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# Evaluation of a Nitric-Oxide-Compensated Carbon Monoxide Fire Sensor

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## ILLUSTRATIONS

## UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

| | | | |
|---|---|---|---|
| °C | degree Celsius | $m^2$ | square meter |
| h | hour | min | minute |
| hp | horsepower | m/s | meter per second |
| kg | kilogram | pct | percent |
| kW | kilowatt | ppm | part per million |
| m | meter | V | volt |
| $m^{-1}$ | reciprocal meter | | |

## UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

### With Factors for Conversion of Selected Units to U.S. Customary Units

| Abbreviation | Unit of measure | To convert to— | Multiply by— |
|---|---|---|---|
| °C . . . . . . . . . . . . . . . . . . . . . . . . | degree Celsius | degrees Fahrenheit | 1.8 and add 32 |
| m . . . . . . . . . . . . . . . . . . . . . . . . . | meter | feet | 3.28 |

# EVALUATION OF A NITRIC-OXIDE-COMPENSATED CARBON MONOXIDE FIRE SENSOR

By Charles D. Litton,[1] Ronald S. Conti,[2] John G. Tabacchi,[3] and Richard Grace[4]

## ABSTRACT

This U.S. Bureau of Mines report describes the results of two large-scale tests conducted to evaluate a prototype nitric oxide (NO)-compensated carbon monoxide (CO) fire sensor, developed by Carnegie Mellon Research Institute (CMRI). In the tests, small coal fires were allowed to develop in the presence of diesel exhaust at relatively low ventilation airflows. These tests compared the response of the CMRI fire sensor with that of other fire sensors, including the Bureau's diesel-discriminating smoke detector. During the tests, CO, NO, and smoke levels were continuously monitored in order to determine the sensor alarm times and gas levels as the fire developed.

The data indicated that the NO-compensated CO fire sensor was capable of suppressing the CO produced by a diesel engine and that the sensor responded reliably to the CO produced from the test fires. The tests also showed that the Bureau's diesel-discriminating smoke detector alarmed earlier than the prototype NO-compensated CO fire sensor.

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## INTRODUCTION

Very often CO sensor alarms occur in underground mines that utilize diesel equipment. To compensate for elevated background levels of CO due to diesels, mine operators frequently increase the threshold alarm level of their CO sensors. The higher alarm levels of these sensors expose the mine to a greater risk potential in case of a fire, particularly in latent areas where diesel backgrounds may be low. The alarm time of the sensor is increased because of the high alarm level of the CO sensor, thus decreasing the amount of time that miners have to escape. There are several factors that influence the time required for a system to go into alarm. During the smoldering stages of a fire, considerable amounts of smoke and CO are produced. The time it takes for a sensor to alarm to the fire emissions is dependent upon the threshold alarm level, sensor spacing and vertical placement, and ventilation airflow. Tests (*1-2*)[5] have shown that it may take several minutes for the sensor to respond to the products of a fire, let alone to reach an alarm mode.

This work was done in support of the U.S. Bureau of Mines goal to enhance the safety of the Nation's miners.

## DEFINITIONS

Some of the terminology used in this report may not be familiar to some readers; therefore, to better familiarize the reader with possibly unfamiliar expressions, a short section on definitions is presented.

- *Smoldering fire*.—A fire that produces smoke and CO but that is not yet flaming.
- *ppm of CO*.—The unit of measure for CO used by CO fire sensors. 10,000 ppm (parts per million) of CO equals 1.0 pct of CO.
- *CO fire sensor*.—A sensor that detects CO and issues an alarm when the level equals or exceeds some preset alarm threshold level, taken to be 10 ppm in this report.
- *Smoke fire sensor*.—A sensor that detects smoke and issues an alarm when the set alarm threshold level is exceeded, taken to be 0.044 $m^{-1}$ optical density in this report.
- *Diesel-discriminating smoke detector*.—A smoke detector that can be used to discriminate between smoke produced by a fire and smoke produced by a diesel engine.
- *Nitric oxide (NO)-compensated carbon monoxide (CO) fire sensor*.—A sensor that can be used to suppress the CO produced by diesel engines through compensation by the NO production so that the sensor responds only to the CO produced by a fire.
- *Ventilation air velocity*.—The air speed in a mine entry, in meters per second.

