
- 3) Connect the 5 leads for each sensor (2 gage coil leads, 2 thermistor leads, and 1 ground shield) to the desired switch module channel as outlined in Section 2.4 and Figure 1.
- 4) Connect the switch module to the readout using the 6-conductor cable.

[Note: The readout provides for "SWITCH MODULE" and "SINGLE GAGE" connectors. The "SINGLE GAGE" connection does not provide for thermal correction (which takes place in the switch module), and should not be used during dust measurements.]

*Each sensor is shipped with three 6" threaded stainless steel standoffs. A canopy assembly can be made from the protective cover lid clamped onto the standoffs, which are threaded into the sensor housing. This canopy will protect the diaphragm/thermal shield from damage by heavy particles.

4. SYSTEM INITIALIZATION

1) After connecting the gages to the switch module and readout, determine that each sensor is at thermal equilibrium by the following steps.

- a) Turn the readout ON.
- b) Press CHANNEL number (for the gage to be read).
- c) Press CURRENT PERIOD.
- d) Monitor the temperature reading, making sure the gage temperature stabilizes (less than 0.5°C per hour drift should be satisfactory).
[Note: The CURRENT PERIOD alternates between the current period reading and the current temperature (°C).]

2) Initialize each sensor by reading and recording the 0 DUST LOAD (established above) as follows:

- a) Select CHANNEL.
- b) Press the INITIAL PERIOD key.
- c) Press the CURRENT PERIOD key. (This will enter the current period and temperature on the display).
- d) Store this INITIAL PERIOD by repressing the INITIAL PERIOD key and then the ENTER key.
- e) The display will show INIT STORED.

3) Store the GAGE FACTOR for each sensor:

- a) Select CHANNEL.
- b) Press GAGE FACTOR key.
- c) Select the desired digit keys equal to the GAGE FACTOR (see Appendix 2).
- d) Repress the GAGE FACTOR key.
- e) Press the ENTER key.
- f) The display will show CAL STORED.

4) Check that initialization is complete by reviewing the 0 DUST LOAD of each channel. Press DUST LOAD after selecting CHANNEL.

Remember that the DUST LOAD key displays either mg/cm² or % PRESET. The LCD display alternates between these two outputs each time the key is pressed.

5. PRESET MIN/PRESET MAX

A range of DUST LOAD can be entered into the readout unit to calculate the percent of the dust load range presently sensed by the current load on the gage. In order to do this, follow these steps:

- 1) Select a PRESET MIN value equal to the value of the lower limit of the preset range. To store a new preset value, press the PRESET MIN key.
- 2) Press the digit keys that enter the new value of the lower preset limit.
- 3) Store the new value by pressing the PRESET MIN key followed by pressing the ENTER key.
- 4) The LCD display will show PMIN STORED.
- 5) A check can be made that the preset min value has been stored by pressing PRESET MIN key.
- 6) To store a new value of the upper limit of the preset range, press the PRESET MAX key.
- 7) Press the DIGIT keys corresponding to the new upper limit value.
- 8) Press the PRESET MAX (again) and then press the ENTER key. The LCD display will show PMAX STORED.
- 9) To display the present max value, press the PRESET MAX key.

Having selected PRESET MIN and PRESET MAX values and having entered them into the readout unit, pressing the DUST LOAD key in the % PRESET mode will display the % PRESET value.

6. FIELD READINGS

After completing the initialization and storage of gage parameters, operation of the unit to obtain DUST LOAD readings involves only the use of the "black" READ block of keys.

At any time, presently stored values on any channel of the readout can be obtained for the variables:

PRESET MIN
PRESET MAX
INITIAL PERIOD
GAGE PERIOD

These can be checked by turning the unit ON, selecting the CHANNEL of interest, and then pressing the appropriate key corresponding to one of the four values above.

It is also advisable that, following initialization, a permanent written record of the above stored values for each channel be maintained.

