RI 8051

Bureau of Mines Report of Investigations/1975

Evaluation of Small, Color-Changing Carbon Monoxide Dosimeters

UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 8051

Evaluation of Small, Color-Changing Carbon Monoxide Dosimeters

By R. M. Ray, H. B. Carroll, and F. E. Armstrong
Bartlesville Energy Research Center, Bartlesville, Okla.

UNITED STATES DEPARTMENT OF THE INTERIOR
Rogers C. B. Morton, Secretary

Jack W. Carlson, Assistant Secretary—Energy and Minerals

BUREAU OF MINES
Thomas V. Falkie, Director

This publication has been cataloged as follows:

Ray, Robert M

Evaluation of small, color-changing carbon monoxide dosimeters, by R. M. Ray, H. B. Carroll, and F. E. Armstrong. [Washington] U.S. Bureau of Mines [1975]

21 p. illus., tables. (U.S. Bureau of Mines. Report of investigations 8051)

Includes bibliography.

1. Dosimeters. 2. Mine gases. I. U.S. Bureau of Mines. II. Carroll, Herbert B., jt. auth. III. Armstrong, Frederick E., jt. auth. IV. Title. V. Title: Carbon monoxide dosimeters. (Series)

TN23.U7 no. 8051 622.06173

U.S. Dept. of the Int. Library

CONTENTS

ILLUSTRATIONS

TABLES

EVALUATION OF SMALL, COLOR-CHANGING CARBON MONOXIDE DOSIMETERS

by

R. M. Ray,[1] H. B. Carroll,[1] and F. E. Armstrong[2]

ABSTRACT

The Bureau of Mines evaluated five commercial badge-type carbon monoxide dosimeters. Color changes in the badge reagent indicated the presence of carbon monoxide. Possible effects of ambient conditions on dosimeter response to CO during or after coal mine fires or explosions were studied. Temperature and humidity changes did not change dosimeter sensitivity to CO. Contaminant gases such as CO_2, NO_2, SO_2, and H_2S had effects that varied with brands of dosimeters ranging from no effect to increased sensitivity to CO. Dosimeters tested after 6 months of storage showed an increase in failure rate as high as 25 percent. Tests were conducted to determine the effects on dosimeter time-for-color change caused by observer's sight (colorblind), lighting, and coal dust on dosimeters. No significant effects were observed. Observer variance was the most pronounced factor observed in all tests.

INTRODUCTION

During coal mine fires and explosions, large quantities of carbon monoxide (CO) are produced resulting in dangerous concentrations in the mine atmosphere encountered by miners and rescue personnel. The Federal Coal Mine Health and Safety Act of 1969 recognizes this hazard and requires that "a self-rescue device approved by the Secretary (of Interior) shall be made available to each miner by the operator which shall be adequate to protect such miner for one hour or longer" (6).[3]

A desirable detection device for this purpose would be lightweight, rapid, reliable, and highly specific for CO, requiring only a minimum of attention for operation or maintenance.

---

[1]Research physicist.
[2]Project leader.
All three authors are at the Bartlesville Energy Research Center, Bartlesville, Okla., formerly part of the Bureau of Mines, U.S. Department of the Interior, now part of the Energy Research and Development Administration.

[3]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

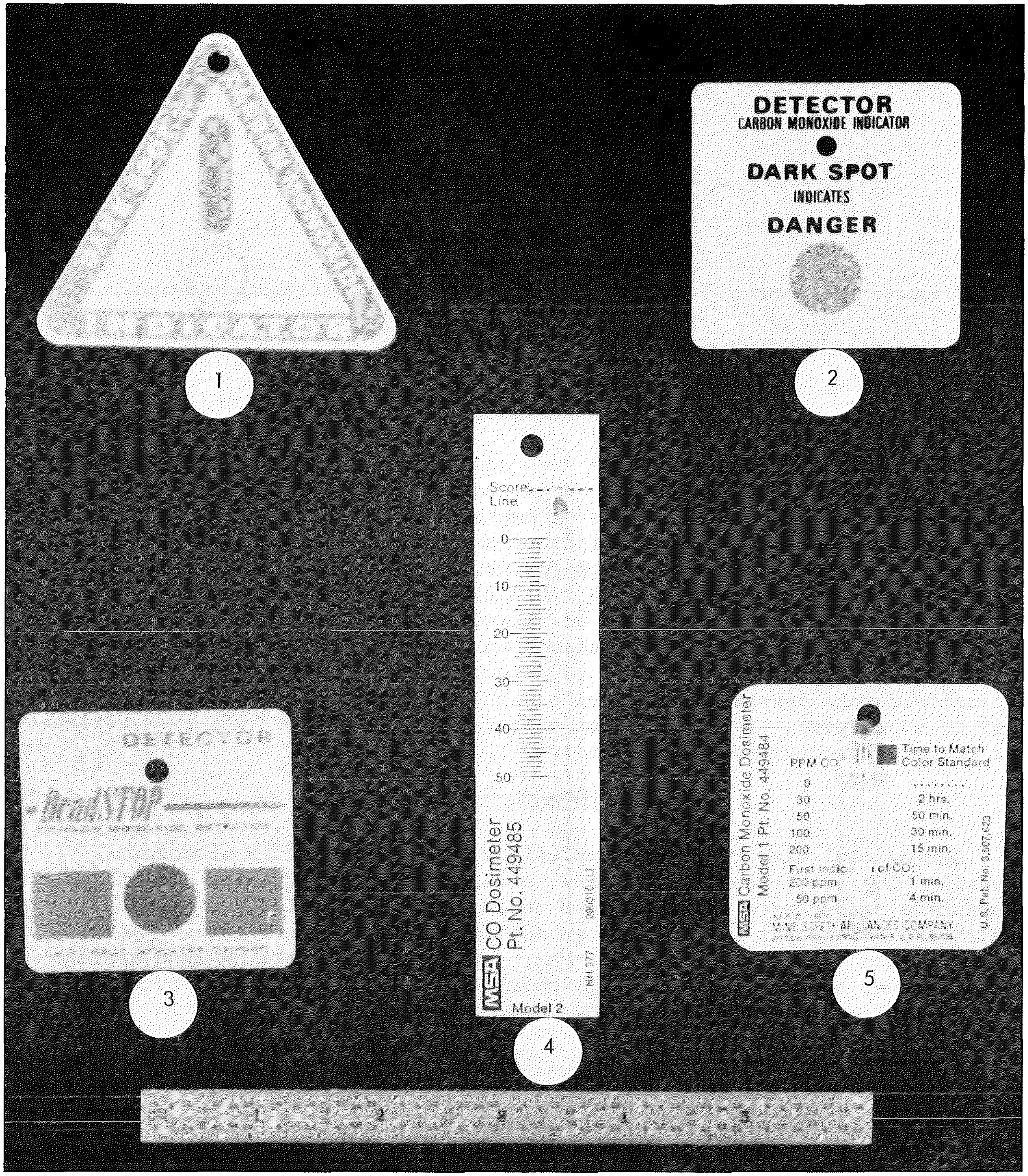

FIGURE 1. - Dosimeters tested in this investigation.

Ferber and Wieser (3) discussed several devices used to measure mine and tunnel gases including carbon monoxide. The report does not list all types and manufacturers of CO measuring devices nor does it attempt to specify the accuracy of the instruments listed. Most of the instruments evaluated required significiant operation time and maintenance. Even the colorimetric and length-of-stain tubes required total attention by the operator.

Both types of tubes have been evaluated. Using chemical indicator tubes, Morgenstern, Ash, and Lynch (4) found variability in the results was often excessive. Murphy (5) evaluated four length-of-stain tubes and found relatively large deviations from the true concentration in using the tubes. Carroll and Armstrong (1) evaluated several chemical indicator tubes and found that the tubes had large deviations from the stated concentration, especially at and below the Threshold Limit Value (TLV).

Small, personal, color-changing CO dosimeters of the badge type worn on the clothing have been available for years and appear to meet all the device criteria.

The purpose of this study was to evaluate five different dosimeters of this type for use in packaging in self-rescuers. The tests were to determine the effects on the time of response to CO due to CO concentration, temperature, humidity, other gases, coal dust discoloration, lighting, observer color blindness, and length of storage time. This study was performed at the Bartlesville Energy Research Center, now part of the Energy Research and Development Administration.

EXPERIMENTAL PROCEDURES

Dosimeters

Five different dosimeters were chosen for study in this evaluation. (See table 1 and fig. 1.)

TABLE 1. - Commercial dosimeters surveyed in this investigation

Dosimeter number	Trade name	Manufacturer or supplier
1........	"Dark spot" Carbon Monoxide Indicator..	Ward International, Granada Hills, Calif.[1] Special-Laboratoriet, Risskov, Denmark[2]
2........	"Detector" Carbon Monoxide Indicator...	American Carbon Monoxide Detector Corporation, Cape Coral, Fla.[1] Dansk-Inpulsfysik, Holt, Denmark[2]
3........	"Dead stop" Carbon Monoxide Detector, Badge #373.	Deco Systems Inc., Houston, Tex.[1]
4........	MSA-Carbon Monoxide Dosimeter--model 2, part No. 449485.	Mine Safety Appliances Co., Pittsburgh, Pa.[2]
5........	MSA-Carbon Monoxide Dosimeter--model 1, part No. 449484.	Mine Safety Appliances Co., Pittsburgh, Pa.[2]

[1]Supplier.
[2]Manufacturer.

The first has a plastic holder in an equilateral triangle shape, 7.6 cm per side, with a removable button of active chemical with an area of approximately 1.3 cm^2. The color of the plastic holder surrounding the active chemical is about the same as that of the nonexposed detector tab. To determine the presence of CO, the sealed plastic case surrounding the badge is removed, thus exposing the active chemical to ambient air. The chemical changes from tan to black in the presence of CO.