## LAKE LYNN LABORATORY

The Bureau's Lake Lynn Laboratory, formerly a limestone mine (*3*), is now a multipurpose mining research facility that is primarily used to conduct fire and explosion prevention research. The laboratory's underground layout and aboveground quarry area are shown in figure 1. The new entry dimensions of the underground mine range from 1.8 to 2.4 m high and from 5.3 to 6.7 m wide. The average dimensions are 2.1 and 5.8 m, for an average cross-sectional area of 12 $m^2$.

The two test fires for this experiment were conducted in A-drift. A detailed layout of a typical underground fire and detection scenario is shown in the perspective view in figure 2. During the experiments the airflow of the mine was reversed, so that the combustion products were exhausted through the main fan. The movable bulkhead door in D-drift was closed, and the bulkhead door in E-drift was open. Temporary stoppings were installed at the last crosscuts of B- and C-drifts. The airflows were adjusted with one of the four positions of the main fan and a 0.61-m butterfly valve located in the bulkhead door of D-drift. The airflow was monitored with a vane-type anemometer 15.2 m inby the fire zone.

Products of combustion sensors were used at two positions along the mine entry. Two diffusion-type electrochemical CO sensors (see figure 2, detail I) were mounted 15.2 m inby the fire zone in the middle of the entry. One CO sensor was mounted near the roof and was labeled CO-50-roof. The other CO sensor was mounted directly below, 0.66 m from the floor, and was labeled CO-50-mid.

[5]Italic numbers in parentheses refer to items in the list of references at the end of this report.