APPENDIX 1

DETERMINATION OF DUST LOAD FROM WIRE PERIOD

DETERMINATION OF DUST LOAD FROM WIRE PERIOD

The reduction of measured wire period to displayed dust load in mg/cm^2 is accomplished by software algorithms in the readout.

The following definitions and relations are used:

T = wire period (μsec)

t = temperature ($^{\circ}\text{C}$)

a = gage factor ($\text{mg}/\text{cm}^2/\mu\text{sec}$)

b = constant parameter (μsec^{-2})

K_T = thermal coefficient for coal dust sensors ($\mu\text{sec}/^{\circ}\text{C}$)

L = dust load (mg/cm^2)

For the ten prototype coal dust sensors developed under this contract, the following are stored as constant parameters in the readout software:

$$b = -3.599 \times 10^{-5}$$

$$K_T = 63$$

The change in coal dust period reading, corrected for temperature changes, is defined as ΔT , and is expressed as

$$\Delta T = [T_1 - T_0 + K_t (t_1 - t_0)]$$

where subscript 0 indicates an initial reading, and subscript 1 corresponds to current readings.

The overall dust load L is expressed in terms of ΔT :

$$L = a \Delta T + b (\Delta T)^2$$

Values of the gage factors 'a' for the 10 sensors developed on this contract are given in Appendix 2.

APPENDIX 2
GAGE FACTOR LISTING

GAGE FACTOR LISTING

<u>COAL DUST SENSOR</u> (Number)	<u>GAGE FACTOR</u> ('a')
1	0.50
2	0.42
3	0.49
4	0.44
5	0.50
6	0.60
7	0.54
8	0.47
9	0.62
10	0.50

APPENDIX B. TABULATED SENSOR TEST RESULTS

CALIBRATION CHECK TESTS
REPEATABILITY TESTS
TEMPERATURE STABILITY TESTS

APPENDIX B. TABULATED SENSOR TEST RESULTS

TEST #1

CALIBRATION CHECK

Date: September 2, 1982

Gage Factor: a = 0.50

Calibrated By: RWH

Gage No: 1

<u>Pennies</u>	<u>Actual Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)	<u>Initialization</u>	
			<u>Measured Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)
0	0	0	0	0
1	41	39	40	40
2	81	-	-	-
3	120	118-9	119	118
4	163	163	165	163
5	199	200	199	198
6	243	244	246	242
7	285	285	286	279
8	326	330	327	327
9	363	365	366	363
10	408	411	411	409
11	446	455	454	448
12	485	490	496	489
13	524	531	533	529
14	567	573	567	567
15	611	608	608	616
0	0	0	1	0

TEST #1

CALIBRATION CHECK

Date: November 16, 1982

Gage Factor: a = 0.42

Calibrated By: RET

Gage No: 2

Initialization

Period - 6973
Temp. - 26.96°C

Period - 6972
Temp. - 26.95°C

Period - 6974
Temp. - 26.96°C

<u>Pennies</u>	<u>Actual Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>
0	0	0	0	0
1	41	39	39	40
2	78	76	77	77
3	120	118	119	117
4	163	162	162	160
5	199	197	196	195
6	245	240	241	237
7	286	278	280	280
8	326	316	320	318
9	363	354	353	352
10	408	399	398	395
11	446	433	435	431
12	485	463	470	471
13	524	504	504	509
14	567	527	534	548
15	611	588	585	588
0	0	2	0	0

TEST #1

CALIBRATION CHECK

Date: September 2, 1982

Gage Factor: a = 0.49

Calibrated By: RET

Gage No: 3

Initialization

Period - 6729 Period - 6726 Period - 6721
Temp. - 26.9°C Temp. - 27.3°C Temp. - 27.3°C

<u>Pennies</u>	<u>Actual Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>
0	0	0	0	0
1	41	40	40	40
2			-	-
3	120	121	120	119
4	163	163	164	163
5	199	198	199	199
6	243	245	245	244
7	285	288	286	289
8	326	325	327	326
9	363	366	367	366
10	408	411	409	411
11	446	458	451	448
12	485	494	492	485
13	524	535	538	529
14	567	563	567	566
15	611	621	611	615
0	0	0	0	0