The second dosimeter has a circular-shaped active chemical area of about 1.8 cm^2 surrounded by a plastic holder 5.5 cm square. Early models of the plastic holder had no color standard for comparison; however, later models have a color standard printed on the badge. To detect the presence of CO, the sealed plastic cover is removed from the badge thus exposing the active chemical to ambient air. The chemical changes from tan to black in the presence of CO.

The third dosimeter has essentially the same configuration as that of dosimeter 2, 1.8 cm^2 active chemical area with a square holder 5.5 cm per side. This badge has a color standard showing color of the chemical disk before use. The disk shows the presence of CO by changing color from orange to black. The method of sampling is the same as with dosimeters 1 and 2: The plastic case is removed to allow the indicator disk to be exposed to ambient air.

The fourth dosimeter is a length-of-stain tube with an active length of about 5.6 cm and an outside tube diameter of 0.5 cm. The glass tube, scored on one end to facilitate breaking, is mounted on a card with a 50-mm scale printed on it. To indicate the presence of CO, the active chemical is exposed to the atmosphere by breaking the scored end of the tube. The elapsed time for a given length of stain is determined and used with the supplied calibration chart to provide a rough estimate of the CO concentration. This dosimeter is unique among those tested in that it is capable of a semiquantitative measurement over a considerable (several days) period of time.

The fifth dosimeter is a color-change-type dosimeter. The active yellow chemical is contained in a sealed glass tube about 4.6 cm long and 0.5 cm in diameter. The active volume is about 0.25 cm long. The glass tube is mounted on a card about 5.6 cm square. A color standard is provided to determine the final color of the indicator chemical after exposure. In use, the tube is broken at the scored line, and the time necessary for the chemical to change from yellow to that of the color standard is measured. This time is then read on the calibration scale (printed on card) to provide a rough estimation of the CO concentration present.

Instrumentation

The controlled-atmosphere system used to provide the required work atmosphere has been previously described in detail (2). Briefly, it consists of a temperature-humidity chamber with all necessary controls to maintain the preselected temperature-humidity condition required. External instrumentation monitored the CO, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon dioxide (CO_2) concentrations of the work atmosphere. A system for introducing atmospheric contaminants at a constant rate was used to maintain the preselected contaminant level because chamber wall interaction and monitor instrumentation sampling causes losses of contaminants.

In addition to this instrumentation, a Tracor Flame Photometric Detector[4] with an associated electrometer was used to measure hydrogen sulfide (H_2S). The flame photometric unit was mounted in a Microtek Gas Chromatograph, Model G-1600 system.

This system allowed maintenance of test conditions between 35° F at 75 and 95 percent relative hymidity (RH) and 120° F at 75 and 95 percent RH with various concentrations of CO, CO_2, NO_2, SO_2, and H_2S.

The dosimeter-evaluation system consisted of a dosimeter mount assembly, the previously described test chamber, and a data-recording system.

The dosimeters were mounted in a mounting assembly (fig. 2). The assembly, made of plexiglas and stainless steel, allows mounting of 20 badges in a 4- by 5-badge configuration. With the lid in the lowered position, the badges are sealed in the 50- by 40- by 5-cm plexiglas box. The box is

[4]Reference to specific trade names does not imply endorsement by the Bureau of Mines.

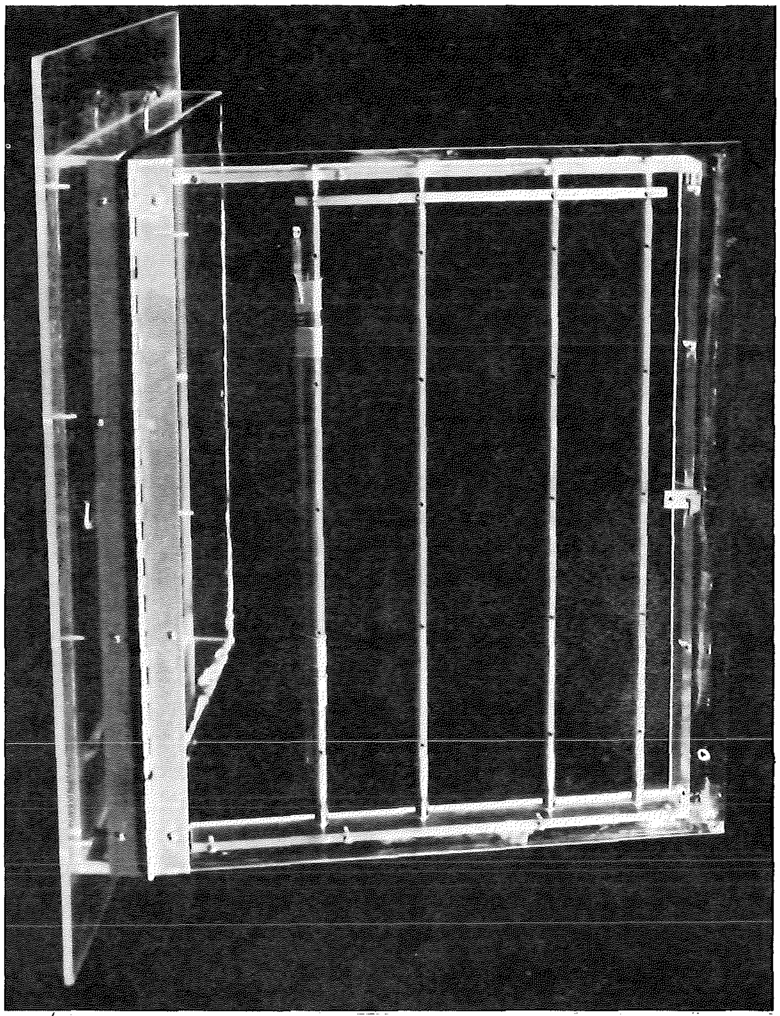

FIGURE 2. - Dosimeter mounting assembly.

continuously purged with dry air until time for exposure. Temperature in the box is monitored with a thermometer visable from outside the chamber.

The data-recording system consisted of three handheld switch panels with 20 single pole, double throw, center off, switches mounted in a 4 by 5 matrix on each, and three 20-channel event recorders. The switches were used as indicators as well as switches; that is, throwing a switch in one direction caused the corresponding recorder pen to deflect. Throwing the switch in the opposite direction released the pen and also, by position of the switch, indicated that the final observation had been made. Each switch corresponded to a dosimeter being tested.

Test Procedure

In preparation for evaluative tests, the chamber was adjusted to the required temperature and humidity. The dosimeters were mounted and sealed in the mounting assembly and placed inside the chamber. The mounting assembly was then pressurized with dry air. The contaminants for the test condition were introduced and adjusted to predetermined levels. The auxiliary contaminant-source system was used to maintain the contaminant concentrations to within ±10 percent of the desired concentrations. When all conditions were as desired, the three observers were positioned in front of the chamber observation window; each was given a switchbox; and the dosimeter-mounting-assembly lid was raised to an upright position exposing the dosimeters to the contaminated atmosphere. The recorders and a stop watch were started simultaneously with the exposure of the badges.

The observers noted two times during the test, "first perceptible color change" and "definite color change." "First perceptible change" was the time at which an observer could see some slight degree of color change; "definite change" was the time at which an observer could see a pronounced change in color. Figure 3 shows typical dosimeter-response curves. Both times were recorded for each dosimeter under test by the event recorders.

A maximum time limit of exposure was set at 15 minutes for all tests. Any dosimeter that failed to indicate at the end of 15 minutes was classified a failure. Five dosimeters from each manufactuer were exposed simultaneously. Dosimeters 1, 2, and 3 were exposed simultaneously as were dosimeters 4 and 5.

Figure 4 shows the complete test condition matrix. Item 1 tests for effects of CO concentration, temperature, and humidity; item 2 tests for effects of various contaminants on sensitivity to CO; item 3 tests for effects of combinations of contaminants; item 4 tests for effects of coal dust being lightly sprinkled on the active chemical area; item 5 tests for effects of lighting on observer's measured time for color change; and item 6 tests for effects of color-blind observers and their ability to see a change of color. Items 7 and 8 are tests for the effects of storage (dosimeter aging) compared with items 1 and 2, respectively.