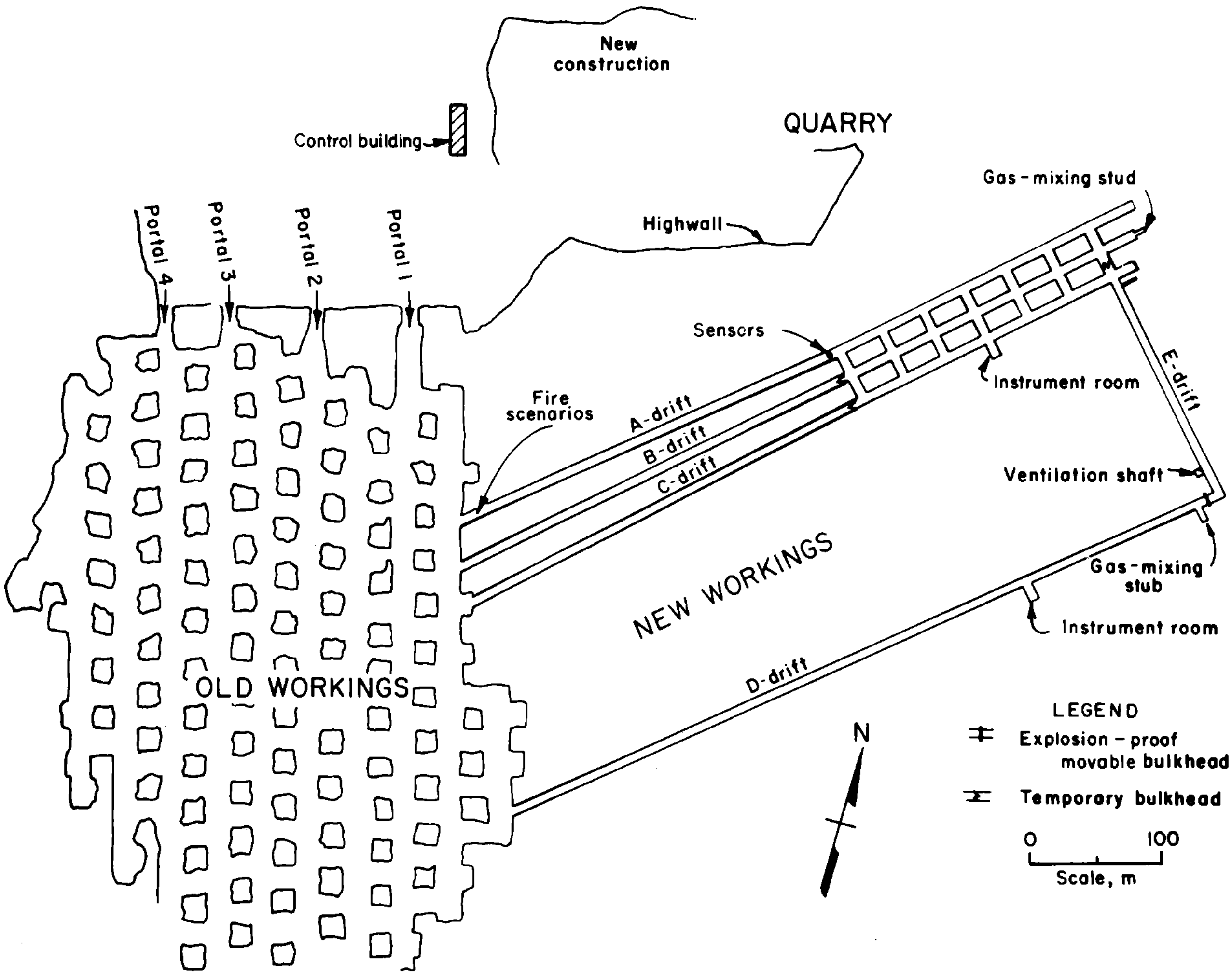


**Figure 1.—Plan view of Lake Lynn mine and quarry area, showing configuration for fire detection studies in A-drift.**

A continuous length of a thermal line-type fire detector (heat-sensitive cable) was mounted at the roof from the portal of A-drift and extended 30.5 m past the fire zone. A line-type fire detector is a twisted pair of insulated wires that short circuit when exposed to temperatures in excess of 68° C.

Six fire sensors were mounted as shown in detail II of figure 2, in the entry cross section at a point 274 m inby the fire zone. Three diffusion-type electrochemical CO sensors were used. Two were mounted at the roof and labeled CO-roof and CO-roof-B; they represented two brands of CO sensors. The other CO sensor was mounted 0.66 m from the floor on the rib and identified as CO-rib; it was the same brand as the CO-roof sensor. A commercially available ionization-type smoke sensor, labeled smoke, was mounted on the rib, with the intake sampling point located beside the CO-roof-B sensor at the 274-m location. A prototype diesel-discriminating detector (*4*), labeled DDD, and an NO-compensated CO fire sensor (*5*) were mounted at the roof beside the intake sampling point of the smoke sensor at the 274-m location. CO sensors were calibrated and smoke sensors were tested before each fire test.

The DDD is a novel device that can be used to discriminate between smoke produced by a fire and smoke produced by a diesel engine. The detector uses a pyrolysis technique whereby a sample of smoke-laden gas passes through a short, heated tube within which fire smoke particles pyrolyze, increase in number concentration, and decrease in average size; diesel smoke particles are unaffected. Development of the DDD came about because of the numerous false alarms in mines that use diesel equipment, which makes detection of fires complicated because of the background levels of diesel emissions.