TEST #1

CALIBRATION CHECK

Date: September 2, 1982

Gage Factor: a = 0.44

Calibrated By: RWH

Gage No: 4

<u>Pennies</u>	<u>Actual Load Concentration</u> (mg/cm ²)	<u>Initialization</u>		
		<u>Measured Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)
		Period - 7066 Temp. - 29.8°C	Period - 7063 Temp. - 30.0°C	Period - 7054 Temp. - 30.1°C
0	0	0	0	0
1	41	41	40	41
2	-	-	-	-
3	120	121	120	121
4	163	164	162	164
5	199	201	200	201
6	243	245	244	243
7	285	287-8	286	286
8	326	328	326	326
9	363	364	364	365
10	408	413	407	410
11	446	450	446	448
12	485	484	483	482
13	524	526	523	523
14	567	565	563	564
15	611	610	609	604
0	0	0	0	0

TEST #1

CALIBRATION CHECK

Date: September 2, 1982

Gage Factor: a = 0.50

Calibrated By: RET/RWH

Gage No: 5

Initialization

Period - 5955
Temp. - 29.4°C

Period - 5952
Temp. - 29.5°C

Period - 5947
Temp. - 29.7°C

<u>Pennies</u>	<u>Actual Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>
0	0	0	0	0
1	41	40	40	40
2		-	-	-
3	120	119	119	118
4	163	162	161	160
5	199	198	197	197
6	243	242	242	240
7	285	287	285	285
8	326	323	323	321
9	363	362	362	362
10	408	409	408	405
11	446	446	444	443
12	485	487	484	484
13	524	522	524	526
14	567	572	569	572
15	611	613	611	614
0	0	0	0	0

TEST #1

CALIBRATION CHECK

Date: November 18, 1982

Gage Factor: a = 0.60

Calibrated By: RET

Gage No: 6

<u>Pennies</u>	<u>Actual Load Concentration</u> (mg/cm ²)	<u>Initialization</u>		
		<u>Measured Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)
		Period - 5599 Temp. - 25.85°C	Period - 5598 Temp. - 25.98°C	Period - 5594 Temp. - 26.09°C
0	0	0	0	0
1	41	40	38	40
2	78	75	73	76
3	120	111	110	112
4	163	158	157	154
5	199	199	194	194
6	245	245	245	247
7	286	293	293	291
8	326	329	331	333
9	363	371	368	367
10	408	412	408	417
11	446	468	466	467
12	485	495	496	495
13	-	-	-	-
14	-	-	-	-
15	-	-	-	-
0	0	0	0	0

TEST #1

CALIBRATION CHECK

Date: November 18, 1982

Gage Factor: a = 0.54

Calibrated By: RET

Gage No: 7

<u>Pennies</u>	<u>Actual Load Concentration (mg/cm²)</u>	<u>Initialization</u>		
		<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>
		Period - 5821 Temp. - 24.52°C	Period - 5818 Temp. - 24.61°C	Period - 5806 Temp. - 24.79°C
0	0	0	0	0
1	41	40	40	40
2	78	77	78	78
3	120	119	120	120
4	163	162	162	162
5	199	200	200	200
6	245	246	246	245
7	286	287	288	287
8	326	329	329	328
9	363	367	367	366
10	408	414	414	412
11	446	453	453	451
12	485	494	493	492
13	524	535	534	532
14	567	577	577	576
15	611	624	624	622
0	0	0	0	0