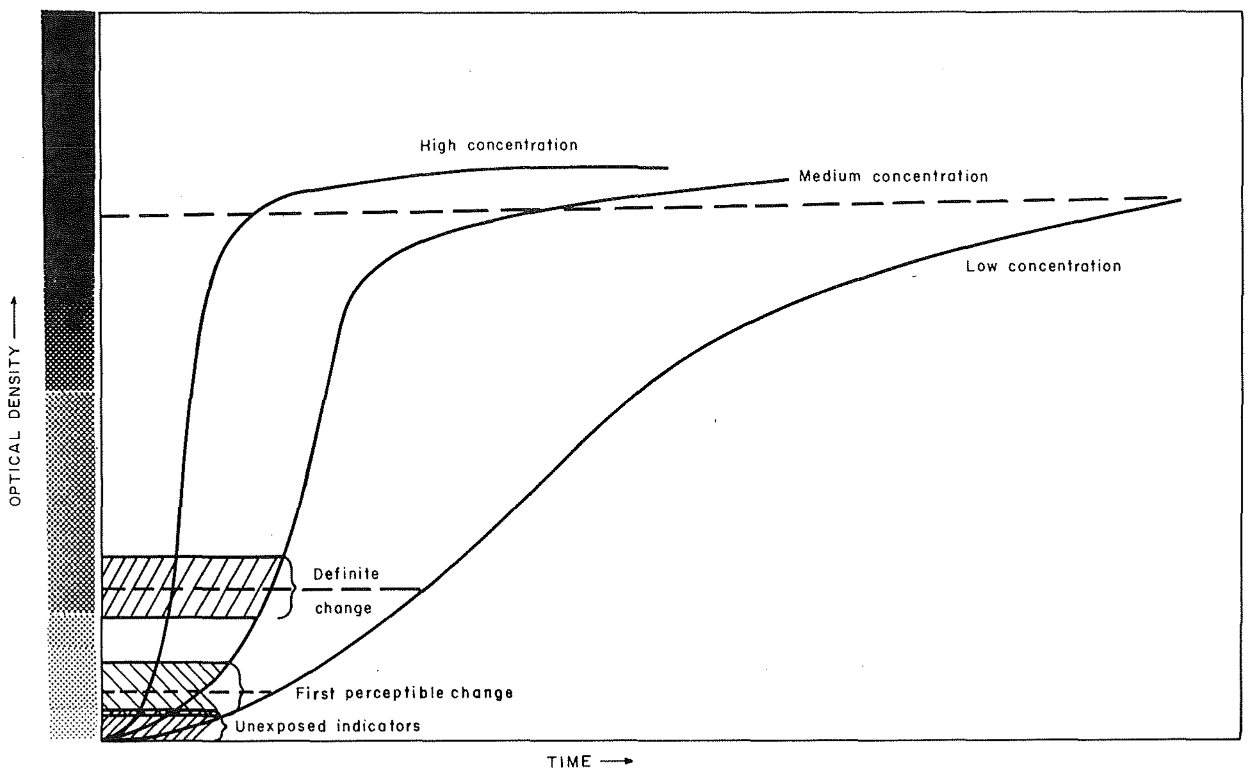

FIGURE 3. - Expected test cycle.

Humidity	75 percent RH					95 percent RH				
CO, ppm \ Temp., °F	35	50	75	100	120	35	50	75	100	120
200										
500										
1,000										
5,000										

Item 1. - Effect of CO concentration, temperature, and humidity on dosimeter sensitivity to CO.

Temperature, °F	50								75							
Humidity, pct RH	75				95				75				95			
CO, ppm x 100	2	5	10	50	2	5	10	50	2	5	10	50	2	5	10	50
NO_2 at 10 ppm																
CO_2 at 2 pct																
H_2S at 10 ppm																
SO_2 at 5 ppm																

Item 2. - Effect of contaminant gases on sensitivity of dosimeter to CO.

SO_2, ppm	1	5	-	-
H_2S, ppm	-	-	2	10
NO_2, ppm	2	10	5	5
CO_2, pct	.5	2	1	1
Temperature, °F	50	75	50	75
Humidity, pct RH	75	95	75	95
CO, ppm 200				
CO, ppm 500				
CO, ppm 1,000				
CO, ppm 5,000				

Item 3. - Effect of combinations of contaminant gases on dosimeter sensitivity to CO.

Temperature, °F	50			
Humidity, pct RH	95			
CO, ppm	200	500	1,000	5,000
Dosimeter lightly coated with coal dust				
Dosimeter observed under miners' light				
Dosimeter observed by color blind observer				

Items 4, 5, and 6. - Special tests to determine effects of coal dust, lighting, and observer color blindness on observed dosimeter sensitivity to CO.

Note: Each square represents five dosimeter from each of five manufacturers.

Humidity	75 percent RH					95 percent RH				
CO, ppm \ Temp., °F	35	50	75	100	120	35	50	75	100	120
200										
500										
1,000										
5,000										

Item 7. - Effect of storage, CO concentration, temperature, and humidity on dosimeter sensitivity to CO.

Temperature, °F	50			
Humidity, pct RH	95			
CO, ppm x 100	2	5	10	50
NO_2 at 10 ppm				
CO_2 at 2 pct				
H_2S at 10 ppm				
SO_2 at 5 ppm				

Item 8. - Effect of storage and contaminant gases on dosimeter sensitivity to CO.

FIGURE 4. - Test condition matrix.

RESULTS AND DISCUSSION

The results of this evaluation are summarized in this section. The concentration of CO present had a significant effect upon time for color change in all dosimeters tested. Figure 5 shows the effects of CO concentration on color change time at 50° F and 75 percent RH. Table 2 shows the maximum observed time for color change due to CO and shows that the first detector had an average response time (definite change) ranging from 9 minutes at 200 ppm CO to 1 minute at 5,000 ppm CO. Appendix A shows the complete matrix of data collected for CO, temperature, and humidity effects. Dosimeter 1 had a 3-percent failure rate. Dosimeter 3 had a 1.5-percent failure rate. Dosimeters 2, 4, and 5 had no failures observed during this portion of the evaluation. Appendix A does not include detector failures in the calculation for the mean or the confidence limit on the mean of the data collected.

Temperature and Humidity

The effects of temperature and humidity on color changes due to CO were within experimental error limits. Humidity appeared to have no effect on reaction rate.

The 95-percent-relative-humidity tests did show the response trends with far less variation. Conversely, the largest variation occurred at 75 percent RH at the 200- to 500-ppm CO range. This large variation is believed to be caused by lack of observer experience since these were among the first tests. Detectors 4 and 5 were tested last in the test sequence because of delay in delivery; thus, these tests tend to show less variation than that found in the earlier work, again probably because of increasing observer experience. Temperature had a slight effect on color change time. Increasing the temperature caused an increase in sensitivity to CO. Most of the effects were noted as the temperature increased from 35° to 75° F.

Effect of Storage

A second group of dosimeters was stored 6 months to study the effects of storage on color change time. These dosimeters were tested in the same manner as the first group. Appendix B shows the results of these tests. Compared to tests with new indicators, dosimeters 2, 3, and 5 showed an average loss of sensitivity over the range of temperatures and humidities tested. Detector 4 showed an average loss of sensitivity to CO only at the lower concentrations of 200 to 500 ppm CO. Detector 1 showed an average gain in sensitivity to CO, especially at 200 to 500 ppm CO.

Failure Rate

Of prime significance was the failure rate change caused by storage effects. Dosimeters 4 and 5 had no failure rate change, but the failure rate of dosimeter 1 increased from 3 to 5 percent; dosimeter 2, from 0 to 11 percent; and dosimeter 3, from 1.5 to 10 percent. All failures were observed at the lowest concentration tested, 200 ppm CO, probably indicating severe loss of sensitivity rather than total failure.

TABLE 2. - Maximum observed time for color change due to CO

Relative humidity, percent	Temperature, °F	CO, ppm	Maximum time for color change → seconds									
			First change					Definite change				
			Dosimeter number					Dosimeter number				
			1	2	3	4	5	1	2	3	4	5
75	35	200	167	27	66	115	95	(1/)	159	108	166	169
		500	57	16	67	61	50	292	85	148	67	57
		1,000	85	35	51	26	18	239	78	90	37	30
		5,000	115	11	12	8	7	144	18	22	10	11
	50	200	228	66	414	115	67	330	378	768	193	147
		500	789	228	531	100	44	(1/)	414	894	143	94
		1,000	117	36	102	16	10	216	150	699	33	20
		5,000	71	7	15	10	7	84	19	25	17	14
	75	200	204	51	111	131	124	435	240	495	169	153
		500	204	189	99	43	41	363	345	219	63	60
		1,000	174	66	97	32	19	224	183	204	51	38
		5,000	36	30	24	11	6	66	60	45	15	12
	100	200	207	57	45	139	125	861	792	570	178	140
		500	20	33	18	39	44	123	66	141	57	48
		1,000	28	19	15	30	30	39	34	44	44	36
		5,000	13	10	16	9	7	27	22	33	14	11
	120	200	390	45	117	96	51	480	471	189	174	93
		500	68	34	29	33	29	78	64	57	81	56
		1,000	NDA	NDA	NDA	42	24	NDA	NDA	NDA	51	41
		5,000	13	10	15	11	8	20	18	22	17	14
95	35	200	(1/)	271	(1/)	122	106	(1/)	758	(1/)	150	147
		500	594	167	214	56	43	705	210	349	65	64
		1,000	318	69	90	16	20	359	121	115	25	27
		5,000	87	25	20	10	8	115	27	25	12	10
	50	200	390	39	33	50	56	834	141	198	113	110
		500	342	63	61	28	24	696	96	103	59	45
		1,000	302	46	53	24	23	448	91	153	36	36
		5,000	99	20	21	8	7	103	30	33	11	11
	75	200	408	66	45	85	78	504	312	348	127	116
		500	161	27	45	46	41	249	75	134	67	59
		1,000	105	11	53	11	7	177	36	73	18	15
		5,000	34	9	14	8	7	40	20	19	13	11
	100	200	90	42	48	136	32	558	189	246	142	96
		500	57	24	27	20	17	176	69	75	41	33
		1,000	57	17	51	29	16	72	36	63	46	37
		5,000	22	10	15	11	8	26	21	27	15	14
	120	200	80	27	34	89	81	281	114	112	138	127
		500	101	25	50	42	22	263	75	86	64	50
		1,000	15	9	15	30	25	22	18	25	50	38
		5,000	12	6	15	10	7	21	16	25	16	12

NDA No data available.
(1/) Indicator failure.