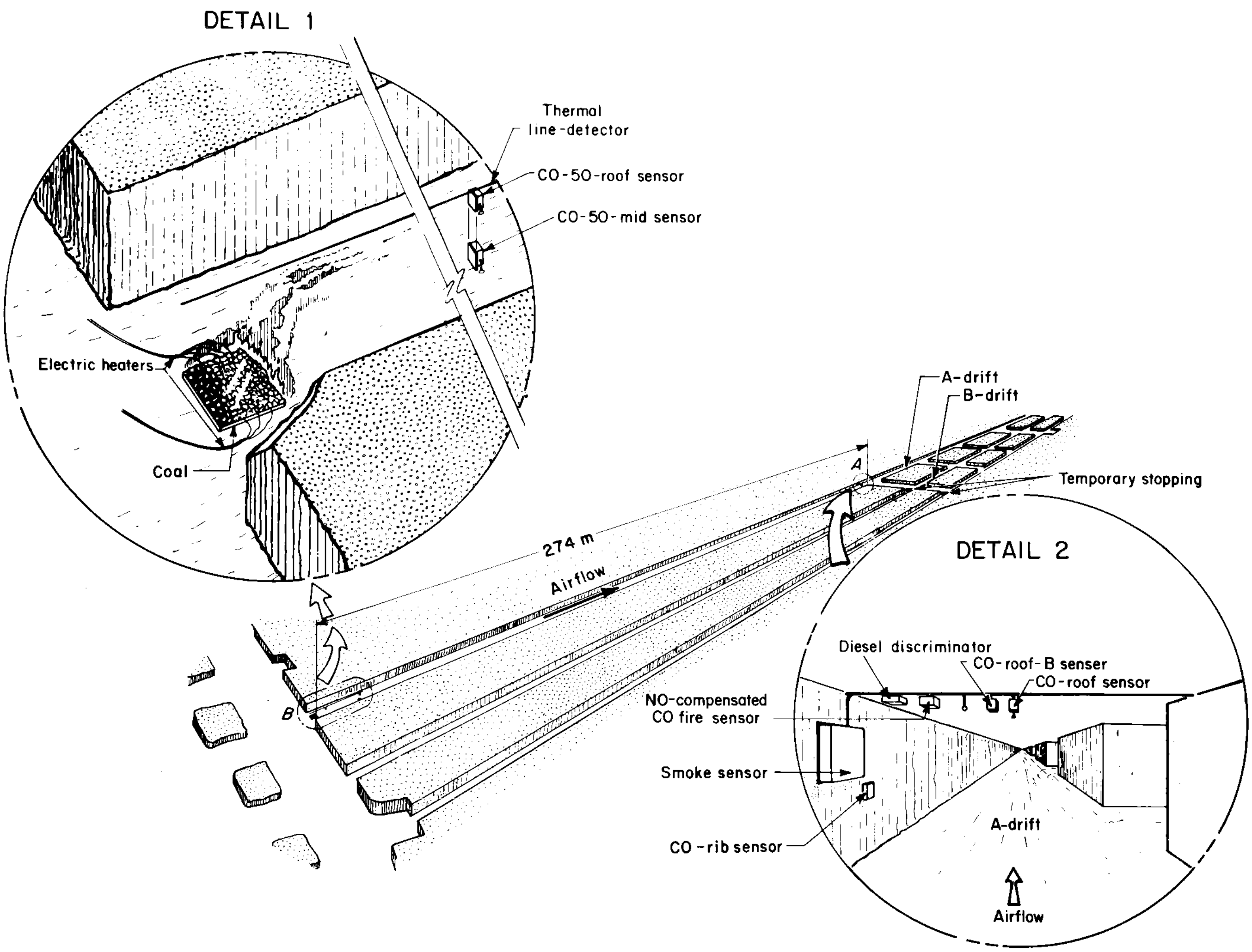


**Figure 2.—Perspective view of underground fire detection scenario in A-drift. Exploded views of sensor placement with respect to fires are shown in details I and II.**

The NO-compensated CO fire sensor, developed by Carnegie Mellon Research Institute, is a sensor that can be used to suppress the CO produced by diesel engines through compensation by the NO production so that the sensor responds only to the CO produced from a fire.

## SENSOR RESPONSE TO DIESEL EXHAUST AND TO COAL FIRES

The scenarios studied were designed to simulate numerous alarms that occur in mines using diesel equipment. The airflow during the first 67 min of test 1 was 0.58 m/s; it was reduced to 0.43 m/s for the remainder of the test. During the initial stages of test 1, a small 65-hp diesel engine was originally positioned near the portal of A-drift, but was moved several meters into A-drift 82 min later. The diesel engine was again moved and finally placed 236 m into A-drift (after 168 min) and allowed to operate for the remainder of the 4-h test. By moving the diesel engine closer to the sensors, a worst case scenario was simulated. The level of CO near the roof, as measured by the three CO sensors, is shown in figure 3. The levels of CO for the three sensors agree reasonably well. The rapid decrease in CO levels of the three CO sensors delineates the initial changes that were made in ventilation and placement of the diesel engine.