TEST #1

CALIBRATION CHECK

Date: November 18, 1982

Gage Factor: a = 0.47

Calibrated By: RET

Gage No: 8

<u>Pennies</u>	<u>Actual Load Concentration</u> (mg/cm ²)	<u>Initialization</u>		
		<u>Measured Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)
		Period - 6398 Temp. - 25.05°C	Period - 6392 Temp. - 25.16°C	Period - 6395 Temp. - 25.23°C
0	0	0	0	0
1	41	37	40	39
2	78	74	75	75
3	120	117	120	119
4	163	162	165	163
5	199	199	202	199
6	245	245	248	246
7	286	286	288	286
8	326	324	326	323
9	363	361	360	359
10	408	405	407	403
11	446	441	445	443
12	485	480	482	481
13	524	521	521	518
14	567	559	560	559
15	611	606	605	604
0	0	0	1	0

TEST #1

CALIBRATION CHECK

Date: November 18, 1982

Gage Factor: a = 0.62

Calibrated By: RET

Gage No: 9

<u>Pennies</u>	<u>Actual Load Concentration (mg/cm²)</u>	<u>Initialization</u>		
		<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>
		Period - 5029 Temp. - 24.09°C	Period - 5018 Temp. - 24.30°C	Period - 5012 Temp. - 24.40°C
0	0	0	0	0
1	41	39	38	40
2	78	76	73	75
3	120	115	115	117
4	163	157	157	159
5	199	194	192	195
6	245	242	238	241
7	286	278	277	280
8	326	325	321	326
9	363	359	356	359
10	408	412	406	406
11	446	448	442	444
12	485	487	493	490
13	524	527	535	538
14	567	575	582	586
15	611	625	627	629
0	0	0	0	0

TEST #1

CALIBRATION CHECK

Date: September 2, 1982

Gage Factor: a = 0.50

Calibrated By: RWH

Gage No: 10

Initialization

Period - 6211
Temp. - 31.1°C

Period - 6230
Temp. - 31.1°C

Period -
Temp. -

<u>Pennies</u>	<u>Actual Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Measured Load Concentration (mg/cm²)</u>
0	0	0	0	0
1	41	40	39	40
2		-	-	-
3	120	117	117	118
4	163	159	162	160
5	199	196	198	196
6	243	238	239	238
7	285	281	284	282
8	326	322	326	325
9	363	360	358	360
10	408	405	404	409
11	446	336	448	446
12	485	482	482	485
13	524	518	519	522
14	567	563	565	565
15	611	611	613	611
0	0	0	0	0

TEST #2

REPEATABILITY TEST

Date: September 8, 1982

Gage Factor: a = 0.50

Calibrated By: RWH

Gage No: 1

<u>Actual Load Concentration</u>	<u>Initialization</u> Period - 6150 Temp. - 29.2°C <u>Measured Load Concentration</u> (mg/cm ²)	<u>Actual Load Concentration</u> (mg/cm ²)	<u>Initialization</u> Period - 6170 Temp. - 29.0°C <u>Measured Load Concentration</u> (mg/cm ²)
0	0	0	0
243	241	485	491
0.	0	0	0
243	243	485	489
0	0	0	0
243	242	485	490
0	0	0	0
243	241	485	490
0	0	0	0
243	242	485	490
0	0	0	1
243	244	485	490
0	1	0	1
243	241	485	490
0	1	0	0
243	245	485	489
0	1	0	0

TEST #2

REPEATABILITY TEST

Date: November 19, 1982

Gage Factor: a = 0.42

Calibrated By: RET

Gage No: 2

Initialization

Period - 6984

Temp. - 26.63°C

Initialization

Period - 6985

Temp. - 26.61°C

<u>Actual Load Concentration</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Actual Load Concentration</u>	<u>Measured Load Concentration (mg/cm²)</u>
0	0	0	0
245	240	485	477
0	0	0	0
245	240	485	476
0	0	0	0
245	241	485	477
0	0	0	0
245	240	485	477
0	0	0	0
245	241	485	476
0	0	0	0
245	240	485	476
0	0	0	0
245	241	485	477
0	0	0	0
245	242	485	477
0	0	0	0