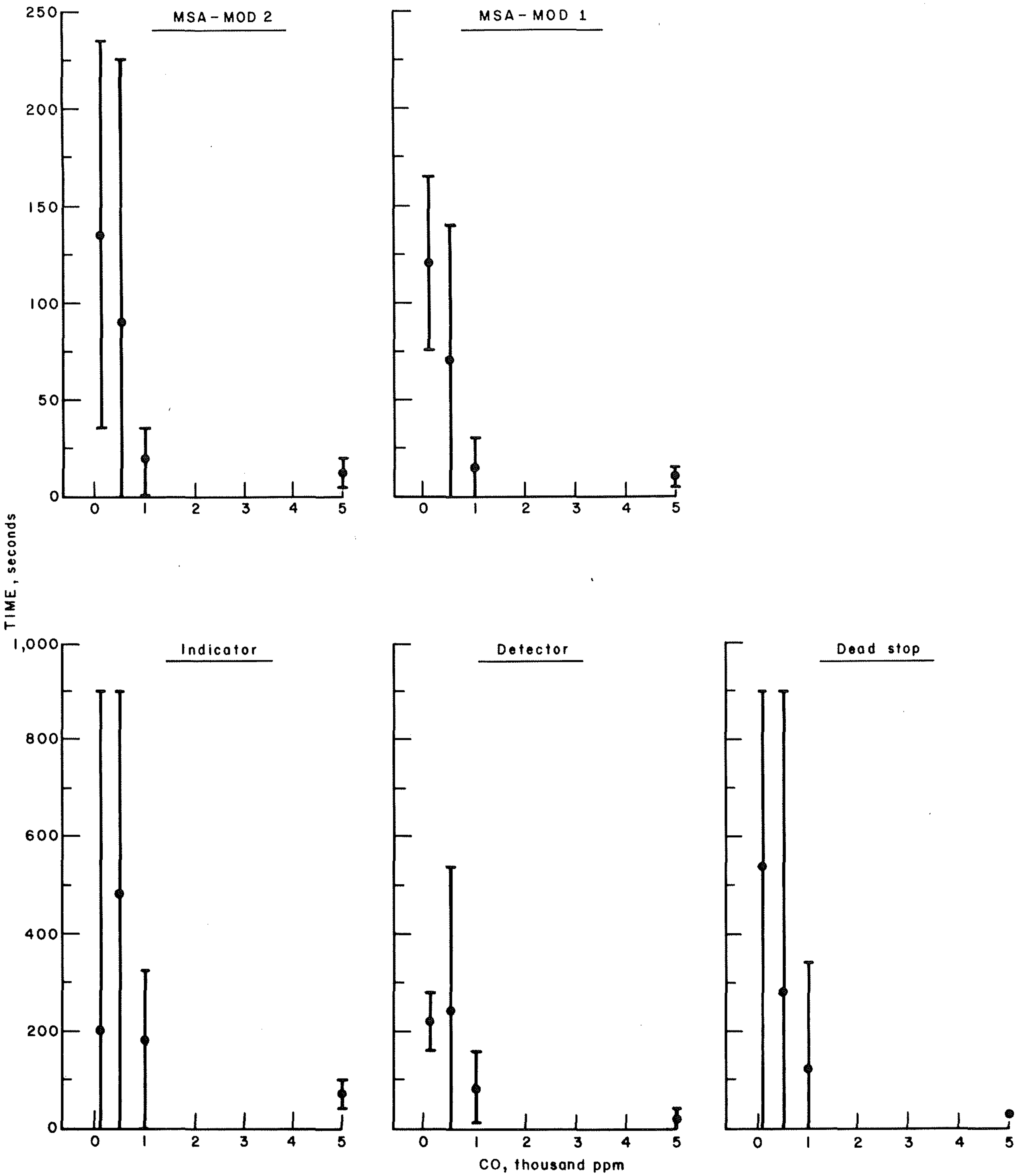

FIGURE 5. - Effect of CO concentration on time for definite color change ±95 percent confidence limits (50° F, 75 percent RH).

Interference Gas Effects

The gases tested for possible interference with color change were CO_2, NO_2, SO_2, and H_2S. The results of these tests are shown in appendix C. In tests with CO_2, detectors 1, 2, and 3 indicated an increase in sensitivity to CO as compared with tests with no interference gases. Detectors 4 and 5 were not affected by CO_2. The time for color change in dosimeters 1, 2, and 3 was about half that measured with no interferant gases, but again this increase in sensitivity was possibly due to observer experience that tended to reduce the time between the two "points" being measured.

Tests for interference by NO_2 on time for color change due to CO showed essentially the same result as tests for CO_2 interference. Dosimeters 1, 2, and 3 had about twice as much sensitivity to CO as that measured without interference gas.

The tests to determine the effect of SO_2 on detection time showed that although dosimeters 1, 2, and 3 again had about twice the sensitivity compared to tests with no interferant gases, dosimeter 4 showed no significant change, but dosimeter 5 showed a loss in sensitivity to CO by a factor of approximately 1.4.

Tests to determine the effect of H_2S on dosimeter time for color change had somewhat the same result as tests with SO_2. Dosimeters 1 and 3 showed more sensitivity than that observed with SO_2 tests. These dosimeters had sensitivity gain factors of about 4 and 3, respectively, compared with tests without interference gases.

The failure rate of each dosimeter during interference tests with CO_2, SO_2, and H_2S was zero. Of the dosimeters tested, 23 percent of number 1 failed during the NO_2 interference tests, as did 3 percent of number 2 dosimeters. All failures noted occurred at 200 ppm CO.

Tests also were conducted to determine effects of combinations of CO_2, NO_2, SO_2, and H_2S on dosimeter sensitivity to CO. A study of the data (appendix D) for NO_2, SO_2, and CO_2 combination interference effects showed that the combinations tested had no significant effect (0.05 significance level) on dosimeter time for color change for dosimeters 1, 2, 3, and 4. Dosimeter 5 showed a significant difference between NO_2, SO_2, CO_2 at 10 ppm, 5 ppm, 2 percent, respectively, and tests with no interference gases, although all number 5 dosimeters showed definite color change in less than 2 minutes (200-ppm CO level). The NO_2, CO_2, H_2S interference effects tests showed only dosimeter 1 with any significant time change at CO_2, NO_2, H_2S concentrations of 1 percent, 5 ppm, 2 ppm, respectively. Generally, all combinations of contaminant gases produced average observed times for color changes slightly less than those times measured without contaminant gases.

Another series of tests on effects for contaminants was performed on dosimeters after 6 months of storage. These indicators were stored at 75° F and 50 percent RH for 6 months, and the series of interference tests was performed again (see appendix E). No significant effects on CO response time with CO_2 as an interferant were observed at the "definite change" point. Indicators 4 and 5 did show a significant decrease in time for color change, but the time measured was less than 1.5 minutes on both series of tests for "first change" and less than 2 minutes on "definite change."

No significant effects were observed with either NO_2 or SO_2 after storage, but H_2S produced a significant decrease in the time interval before the "definite change" point with indicators 1, 2, and 3.

No indicator failures were observed during H_2S and SO_2 interferant tests after storage. Indicator 1 had an observed failure rate of 15 percent with CO_2 as an interferant after storage and 25 percent with NO_2 as an interferant after storage. Dosimeters 2 and 3 had failure rates of 25 percent with NO_2 only as an interferant after storage. All indicator failures were observed at 200-ppm CO levels.

Tests were conducted on the indicators to determine effects of coal dust on the indicators, observing indicator color change by miners' light, and observation of indicator color change by a color-blind observer. Results of these tests are shown in appendix F.

A light coating of coal dust had no significant effect on observations of color change time.

Tests for effects of lighting conditions were hampered by multiple reflections of the miners' light in the chamber window. Detectors 1, 3, 4, and 5 showed no significant change in time for color change at the "first perceptible change" point. Dosimeter 2 showed a decreased sensitivity to CO. At the "definite change" point, dosimeters 2, 3, and 4 showed no significant difference from earlier tests. Dosimeter 1 increased and dosimeter 5 decreased in sensitivity.

Tests to determine the efficiency of a colorblind observer were conducted. No significant differences because of color blindness were noted.

CONCLUSIONS

1. From a study of the individual measurements made by each observer on each dosimeter, it is apparent that observer variance is the most significant deviation noted.

2. The devices tested were essentially qualitative in nature.

3. Temperature effects are not significant.

4. Humidity causes no significant sensitivity changes.

5. The gases tested for interference have little or no effect upon the time required for color changes; NO_2 caused an increase in failure rate.

6. CO concentrations of 1,000 ppm or higher are required to obtain a definite "color change" within a short period of time (3 to 4 minutes).

ACKNOWLEDGMENTS

The authors wish to express their appreciation to Marilyn Goff, Patsy Sears, and Carol Parsons of the Bartlesville Energy Research Center for their cooperation and help as observers in this research study.

REFERENCES

1. Carroll, H. B., Jr., and F. E. Armstrong. Accuracy and Precision of Several Portable Gas Detectors. BuMines RI 7811, 1973, 42 pp.

2. Carroll, H. B., Jr., R. M. Ray, and F. E. Armstrong. Controlled-Atmosphere System for Testing Gas Monitors. BuMines RI 7859, 1973, 10 pp.

3. Ferber, B. I., and A. H. Wieser. Instruments for Detecting Gas in Underground Mines and Tunnels. BuMines IC 8548, 1972, 16 pp.

4. Morgenstern, A. S., R. M. Ash, and J. R. Lynch. The Evaluation of Gas Detector Tube Systems: 1. Carbon Monoxide. Am. Ind. Hygiene Assoc. J., v. 31, No. 5, September-October 1970, pp. 630-632.