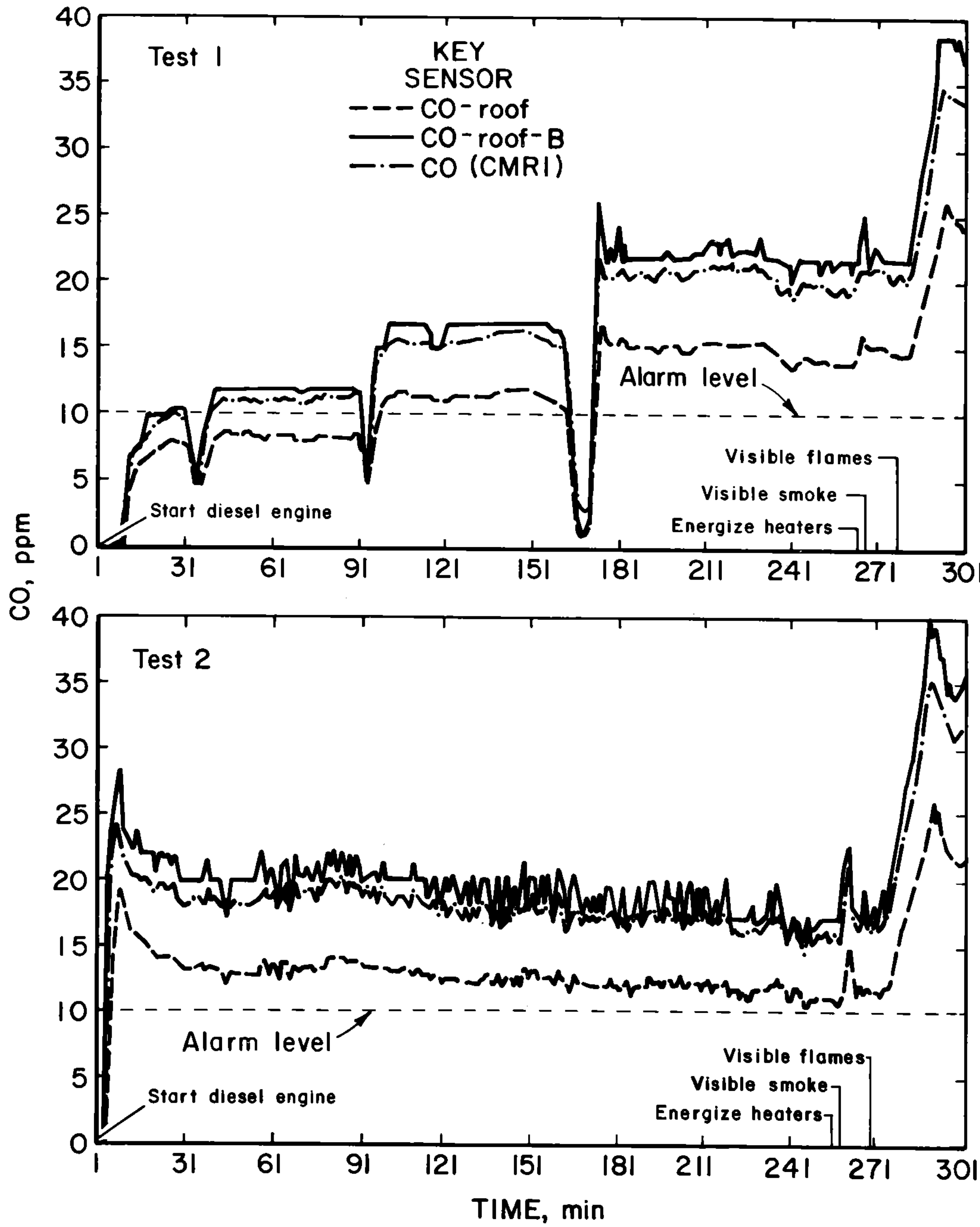


**Figure 3.—Measured CO levels near roof for three brands of CO sensors at 274-m station for two tests. CMRI = Carnegie Mellon Research Institute**

Figure 3 also shows the CO data for test 2 and again shows reasonable agreement in CO levels for the three CO sensors. For this test, the airflow was set for 0.41 m/s and the diesel engine was positioned 236 m into A-drift, creating a diesel background for 4 h before the test fire was started.