TEST #2

REPEATABILITY TEST

Date: September 8, 1982

Gage Factor: a = 0.49

Calibrated By: RWH

Gage No: 3

	<u>Initialization</u>		<u>Initialization</u>
	Period - 6562 Temp. - 29.6°C		Period - 6565 Temp. - 29.6°C
<u>Actual Load Concentration</u>	<u>Measured Load Concentration</u> (mg/cm ²)	<u>Actual Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)
0	0	0	0
243	242	485	484
0	0	0	0
243	241	485	483
0	0	0	0
243	242	485	483
0	0	0	0
243	241	485	485
0	0	0	0
243	241	485	483
0	0	0	0
243	241	485	484
0	0	0	0
243	242	485	483
0	1	0	1
243	241	485	484
0	0	0	1

TEST #2

REPEATABILITY TEST

Date: September 8, 1982

Gage Factor: a = 0.44

Calibrated By: RWH

Gage No: 4

<u>Actual Load Concentration</u>	<u>Initialization</u> Period - 7050 Temp. - 29.7°C <u>Measured Load Concentration</u> (mg/cm ²)	<u>Actual Load Concentration</u> (mg/cm ²)	<u>Initialization</u> Period - 7055 Temp. - 29.7°C <u>Measured Load Concentration</u> (mg/cm ²)
0	0	0	0
243	244	485	485
0	0	0	0
243	244	485	486
0	0	0	0
243	245	485	486
0	0	0	0
243	245	485	484
0	1	0	0
243	243	485	487
0	1	0	0
243	246	485	484
0	1	0	0
243	246	485	488
0	1	0	0
243	246	485	487
0	1	0	0

TEST #2

REPEATABILITY TEST

Date: September 8, 1982

Gage Factor: a = 0.50

Calibrated By: RWH

Gage No: 5

	<u>Initialization</u>		<u>Initialization</u>
	Period - 5908		Period -
	Temp. - 29.8°C		Temp. -
<u>Actual Load Concentration</u>	<u>Measured Load Concentration</u> (mg/cm ²)	<u>Actual Load Concentration</u> (mg/cm ²)	<u>Measured Load Concentration</u> (mg/cm ²)
0	0	0	0
243	241	485	483
0	0	0	0
243	240	485	484
0	0	0	0
243	241	485	483-4
0	0	0	0
243	241	485	485
0	0	0	0
243	241	485	486
0	0	0	0
243	242	485	483
0	0	0	0
243	242	485	484
0	0	0	0
243	241	485	484
0	0	0	0

TEST #2

REPEATABILITY TEST

Date: February 28, 1983

Gage Factor: a = 0.60

Calibrated By: RET

Gage No: 6

Initialization

Period - 5627

Temp. - 24.72°C

Initialization

Period - 5630

Temp. - 24.78°C

<u>Actual Load Concentration</u>	<u>Measured Load Concentration</u> (mg/cm ²)	<u>Actual Load Concentration</u>	<u>Measured Load Concentration</u> (mg/cm ²)
0	0	0	0
245	246	485	497
0	0	0	0
245	247	485	499
0	0	0	0
245	247	485	494
0	0	0	0
245	245	485	495
0	0	0	0
245	249	485	499
0	0	0	1
245	246	485	498
0	1	0	1
245	247	485	498
0	1	0	1
245	249	485	498
0	1	0	2

TEST #2

REPEATABILITY TEST

Date: November 19, 1982

Gage Factor: a = 0.54

Calibrated By: RET

Gage No: 7

Initialization

Period - 5858

Temp. - 24.66°C

Initialization

Period - 5770

Temp. - 24.79°C

<u>Actual Load Concentration</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Actual Load Concentration</u>	<u>Measured Load Concentration (mg/cm²)</u>
0	0	0	0
245	249	485	489
0	0	0	0
245	248	485	489
0	0	0	0
245	248	485	488
0	0	0	0
245	247	485	489
0	0	0	0
245	247	485	488
0	0	0	0
245	247	485	488
0	0	0	0
245	246	485	488
0	0	0	0
245	246	485	489
0	0	0	0