5. Murphy, E. J. Comparison of Methods for Detecting and Analyzing Fumes From Explosives. BuMines RI 5883, 1961, 13 pp.

6. U.S. Congress. Federal Coal Mine Health and Safety Act of 1969. Public Law 91-173, Dec. 30, 1969, 83 Stat. 790.

Appendix A

Table A-1. - Test results for CO concentration, temperature, and humidity effects on time for color change

Relative humidity, percent	Temperature, °F	CO concentration, ppm	Time average of three observers with five dosimeters ± 95 percent confidence limit									
			First perceptible change, seconds					Definite change, seconds				
			Dosimeter number[1/]					Dosimeter number[1/]				
			1	2	3	4	5	1	2	3	4	5
75	35	200	84 ± 21	31 ± 14	18 ± 3	82 ± 16	67 ± 14	368 ± 209	110 ± 22	84 ± 9	125 ± 17	132 ± 14
		500	25 ± 8	12 ± 1	35 ± 9	29 ± 11	20 ± 9	111 ± 54	48 ± 15	73 ± 26	52 ± 8	46 ± 6
		1,000	57 ± 13	22 ± 4	38 ± 5	16 ± 4	11 ± 2	128 ± 32	54 ± 10	78 ± 5	30 ± 3	24 ± 3
		5,000	50 ± 31	9 ± 1	9 ± 2	6 ± 1	5 ± 1	119 ± 12	16 ± 1	15 ± 1	9 ± 0	9 ± 1
	50	200	309 ± 123	39 ± 11	147 ± 75	76 ± 17	57 ± 6	328 ± 4	220 ± 52	568 ± 178	136 ± 20	118 ± 10
		500	412 ± 121	59 ± 30	75 ± 79	58 ± 18	29 ± 4	460 ± 148	303 ± 49	245 ± 229	90 ± 26	66 ± 14
		1,000	51 ± 20	17 ± 4	22 ± 19	12 ± 2	7 ± 1	169 ± 35	80 ± 19	131 ± 105	20 ± 4	14 ± 3
		5,000	27 ± 10	6 ± 1	13 ± 1	9 ± 0	6 ± 0	67 ± 10	13 ± 3	24 ± 0	14 ± 1	10 ± 1
	75	200	68 ± 35	32 ± 5	59 ± 16	92 ± 16	65 ± 13	277 ± 60	154 ± 40	304 ± 76	144 ± 11	121 ± 13
		500	90 ± 36	74 ± 38	62 ± 45	33 ± 5	28 ± 5	184 ± 42	152 ± 49	176 ± 41	51 ± 6	50 ± 2
		1,000	113 ± 21	48 ± 5	63 ± 14	19 ± 4	16 ± 2	196 ± 18	113 ± 20	155 ± 25	36 ± 4	33 ± 2
		5,000	27 ± 7	26 ± 10	22 ± 10	8 ± 1	5 ± 1	48 ± 6	38 ± 10	41 ± 9	13 ± 1	9 ± 1
	100	200	140 ± 33	31 ± 12	35 ± 6	90 ± 17	64 ± 12	531 ± 176	301 ± 151	249 ± 101	144 ± 15	113 ± 13
		500	13 ± 3	17 ± 5	11 ± 2	18 ± 6	16 ± 5	52 ± 20	45 ± 10	69 ± 28	43 ± 5	37 ± 4
		1,000	19 ± 2	14 ± 2	11 ± 1	24 ± 2	19 ± 4	32 ± 2	29 ± 3	35 ± 4	38 ± 2	32 ± 2
		5,000	11 ± 1	8 ± 1	14 ± 1	8 ± 0	5 ± 1	24 ± 1	21 ± 1	26 ± 3	12 ± 1	10 ± 1
	120	200	164 ± 70	27 ± 5	52 ± 27	57 ± 12	32 ± 6	264 ± 60	179 ± 85	134 ± 26	116 ± 18	79 ± 4
		500	30 ± 8	23 ± 5	21 ± 4	25 ± 3	21 ± 3	54 ± 10	51 ± 10	52 ± 2	56 ± 9	43 ± 7
		1,000	21 ± 4	9 ± 1	22 ± 5	30 ± 3	20 ± 1	37 ± 6	38 ± 7	41 ± 2	45 ± 2	37 ± 1
		5,000	11 ± 1	8 ± 1	13 ± 1	9 ± 1	6 ± 0	17 ± 1	16 ± 1	19 ± 2	13 ± 1	10 ± 1
95	35	200	189 ± 104	196 ± 58	87 ± 46	73 ± 15	81 ± 11	590 ± 122	469 ± 201	297 ± 8	126 ± 10	127 ± 8
		500	338 ± 232	105 ± 58	107 ± 87	43 ± 9	28 ± 5	591 ± 98	163 ± 46	229 ± 97	59 ± 4	50 ± 5
		1,000	219 ± 68	54 ± 14	47 ± 24	12 ± 2	8 ± 3	319 ± 22	94 ± 22	90 ± 16	24 ± 1	22 ± 2
		5,000	43 ± 36	17 ± 6	15 ± 3	8 ± 1	6 ± 1	73 ± 37	22 ± 5	23 ± 5	11 ± 0	9 ± 1
	50	200	168 ± 58	22 ± 7	22 ± 2	33 ± 6	34 ± 5	643 ± 122	84 ± 26	116 ± 32	71 ± 14	81 ± 11
		500	91 ± 45	31 ± 13	23 ± 6	16 ± 3	16 ± 2	341 ± 119	64 ± 12	82 ± 10	38 ± 7	38 ± 4
		1,000	94 ± 37	23 ± 9	32 ± 7	20 ± 2	19 ± 2	242 ± 53	52 ± 14	78 ± 24	31 ± 2	30 ± 3
		5,000	55 ± 14	15 ± 2	14 ± 2	6 ± 1	5 ± 1	93 ± 5	24 ± 3	29 ± 2	9 ± 1	9 ± 1
	75	200	195 ± 50	45 ± 10	32 ± 5	48 ± 11	53 ± 7	372 ± 34	167 ± 66	185 ± 74	102 ± 10	96 ± 7
		500	76 ± 17	18 ± 4	23 ± 6	37 ± 3	35 ± 3	135 ± 29	51 ± 11	89 ± 19	52 ± 5	53 ± 2
		1,000	36 ± 12	7 ± 1	19 ± 6	9 ± 1	5 ± 1	87 ± 21	30 ± 3	54 ± 4	16 ± 1	13 ± 0
		5,000	27 ± 4	6 ± 1	11 ± 1	7 ± 1	5 ± 1	34 ± 2	16 ± 1	17 ± 1	11 ± 1	9 ± 1
	100	200	57 ± 13	14 ± 5	30 ± 5	35 ± 18	20 ± 4	183 ± 72	91 ± 37	134 ± 38	84 ± 22	68 ± 12
		500	39 ± 6	15 ± 3	21 ± 2	17 ± 2	9 ± 2	91 ± 25	42 ± 10	49 ± 4	32 ± 3	31 ± 1
		1,000	34 ± 7	12 ± 2	18 ± 5	22 ± 3	11 ± 2	56 ± 6	29 ± 4	52 ± 6	38 ± 2	30 ± 2
		5,000	17 ± 1	8 ± 1	13 ± 1	9 ± 0	6 ± 1	25 ± 1	16 ± 2	22 ± 2	14 ± 1	12 ± 0
	120	200	50 ± 9	15 ± 3	26 ± 3	74 ± 8	58 ± 9	162 ± 32	59 ± 22	85 ± 11	124 ± 5	106 ± 7
		500	49 ± 13	14 ± 2	25 ± 5	26 ± 4	14 ± 3	115 ± 31	53 ± 11	66 ± 12	50 ± 5	37 ± 5
		1,000	11 ± 1	7 ± 1	12 ± 1	25 ± 2	17 ± 2	19 ± 1	15 ± 1	22 ± 1	42 ± 3	34 ± 1
		5,000	11 ± 1	5 ± 0	11 ± 2	8 ± 1	5 ± 0	16 ± 2	12 ± 2	18 ± 1	13 ± 1	11 ± 0

1/ Dosimeter number refers to different manufacturer's dosimeters.

Appendix B

Table B-1. - Time measurements on dosimeter color change — effects of storage tests