Figure 4 shows the actual CO-to-NO ratios and the NO-compensated CO sensor's learned CO-to-NO ratio as a function of time for tests 1 and 2. After a 4-h learning period for the NO-compensated CO fire sensor, a slowly developing coal fire was allowed to develop. Seven electric strip heaters with a combined power rating of 9.5 kW were embedded into a 1.2- by 1.2-m coal pile and used to ignite 82 kg of Pittsburgh coal, which was seeded with an additional 12 kg of Pittsburgh pulverized dust. Full electrical power was applied to the heating elements. Visible smoke from the coal pile was observed in 1 to 2 min, with flames emitting from the coal 9 min later.

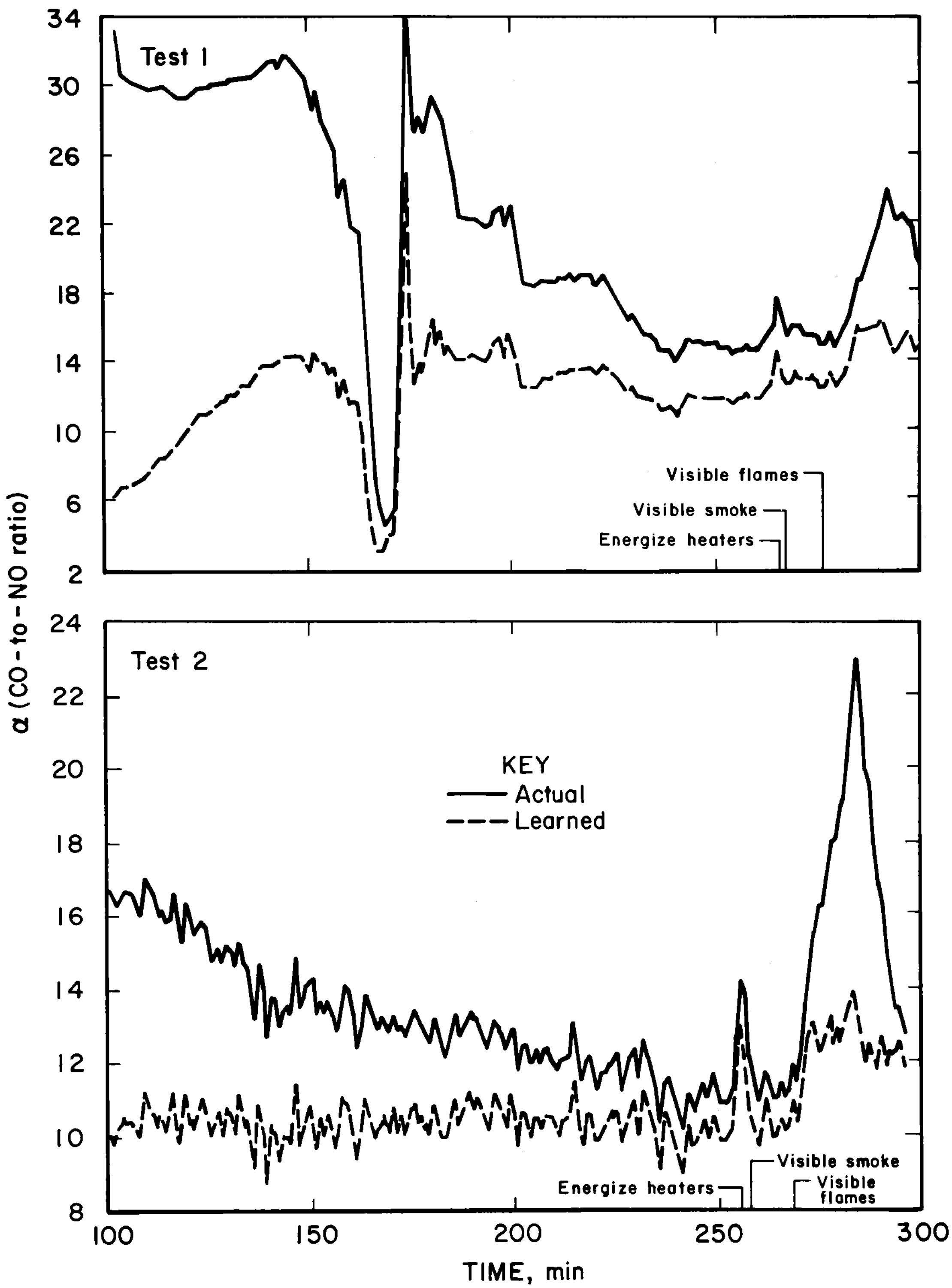


**Figure 4.—Actual CO-to-NO ratios compared with NO-compensated CO sensor's learned CO-to-NO ratio for two tests.**

In the experiments, the smoldering of the coal pile was controlled primarily by the time required to raise the surface temperature of the heating elements to temperatures sufficient to ignite the coal. For these two tests, the smoldering stages generally lasted 11 min until visual flames were first observed.

The heating elements in test 1 were energized 265 min into the experiment. The actual CO-to-NO ratio ($\alpha_D$) and learned CO-to-NO ratio ($\alpha_{DO}$) for the NO-compensated CO fire sensor during the diesel background buildup and smoldering and flaming stages of the coal are compared in figure 4. The curves are defined by the actual CO-to-NO ratio. Of particular interest is the ability of the NO-compensated CO fire sensor to suppress the CO produced by the diesel yet to respond rapidly to the CO produced by the fire.

The CO, NO, and CO-corrected levels are shown in figure 5 for tests 1 and 2. Clearly, the CO-corrected levels were significantly below the actual diesel-produced CO levels and the corrected levels began to increase within 2 to 3 min after the fire-produced CO reached the sensor location. It should also be noted that the CO-corrected level peaks and then begins to decline. As is clearly evident in figure 5, this effect is due to the low levels of NO produced by the flaming coal fire.