TEST #2

REPEATABILITY TEST

Date: February 28, 1983

Gage Factor: a = 0.47

Calibrated By: RET

Gage No: 8

Initialization

Period - 6431
Temp. - 24.84°C

Initialization

Period - 6427
Temp. - 24.90°C

<u>Actual Load Concentration</u>	<u>Measured Load Concentration</u> (mg/cm ²)	<u>Actual Load Concentration</u>	<u>Measured Load Concentration</u> (mg/cm ²)
0	0	0	0
245	242	485	478
0	0	0	0
245	241	485	479
0	0	0	0
245	241	485	479
0	0	0	1
245	241	485	480
0	0	0	1
245	241	485	480
0	0	0	0
245	241	485	475
0	0	0	0
245	241	485	476
0	0	0	0
245	241	485	475
0	0	0	0

TEST #2

REPEATABILITY TEST

Date: November 19, 1982

Gage Factor: a = 0.62

Calibrated By: RET

Gage No: 9

Initialization

Period - 4963
Temp. - 25.33°C

Initialization

Period - 4956
Temp. - 25.47°C

<u>Actual Load Concentration</u>	<u>Measured Load Concentration (mg/cm²)</u>	<u>Actual Load Concentration</u>	<u>Measured Load Concentration (mg/cm²)</u>
0	0	0	0
245	237	485	484
0	0	0	0
245	238	485	482
0	0	0	0
245	236	485	482
0	0	0	0
245	236	485	478
0	0	0	0
245	238	485	477
0	0	0	0
245	239	485	480
0	0	0	0
245	239	485	478
0	0	0	0
245	238	485	475
0	0	0	0

TEST #1

REPEATABILITY TEST

Date: September 8, 1982

Gage Factor: a = 0.50

Calibrated By: RWH

Gage No: 10

<u>Actual Load Concentration</u>	<u>Initialization</u> Period - 6277 Temp. - 29.4°C <u>Measured Load Concentration</u> (mg/cm ²)	<u>Actual Load Concentration</u> (mg/cm ²)	<u>Initialization</u> Period - 6294 Temp. - 29.3°C <u>Measured Load Concentration</u> (mg/cm ²)
0	0	0	0
243	242	485	492
0	0	0	0
243	241	485	492
0	0	0	0
243	242	485	487
0	0	0	0
243	241	485	489
0	0	0	0
243	243	485	489
0	0	0	1
243	242	485	489
0	0	0	1
243	243	485	488
0	0	0	1
243	243	485	492
0	1	0	0

TEST #3

TEMPERATURE STABILITY TEST

Date: September 14, 1982

Gage Factor: a = 0.50

Calibrated By: RWH

Gage No: 1

Load Concentration: 81 mg/cm²; 2 pennies, #4, wgt. 6.268 gm.

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u> <u>Period</u>	<u>Temp.</u> °C	<u>Current</u> <u>Period</u>	<u>Temp.</u> °C
<u>Day #1</u>	8:30	0	6367	26.1		
	8:30	86			6544	26.12
	9:30	86			6537	26.19
	11:00	85			6509	26.68
	1:30	86			6424	27.55
	3:30	80			6373	28.60
	5:00	80			6361	28.79
<u>Day #2</u>	9:30	81			6533	26.15
	10:45	80			6481	26.91
	1:10	74			6399	28.02
	7:00	65			6286	29.55
<u>Day #3</u>	9:45	81			6675	23.84
	11:10	80			6598	25.03

TEST #3

TEMPERATURE STABILITY TEST

Date: February 7, 1983

Gage Factor: a = 0.42

Calibrated By: RWH/RET

Gage No: 2

Load Concentration: 81 mg/cm²

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u> <u>Period</u>	<u>Temp.</u> °C	<u>Current</u> <u>Period</u>	<u>Temp.</u> °C
Day #1	11:30	0	7165	24.10		
Day #2	11:30	84			7374	24.06
Day #3	8:15	81			7357	24.25
Day #4	8:40	77			7328	24.56
Day #5	8:00	74			7302	24.84
Day #6	8:00	80			7357	24.21
Day #7	8:15	73			7284	25.08
Day #8	10:50	83			7383	23.92
Day #9	8:15	83			7377	23.99
Day #11	9:00	80			7368	24.03
Day #15	9:30	71			7285	24.91
Day #16	9:00	76			7350	24.16