Relative humidity, percent	Temperature, °F	CO concentration, ppm	Time average of three observers and five dosimeters ± 95 percent confidence limit									
			First perceptible change, seconds					Definite change, seconds				
			Dosimeter number 1/					Dosimeter number 1/				
			1	2	3	4	5	1	2	3	4	5
75	35	200	652 ± 37	618 ± 19	534 ± 60	92 ± 13	109 ± 5	800 ± 22	-	855 ± 33	140 ± 13	150 ± 15
		500	281 ± 83	193 ± 10	139 ± 16	34 ± 3	44 ± 3	543 ± 45	277 ± 2	248 ± 17	57 ± 1	63 ± 5
		1,000	331 ± 118	189 ± 8	112 ± 18	22 ± 3	28 ± 2	627 ± 88	248 ± 21	205 ± 19	37 ± 2	43 ± 2
		5,000	85 ± 15	46 ± 2	35 ± 3	8 ± 1	10 ± 0	130 ± 12	57 ± 1	51 ± 2	13 ± 1	14 ± 1
	50	200	135 ± 14	99 ± 5	187 ± 26	95 ± 7	104 ± 11	211 ± 30	145 ± 10	401 ± 110	130 ± 10	141 ± 11
		500	91 ± 11	58 ± 1	65 ± 10	34 ± 9	56 ± 4	133 ± 18	74 ± 3	148 ± 29	66 ± 9	75 ± 4
		1,000	80 ± 7	50 ± 3	58 ± 7	17 ± 1	19 ± 2	107 ± 8	64 ± 1	78 ± 8	27 ± 3	27 ± 3
		5,000	52 ± 21	32 ± 1	32 ± 3	7 ± 0	10 ± 0	111 ± 24	43 ± 2	44 ± 3	13 ± 1	14 ± 1
	75	200	88 ± 7	87 ± 5	194 ± 47	87 ± 11	119 ± 14	123 ± 7	121 ± 7	345 ± 42	131 ± 11	166 ± 15
		500	44 ± 2	47 ± 3	51 ± 3	36 ± 6	50 ± 5	54 ± 3	58 ± 3	83 ± 3	147 ± 21	206 ± 16
		1,000	35 ± 2	115 ± 32	41 ± 4	18 ± 2	26 ± 2	49 ± 3	220 ± 17	61 ± 5	34 ± 3	39 ± 2
		5,000	21 ± 4	36 ± 2	19 ± 1	9 ± 0	11 ± 0	32 ± 3	43 ± 2	25 ± 1	14 ± 1	14 ± 1
	100	200	46 ± 3	482 ± 37	315 ± 63	90 ± 12	122 ± 10	95 ± 9	719 ± -	560 ± -	145 ± 8	157 ± 4
		500	27 ± 2	254 ± 24	64 ± 9	41 ± 4	55 ± 4	37 ± 2	335 ± 23	122 ± 18	62 ± 4	76 ± 2
		1,000	18 ± 1	162 ± 26	29 ± 2	27 ± 3	35 ± 2	25 ± 3	209 ± 29	79 ± 16	43 ± 3	47 ± 3
		5,000	12 ± 1	45 ± 10	17 ± 2	8 ± 1	9 ± 1	16 ± 1	72 ± 7	22 ± 2	12 ± 1	14 ± 1
	120	200	59 ± 11	388 ± 59	156 ± 32	67 ± 11	109 ± 12	107 ± 16	672 ± 57	437 ± 95	118 ± 12	147 ± 10
		500	25 ± 2	220 ± 26	80 ± 22	32 ± 4	46 ± 4	36 ± 4	341 ± 25	213 ± 28	54 ± 7	72 ± 5
		1,000	14 ± 2	68 ± 7	22 ± 2	17 ± 3	33 ± 4	23 ± 4	167 ± 12	50 ± 11	32 ± 2	47 ± 5
		5,000	8 ± 1	59 ± 14	14 ± 2	7 ± 0	11 ± 1	11 ± 1	88 ± 6	21 ± 5	13 ± 1	14 ± 1
95	35	200	494 ± 109	435 ± 28	299 ± 58	41 ± 5	55 ± 3	-	-	-	89 ± 6	96 ± 7
		500	165 ± 41	185 ± 8	158 ± 11	33 ± 4	44 ± 2	435 ± 108	322 ± 17	233 ± 15	50 ± 5	59 ± 4
		1,000	212 ± 46	103 ± 3	62 ± 6	22 ± 3	29 ± 2	343 ± 43	128 ± 3	103 ± 14	38 ± 2	41 ± 2
		5,000	94 ± 9	38 ± 1	23 ± 1	8 ± 1	11 ± 1	119 ± 6	45 ± 1	32 ± 1	12 ± 1	14 ± 1
	50	200	119 ± 29	129 ± 5	235 ± 38	93 ± 8	129 ± 8	143 ± 38	156 ± 4	537 ± 37	161 ± 11	168 ± 5
		500	86 ± 12	55 ± 2	83 ± 12	35 ± 5	43 ± 3	122 ± 15	75 ± 1	123 ± 21	57 ± 5	61 ± 3
		1,000	59 ± 7	40 ± 1	49 ± 4	17 ± 1	28 ± 2	77 ± 7	48 ± 2	64 ± 8	34 ± 2	41 ± 2
		5,000	42 ± 7	29 ± 3	30 ± 6	9 ± 1	10 ± 1	56 ± 5	37 ± 0	42 ± 3	13 ± 1	15 ± 1
	75	200	70 ± 4	417 ± 14	125 ± 39	94 ± 14	123 ± 12	98 ± 9	839 ± 26	415 ± 108	151 ± 11	159 ± 10
		500	37 ± 4	151 ± 15	41 ± 2	40 ± 4	49 ± 3	53 ± 5	235 ± 15	69 ± 12	65 ± 8	65 ± 5
		1,000	35 ± 8	113 ± 8	32 ± 3	32 ± 4	24 ± 5	47 ± 7	150 ± 8	53 ± 9	46 ± 4	40 ± 4
		5,000	20 ± 3	31 ± 3	20 ± 2	9 ± 0	11 ± 1	30 ± 4	30 ± 3	42 ± 5	14 ± 1	16 ± 1
	100	200	70 ± 7	402 ± 92	204 ± 33	71 ± 9	125 ± 9	343 ± 39	230 ± 150	112 ± 19	117 ± 13	171 ± 9
		500	17 ± 2	162 ± 19	43 ± 8	41 ± 1	47 ± 4	28 ± 4	260 ± 15	89 ± 13	59 ± 5	66 ± 6
		1,000	17 ± 2	105 ± 3	27 ± 1	25 ± 4	29 ± 3	26 ± 2	141 ± 6	46 ± 3	40 ± 4	47 ± 5
		5,000	9 ± 0	38 ± 3	13 ± 1	8 ± 0	10 ± 1	12 ± 1	49 ± 3	17 ± 2	13 ± 0	15 ± 0
	120	200	210 ± 38	271 ± 77	221 ± 28	73 ± 8	91 ± 3	396 ± 26	427 ± 96	475 ± 41	118 ± 9	134 ± 6
		500	20 ± 4	135 ± 19	52 ± 13	25 ± 2	43 ± 2	39 ± 4	285 ± 34	133 ± 25	47 ± 5	61 ± 2
		1,000	12 ± 2	108 ± 5	41 ± 11	14 ± 1	25 ± 1	20 ± 2	140 ± 4	92 ± 6	28 ± 2	34 ± 1
		5,000	9 ± 0	33 ± 5	12 ± 1	7 ± 1	9 ± 1	11 ± 0	44 ± 1	16 ± 2	11 ± 1	13 ± 1

1/ Dosimeter number refers to different manufacturer's dosimeters.

Appendix C

Table C-1. - Test results for interference gas effects on dosimeter sensitivity to CO.

Interferent gas	Relative humidity, percent	Temperature, °F	CO concentration, ppm	Time average of three observers with five dosimeters ± 95 percent confidence limit									
				First perceptible change, seconds					Definite change, seconds				
				Dosimeter number 1/					Dosimeter number 1/				
				1	2	3	4	5	1	2	3	4	5
CO_2	75	50	200	201 ± 48	73 ± 10	103 ± 34	70 ± 14	100 ± 11	261 ± 33	103 ± 5	146 ± 33	122 ± 18	164 ± 18
			500	119 ± 34	26 ± 3	35 ± 7	29 ± 7	23 ± 3	189 ± 26	39 ± 2	52 ± 5	46 ± 4	42 ± 4
			1,000	94 ± 28	30 ± 7	30 ± 5	9 ± 1	14 ± 2	137 ± 14	40 ± 3	43 ± 0	21 ± 4	22 ± 2
			5,000	60 ± 18	21 ± 3	31 ± 8	8 ± 0	7 ± 1	75 ± 18	27 ± 1	37 ± 7	14 ± 1	11 ± 0
		75	200	57 ± 16	25 ± 3	27 ± 4	86 ± 13	96 ± 15	92 ± 13	39 ± 2	63 ± 11	141 ± 22	136 ± 18
			500	42 ± 8	21 ± 5	19 ± 5	28 ± 7	28 ± 6	55 ± 5	31 ± 4	41 ± 6	52 ± 5	49 ± 3
			1,000	-	-	-	14 ± 1	14 ± 3	-	-	-	26 ± 2	26 ± 2
			5,000	22 ± 4	12 ± 1	16 ± 1	10 ± 1	9 ± 1	30 ± 4	15 ± 2	19 ± 1	14 ± 1	13 ± 1
	95	50	200	157 ± 26	83 ± 14	135 ± 24	69 ± 7	87 ± 7	209 ± 19	122 ± 7	189 ± 28	112 ± 5	122 ± 7
			500	91 ± 30	38 ± 8	51 ± 10	39 ± 1	44 ± 5	138 ± 21	57 ± 5	76 ± 11	57 ± 2	63 ± 3
			1,000	60 ± 18	39 ± 4	56 ± 15	18 ± 1	23 ± 1	91 ± 12	51 ± 1	74 ± 14	27 ± 2	31 ± 2
			5,000	59 ± 34	15 ± 1	32 ± 10	9 ± 1	10 ± 1	106 ± 31	42 ± 4	47 ± 9	13 ± 0	16 ± 1
		75	200	126 ± 37	42 ± 6	79 ± 31	94 ± 24	108 ± 29	190 ± 34	70 ± 6	122 ± 28	147 ± 19	160 ± 16
			500	42 ± 1	24 ± 5	39 ± 8	41 ± 7	39 ± 8	55 ± 2	43 ± 4	55 ± 5	67 ± 3	68 ± 2
			1,000	22 ± 4	11 ± 1	17 ± 3	18 ± 1	13 ± 3	31 ± 3	16 ± 1	25 ± 4	32 ± 2	27 ± 3
			5,000	23 ± 3	13 ± 2	15 ± 2	9 ± 1	9 ± 1	28 ± 4	17 ± 1	18 ± 2	13 ± 0	12 ± 1
NO_2	75	50	200	376 ± 15	302 ± 62	286 ± 32	72 ± 9	94 ± 9	789 ± -	511 ± 66	460 ± 51	120 ± 7	127 ± 5
			500	110 ± 31	74 ± 24	71 ± 20	36 ± 3	42 ± 5	148 ± 27	114 ± 6	119 ± 13	49 ± 2	62 ± 5
			1,000	68 ± 16	34 ± 10	53 ± 14	14 ± 1	19 ± 2	99 ± 18	59 ± 3	82 ± 12	24 ± 2	27 ± 1
			5,000	66 ± 13	39 ± 3	44 ± 9	8 ± 1	7 ± 1	100 ± 24	46 ± 3	52 ± 6	13 ± 1	12 ± 2
		75	200	213 ± 48	153 ± 42	213 ± 25	72 ± 7	96 ± 14	453 ± 139	269 ± 31	311 ± 34	135 ± 6	153 ± 6
			500	67 ± 9	72 ± 13	65 ± 20	42 ± 3	41 ± 8	86 ± 7	97 ± 8	104 ± 13	61 ± 5	60 ± 10
			1,000	36 ± 2	33 ± 6	37 ± 6	13 ± 1	16 ± 0	46 ± 3	43 ± 3	53 ± 5	22 ± 2	23 ± 1
			5,000	17 ± 4	24 ± 2	14 ± 2	9 ± 1	10 ± 1	25 ± 4	27 ± 3	29 ± 3	14 ± 1	14 ± 1
	95	50	200	189 ± 78	176 ± 66	230 ± 108	84 ± 15	107 ± 21	488 ± 174	485 ± 108	420 ± 112	133 ± 12	155 ± 18
			500	124 ± 27	74 ± 9	117 ± 38	39 ± 6	38 ± 4	175 ± 30	100 ± 6	154 ± 29	65 ± 3	57 ± 3
			1,000	59 ± 16	44 ± 16	71 ± 12	22 ± 4	20 ± 3	82 ± 10	66 ± 4	83 ± 7	35 ± 2	31 ± 2
			5,000	25 ± 5	20 ± 1	16 ± 3	9 ± 1	10 ± 1	34 ± 5	32 ± 2	30 ± 2	14 ± 1	14 ± 1
		75	200	246 ± 92	145 ± 28	176 ± 20	91 ± 7	109 ± 14	-	285 ± 48	265 ± 4	150 ± 16	161 ± 11
			500	68 ± 7	45 ± 4	51 ± 8	29 ± 4	41 ± 6	86 ± 8	58 ± 3	73 ± 8	49 ± 5	60 ± 4
			1,000	30 ± 1	23 ± 1	27 ± 2	15 ± 1	21 ± 3	38 ± 2	28 ± 2	36 ± 3	25 ± 1	30 ± 2
			5,000	15 ± 3	15 ± 1	19 ± 2	8 ± 1	9 ± 1	22 ± 2	22 ± 2	25 ± 2	13 ± 1	13 ± 1