For comparison purposes, the output signal of the Bureau's DDD is shown in figure 6. This detector responded more rapidly to the fire than corrected CO level of the NO-compensated CO sensor, but also showed a decrease in signal after achieving its peak response. It is believed that increasing the pyrolysis temperature would allow the detector to maintain a high response and to eliminate the signal reduction, since all fire smoke particles could be expected to pyrolyze.

In order to address the signal loss of the NO-compensated CO fire sensor toward the end of the test, as shown in figure 5, the data were analyzed in terms of the CO-to-$\sqrt{NO}$ ratio to assess the potential of this compensation ratio rather than CO to NO.

The results of this analysis are shown in figure 7 for the two tests conducted. In both tests, the CO compensated by the $\sqrt{NO}$ increases earlier and more rapidly upon the arrival of fire-produced CO than does the CO-to-NO ratio. It is also worth noting that the $\sqrt{NO}$-compensated CO level does not show as rapid a decrease during the latter stages of the test as does the CO-to-NO ratio. Based upon this analysis, it would appear that a CO sensor that uses a combination of the two ratios, CO to NO and CO to $\sqrt{NO}$, would provide more sensitive and reliable detection.

## CONCLUSIONS

Data from two full-scale tests on the response of an NO-compensated CO fire sensor yielded promising results. The prototype sensor was capable of suppressing the CO produced from the diesel engine, and the sensor provided a clear indication of the arrival of the fire-produced CO. Subsequent analysis of the data using CO to $\sqrt{NO}$ as the compensation ratio indicated that the ratio can improve response and also make the sensor less susceptible to NO produced from the actual fire. Although further testing of such prototype sensors is in order, the potential of this technique to reduce or eliminate nuisance alarms due to diesel-produced CO is clearly evident.