TEST #3

TEMPERATURE STABILITY TEST

Date: September 14, 1982

Gage Factor: a = 0.49

Calibrated By: RWH

Gage No: 3

Load Concentration: 82 mg/cm²; 2 pennies, #1, wgt. 6.329 gm.

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u> <u>Period</u>	<u>Temp.</u> °C	<u>Current</u> <u>Period</u>	<u>Temp.</u> C
<u>Day #1</u>	8:30	0	6753	26.4		
	8:30	82-3			6926	26.41
	9:30	81			6921	26.45
	11:00	84			6897	26.94
	1:30	85			6817	28.21
	3:30	83			6769	28.88
	5:00	82			6753	29.09
<u>Day #2</u>	9:30	80			6920	26.45
	10:45	82			6874	27.20
	1:10	80			6801	28.29
	7:00	80			6698	29.89
<u>Day #3</u>	9:45	79			7070	24.07
	11:10	84			7001	25.25

TEST #3

TEMPERATURE STABILITY TEST

Date: September 14, 1982

Gage Factor: a = 0.44

Calibrated By: RWH

Gage No: 4

Load Concentration: 81 mg/cm²; 2 pennies, #3, wgt. 6.262 gm.

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u> <u>Period</u>	<u>Temp.</u> °C	<u>Current</u> <u>Period</u>	<u>Temp.</u> °C
<u>Day #1</u>	8:30	0	7244	26.5		
	8:30	85			7439	26.50
	9:30	81			7436	26.56
	11:00	86			7411	27.07
	1:30	86			7329	28.34
	3:30	79			7271	29.01
	5:00	81			7263	29.23
<u>Day #2</u>	9:30	84			7439	26.54
	10:45	84			7391	27.32
	1:10	80			7310	28.41
	7:00	71			7188	29.98
<u>Day #3</u>	9:45	92			7608	24.16
	11:10	89			7526	25.39

TEST #3

TEMPERATURE STABILITY TEST

Date: September 14, 1982

Gage Factor: a = 0.50

Calibrated By: RWH

Gage No: 5

Load Concentration: 70 mg/cm²; 2 pennies, #2, wgt. 6.021 gm.

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u> <u>Period</u>	<u>Temp.</u> °C	<u>Current</u> <u>Period</u>	<u>Temp.</u> °C
<u>Day #1</u>	8:30	0	6129	26.5		
	8:30	80			6290	26.53
	9:30	77			6283	26.58
	11:00	82			6259	27.10
	1:30	76			6166	28.36
	3:30	65			6104	29.03
	5:00	67			6089	29.26
<u>Day #2</u>	9:30	77			6285	26.58
	10:45	75			6231	27.34
	1:10	66			6144	28.44
	7:00	52			6016	30.03
<u>Day #3</u>	9:45	81			6437	24.20
	11:10	82			6364	25.40

TEST #3

TEMPERATURE STABILITY TEST

Date: February 7, 1983

Gage Factor: a = 0.60

Calibrated By: RWH/RET

Gage No: 6

Load Concentration: 82 mg/cm²

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u> <u>Period</u>	<u>Temp.</u> °C	<u>Current</u> <u>Period</u>	<u>Temp.</u> °C
Day #0	11:30	0	5655	24.16		
Day #0		84			5798	24.09
Day #1	8:15	82			5788	24.22
Day #2	8:40	79			5771	24.43
Day #3	8:00	79			5752	24.72
Day #4	8:00	80			5792	24.14
Day #7	8:15	83			5738	25.06
Day #8	10:50	83			5808	23.92
Day #9	8:15	82			5808	23.89
Day #11	9:00	79			5801	23.94
Day #15	9:30	80			5739	24.95
Day #16	8:00	79			5789	24.15