See footnote at end of table.

Table C-1. - Test results for interference gas effects on dosimeter sensitivity to CO--Continued

Interferent gas	Relative humidity, percent	Temperature, °F	CO concentration, ppm	Time average of three observers with five dosimeters ± 95 percent confidence limit									
				First perceptible change, seconds					Definite change, seconds				
				Dosimeter number 1/					Dosimeter number 1/				
				1	2	3	4	5	1	2	3	4	5
SO_2	75	50	200	166 ± 25	87 ± 5	86 ± 14	94 ± 12	78 ± 17	296 ± 54	130 ± 2	136 ± 3	149 ± 12	140 ± 14
			500	98 ± 26	47 ± 7	42 ± 9	33 ± 4	46 ± 5	168 ± 23	65 ± 5	69 ± 4	58 ± 2	65 ± 2
			1,000	78 ± 21	36 ± 7	29 ± 6	17 ± 1	21 ± 2	138 ± 14	52 ± 3	54 ± 2	30 ± 1	32 ± 1
			5,000	66 ± 12	26 ± 2	19 ± 8	9 ± 0	8 ± 1	95 ± 9	33 ± 2	33 ± 2	13 ± 1	12 ± 1
		75	200	120 ± 15	96 ± 7	86 ± 3	76 ± 13	104 ± 13	170 ± 20	136 ± 9	137 ± 9	141 ± 8	153 ± 8
			500	52 ± 4	35 ± 4	46 ± 5	29 ± 4	40 ± 5	67 ± 3	47 ± 4	60 ± 3	61 ± 4	72 ± 5
			1,000	35 ± 2	23 ± 1	26 ± 2	20 ± 2	22 ± 1	43 ± 1	27 ± 1	34 ± 2	31 ± 2	36 ± 4
			5,000	18 ± 3	11 ± 1	12 ± 1	8 ± 1	9 ± 1	30 ± 3	17 ± 1	19 ± 1	13 ± 1	12 ± 1
	95	50	200	193 ± 22	89 ± 4	98 ± 4	55 ± 5	79 ± 10	312 ± 30	121 ± 1	127 ± 7	115 ± 9	131 ± 11
			500	104 ± 14	48 ± 5	53 ± 5	31 ± 5	44 ± 3	137 ± 7	61 ± 3	65 ± 6	57 ± 1	62 ± 1
			1,000	75 ± 16	32 ± 4	21 ± 5	15 ± 1	23 ± 2	112 ± 16	42 ± 1	39 ± 3	27 ± 2	31 ± 2
			5,000	60 ± 10	24 ± 1	19 ± 2	8 ± 1	10 ± 1	77 ± 9	29 ± 1	28 ± 2	12 ± 0	14 ± 0
		75	200	83 ± 8	69 ± 5	75 ± 2	59 ± 12	87 ± 16	111 ± 7	96 ± 3	104 ± 3	115 ± 11	141 ± 11
			500	49 ± 5	24 ± 4	30 ± 3	36 ± 4	44 ± 6	58 ± 5	35 ± 3	40 ± 4	64 ± 3	66 ± 4
			1,000	28 ± 5	21 ± 1	28 ± 4	18 ± 2	26 ± 2	37 ± 4	27 ± 2	35 ± 3	32 ± 1	35 ± 1
			5,000	18 ± 1	10 ± 1	11 ± 1	9 ± 1	9 ± 0	21 ± 2	13 ± 1	14 ± 1	14 ± 1	12 ± 0
H_2S	75	50	200	41 ± 6	50 ± 4	51 ± 5	72 ± 9	88 ± 6	66 ± 8	69 ± 7	74 ± 9	108 ± 11	133 ± 10
			500	27 ± 3	40 ± 3	39 ± 5	39 ± 3	52 ± 4	48 ± 5	50 ± 2	49 ± 4	61 ± 5	70 ± 4
			1,000	29 ± 3	25 ± 1	22 ± 1	19 ± 2	28 ± 1	42 ± 3	33 ± 1	32 ± 2	31 ± 3	36 ± 2
			5,000	26 ± 4	25 ± 2	19 ± 3	8 ± 1	10 ± 1	34 ± 4	34 ± 3	30 ± 3	12 ± 1	13 ± 1
		75	200	42 ± 5	57 ± 2	56 ± 7	89 ± 6	114 ± 6	66 ± 8	81 ± 7	77 ± 10	122 ± 8	141 ± 2
			500	29 ± 4	32 ± 12	37 ± 5	31 ± 3	50 ± 4	51 ± 5	50 ± 14	55 ± 6	55 ± 4	69 ± 2
			1,000	23 ± 3	20 ± 2	22 ± 1	18 ± 3	21 ± 2	35 ± 2	42 ± 16	32 ± 2	28 ± 2	29 ± 1
			5,000	13 ± 2	13 ± 0	12 ± 2	9 ± 0	7 ± 0	19 ± 2	20 ± 2	17 ± 2	12 ± 0	11 ± 1
	95	50	200	39 ± 1	40 ± 2	34 ± 2	72 ± 8	90 ± 13	58 ± 5	56 ± 2	50 ± 2	111 ± 11	128 ± 12
			500	50 ± 14	42 ± 4	27 ± 2	25 ± 8	31 ± 8	63 ± 13	55 ± 4	54 ± 9	58 ± 7	60 ± 5
			1,000	36 ± 4	28 ± 3	17 ± 2	16 ± 2	24 ± 2	45 ± 3	39 ± 3	36 ± 1	28 ± 1	31 ± 1
			5,000	20 ± 1	17 ± 2	13 ± 2	6 ± 1	9 ± 0	26 ± 2	25 ± 2	22 ± 1	11 ± 0	12 ± 0
		75	200	51 ± 6	52 ± 9	43 ± 3	66 ± 6	103 ± 5	84 ± 8	87 ± 17	76 ± 4	115 ± 11	146 ± 9
			500	36 ± 3	27 ± 3	28 ± 2	34 ± 4	39 ± 2	44 ± 2	33 ± 3	41 ± 1	52 ± 4	55 ± 8
			1,000	21 ± 1	18 ± 3	15 ± 1	18 ± 2	18 ± 1	29 ± 4	28 ± 15	23 ± 1	25 ± 1	24 ± 1
			5,000	15 ± 1	14 ± 3	11 ± 1	6 ± 0	8 ± 0	20 ± 3	22 ± 2	18 ± 2	11 ± 1	10 ± 1

1/ Dosimeter number refers to different manufacturer's dosimeters.