TEST #3

TEMPERATURE STABILITY TEST

Date: February 7, 1983

Gage Factor: a = 0.54

Calibrated By: RWH/RET

Gage No: 7

Load Concentration: 74 mg/cm²

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u>		<u>Current</u>	
			<u>Period</u>	<u>Temp.</u> °C	<u>Period</u>	<u>Temp.</u> °C
Day #0	11:30	0	5784	24.12		
Day #0	11:30	74			5926	24.09
Day #1	8:15	76			5934	24.03
Day #2	8:40	73			5913	24.28
Day #3	8:00	73			5891	24.61
Day #4	8:00	74			5933	24.00
Day #7	8:15	72			5869	24.95
Day #8	10:50	74			5937	23.89
Day #9	8:15	74			5948	23.74
Day #11	9:00	74			5944	23.81
Day #15	9:30	70			5873	24.82
Day #16	9:00	72			5925	24.05

TEST #3

TEMPERATURE STABILITY TEST

Date: February 7, 1983

Gage Factor: a = 0.47

Calibrated By: RWH/RET

Gage No: 8

Load Concentration: 81 mg/cm²

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u> <u>Period</u>	<u>Temp.</u> °C	<u>Current</u> <u>Period</u>	<u>Temp.</u> °C
Day #0	11:30	0	6460	24.03		
Day #0	11:30	81			6638	23.99
Day #1	8:15	83			6646	23.95
Day #2	8:40	78			6620	24.18
Day #3	8:00	77			6600	24.51
Day #4	8:00	80			6641	23.92
Day #7	8:15	82			6591	24.86
Day #8	10:50	89			6667	23.80
Day #9	8:15	87			6672	23.65
Day #11	9:00	84			6662	23.72
Day #15	9:30	79			6591	24.74
Day #16	9:00	84			6644	23.96

TEST #3

TEMPERATURE STABILITY TEST

Date: February 7, 1983

Gage Factor: a = 0.62

Calibrated By: RWH/RET

Gage No: 9

Load Concentration: 80 mg/cm²

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u> <u>Period</u>	<u>Temp.</u> °C	<u>Current</u> <u>Period</u>	<u>Temp.</u> °C
Day #0	11:30	0	4975	24.45		
Day #0	11:30	76			5102	24.40
Day #1	8:15	77			5113	24.28
Day #2	8:40	75			5094	24.53
Day #3	8:00	77-6			5076	24.88
Day #4	8:00	77			5112	24.28
Day #7	8:15	79			5055	25.25
Day #8	10:50	76			5116	24.19
Day #9	8:15	76			5129	24.00
Day #11	9:00	74			5123	24.06
Day #15	9:30	76			5060	25.11
Day #16	9:00	81			5044	24.31

TEST #3

TEMPERATURE STABILITY TEST

Date: September 14, 1982

Gage Factor: a = 0.50

Calibrated By: RWH

Gage No: 10

Load Concentration: 74 mg/cm²; 2 pennies, #5, wgt. 5.692 gm.

	<u>Time</u>	<u>Readout</u> (mg/cm ²)	<u>Initial</u> <u>Period</u>	<u>Temp.</u> °C	<u>Current</u> <u>Period</u>	<u>Temp.</u> °C
<u>Day #1</u>	8:30	0	6448	26.5		
	8:30	76			6603	26.48
	9:30	70			6590	26.58
	11:00	82			6581	27.10
	1:30	87			6508	28.40
	3:30	82			6458	29.06
	5:00	86			6452	29.23
<u>Day #2</u>	9:30	77			6600	26.61
	10:45	78			6557	27.39
	1:10	80			6494	28.49
	7:00	77			6387	30.02
<u>Day #3</u>	9:45	67			6730	24.26
	11:10	77			6669	25.49