Appendix D

Table D-1. - Test results of combinations of interference gases on sensitivity of dosimeters to CO

Relative humidity, percent	Temperature, °F	Combination number 1/	CO concentration, ppm	Time average of three observers with five dosimeters ± 95 percent confidence limit									
				First perceptible change, seconds					Definite change, seconds				
				Dosimeter number 2/					Dosimeter number 2/				
				1	2	3	4	5	1	2	3	4	5
75	50	1	200	283 ± 45	73 ± 5	107 ± 6	77 ± 4	89 ± 4	479 ± 64	99 ± 1	137 ± 7	123 ± 6	127 ± 8
			500	102 ± 17	48 ± 4	56 ± 3	32 ± 5	38 ± 4	164 ± 29	65 ± 1	79 ± 2	63 ± 6	60 ± 2
			1,000	51 ± 11	28 ± 2	26 ± 3	19 ± 2	22 ± 1	96 ± 12	43 ± 1	39 ± 2	28 ± 1	31 ± 1
			5,000	40 ± 7	18 ± 0	22 ± 1	7 ± 1	8 ± 1	52 ± 7	26 ± 7	26 ± 1	10 ± 1	12 ± 1
95	75	2	200	138 ± 13	107 ± 7	121 ± 4	75 ± 5	72 ± 4	359 ± 107	201 ± 19	233 ± 28	107 ± 10	103 ± 5
			500	44 ± 7	30 ± 2	40 ± 4	32 ± 2	44 ± 4	58 ± 5	41 ± 1	56 ± 3	57 ± 5	66 ± 6
			1,000	25 ± 1	15 ± 0	21 ± 1	16 ± 2	19 ± 1	34 ± 2	23 ± 2	29 ± 1	27 ± 2	27 ± 1
			5,000	18 ± 3	6 ± 1	9 ± 0	6 ± 1	8 ± 0	28 ± 3	11 ± 0	13 ± 0	9 ± 0	11 ± 0
75	50	3	200	97 ± 9	96 ± 6	86 ± 6	79 ± 11	71 ± 13	124 ± 15	136 ± 10	117 ± 11	120 ± 8	107 ± 8
			500	59 ± 7	42 ± 1	53 ± 3	37 ± 3	47 ± 3	107 ± 19	55 ± 1	74 ± 3	59 ± 4	65 ± 3
			1,000	33 ± 2	31 ± 2	33 ± 2	17 ± 1	20 ± 1	49 ± 6	37 ± 2	42 ± 3	26 ± 2	29 ± 1
			5,000	14 ± 2	13 ± 1	11 ± 1	7 ± 1	7 ± 1	22 ± 2	19 ± 1	18 ± 2	10 ± 1	9 ± 1
95	75	4	200	54 ± 8	41 ± 2	51 ± 3	85 ± 13	106 ± 14	73 ± 8	62 ± 2	78 ± 7	136 ± 8	149 ± 15
			500	48 ± 10	26 ± 2	37 ± 6	28 ± 6	33 ± 8	70 ± 13	37 ± 4	56 ± 6	58 ± 9	56 ± 3
			1,000	28 ± 4	15 ± 0	21 ± 1	18 ± 4	25 ± 2	35 ± 3	20 ± 1	29 ± 2	30 ± 4	36 ± 2
			5,000	12 ± 1	14 ± 1	13 ± 2	7 ± 0	8 ± 0	17 ± 2	19 ± 1	16 ± 2	10 ± 1	11 ± 1

1/ Combination number refers to following sequence of interference tests:

Combination number	CO_2, percent	NO_2, ppm	SO_2, ppm	H_2S, ppm
1	0.5	2	1	-
2	2	10	5	-
3	1	5	-	2
4	1	5	-	10

2/ Dosimeter number refers to different manufacturer's dosimeters.

Appendix E

Table E-1. - Effect of storage with effects of contaminant gas on sensitivity of dosimeters to CO (50°F at 95 percent RH)

Interferent gas	Parts per million	CO concentration, ppm	Time average of three observers with five dosimeters ± 95 percent confidence limit									
			First perceptible change, seconds					Definite change, seconds				
			Dosimeter number 1/					Dosimeter number 1/				
			1	2	3	4	5	1	2	3	4	5
CO_2	20,000	200	420 ± 146	58 ± 3	84 ± 7	39 ± 2	45 ± 3	688 ± 91	107 ± 6	134 ± 11	54 ± 3	56 ± 1
		500	73 ± 30	34 ± 2	38 ± 4	26 ± 4	36 ± 2	218 ± 12	45 ± 2	61 ± 4	47 ± 4	51 ± 4
		1,000	68 ± 13	28 ± 2	30 ± 1	25 ± 1	25 ± 2	105 ± 18	34 ± 1	37 ± 1	32 ± 2	33 ± 1
		5,000	39 ± 7	17 ± 1	10 ± 1	7 ± 0	9 ± 0	51 ± 3	22 ± 0	13 ± 1	12 ± 1	12 ± 0
NO_2	10	200	NDA	NDA	NDA	78 ± 10	111 ± 8	NDA	NDA	NDA	132 ± 5	139 ± 5
		500	144 ± 45	46 ± 2	43 ± 2	21 ± 4	38 ± 6	319 ± 85	65 ± 5	77 ± 3	54 ± 4	65 ± 6
		1,000	36 ± 6	32 ± 2	29 ± 3	14 ± 2	24 ± 2	147 ± 13	48 ± 8	51 ± 6	28 ± 2	34 ± 2
		5,000	42 ± 8	15 ± 1	12 ± 2	7 ± 0	9 ± 0	54 ± 10	21 ± 2	19 ± 1	12 ± 1	12 ± 1
SO_2	5	200	215 ± 150	71 ± 5	92 ± 8	59 ± 9	91 ± 7	640 ± 71	114 ± 16	132 ± 10	99 ± 6	123 ± 5
		500	212 ± 108	43 ± 3	50 ± 4	36 ± 3	46 ± 1	411 ± 75	60 ± 7	71 ± 7	55 ± 3	70 ± 5
		1,000	88 ± 31	26 ± 1	29 ± 1	17 ± 3	25 ± 2	145 ± 22	34 ± 2	38 ± 1	31 ± 2	37 ± 1
		5,000	39 ± 7	14 ± 0	17 ± 0	8 ± 0	10 ± 0	48 ± 3	20 ± 1	22 ± 1	12 ± 1	14 ± 1
H_2S	10	200	51 ± 8	53 ± 1	86 ± 10	65 ± 10	95 ± 6	80 ± 9	71 ± 3	107 ± 9	105 ± 11	167 ± 19
		500	30 ± 6	27 ± 1	33 ± 6	27 ± 1	42 ± 7	47 ± 8	39 ± 1	52 ± 3	51 ± 5	62 ± 2
		1,000	34 ± 6	22 ± 1	28 ± 3	19 ± 3	24 ± 1	50 ± 4	32 ± 4	43 ± 1	28 ± 2	32 ± 3
		5,000	20 ± 3	10 ± 0	12 ± 1	7 ± 1	9 ± 1	29 ± 3	16 ± 1	16 ± 2	10 ± 1	11 ± 1

NDA No data available.

1/ Dosimeter number refers to different manufacturer's dosimeters.

Appendix F

Table F-1. - Effects of coal dust, lighting, and observer vision (color blindness) on dosimeter sensitivity to CO (all tests at 50°F and 95 percent RH)

Condition	CO concentration, ppm	Time average of three observers[1] with five dosimeters ± 95 percent confidence limit									
		First perceptible change, seconds					Definite change, seconds				
		Dosimeter number[2]					Dosimeter number[2]				
		1	2	3	4	5	1	2	3	4	5
Dosimeter lightly coated with coal dust	200	293 ± 72	81 ± 9	160 ± 11	113 ± 11	98 ± 8	571 ± 103	149 ± 10	280 ± 28	165 ± 22	151 ± 7
	500	106 ± 27	47 ± 1	52 ± 12	58 ± 6	46 ± 2	233 ± 19	54 ± 2	84 ± 17	83 ± 4	59 ± 2
	1,000	69 ± 15	32 ± 1	36 ± 3	31 ± 4	25 ± 3	126 ± 10	45 ± 1	47 ± 1	46 ± 1	41 ± 3
	5,000	30 ± 3	13 ± 1	17 ± 1	13 ± 1	12 ± 1	44 ± 2	19 ± 1	22 ± 1	16 ± 1	15 ± 2
Dosimeters observed by miners' light	200	333 ± 40	60 ± 2	90 ± 6	96 ± 16	61 ± 3	432 ± 16	84 ± 3	120 ± 9	149 ± 12	105 ± 14
	500	73 ± 7	52 ± 1	61 ± 1	42 ± 4	50 ± 4	91 ± 4	66 ± 5	71 ± 4	63 ± 3	66 ± 2
	1,000	87 ± 31	42 ± 1	36 ± 1	17 ± 1	22 ± 1	147 ± 29	46 ± 1	49 ± 1	26 ± 1	35 ± 3
	5,000	37 ± 6	18 ± 1	15 ± 1	11 ± 1	11 ± 1	48 ± 6	25 ± 1	23 ± 1	13 ± 1	15 ± 1
Color blind observer	200	152 ± 68	64 ± 1	80 ± 22	131 ± 19	167 ± 51	183 ± 37	78 ± 2	110 ± 13	184 ± 8	218 ± 17
	500	117 ± 1	51 ± 1	66 ± 3	43 ± 3	54 ± 3	166 ± 18	58 ± 1	82 ± 1	63 ± 2	69 ± 2
	1,000	81 ± 23	29 ± 2	36 ± 1	21 ± 3	30 ± 3	105 ± 18	40 ± 1	42 ± 1	43 ± 4	36 ± 2
	5,000	55 ± 15	9 ± 1	14 ± 1	11 ± 1	6 ± 1	77 ± 14	16 ± 0	19 ± 1	15 ± 0	17 ± 0

1/ Color blind observer tests had one observer.

2/ Dosimeter number refers to different manufacturer's dosimeters.

INT.-BU.OF MINES,PGH., PA. 20338

204,734
Evaluation of Small Color
Changing Carbon Monoxide
Dosimeters

Ray RM