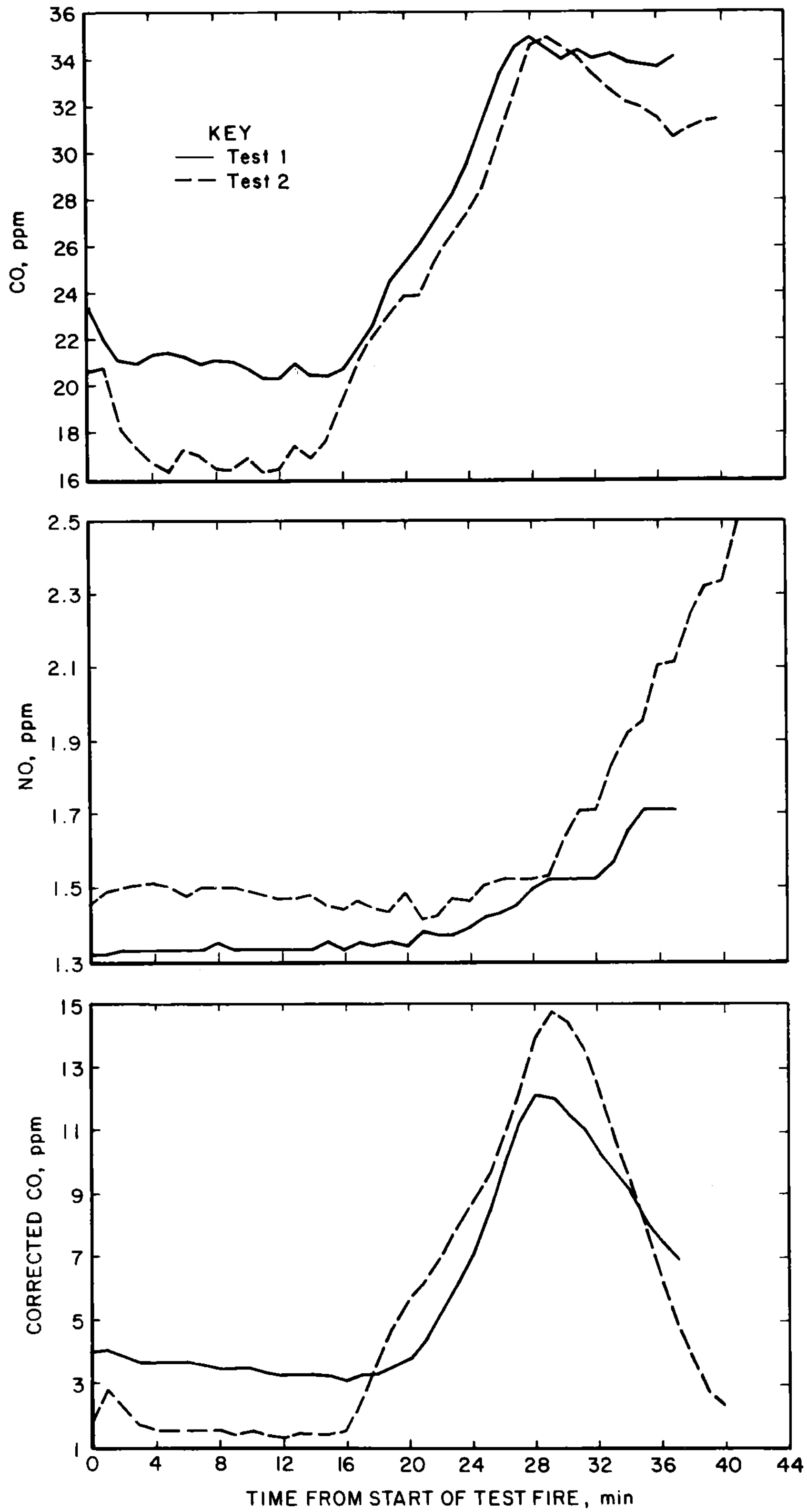


**Figure 5.—CO, NO, and CO-corrected levels at 274-m station during two test fires.**

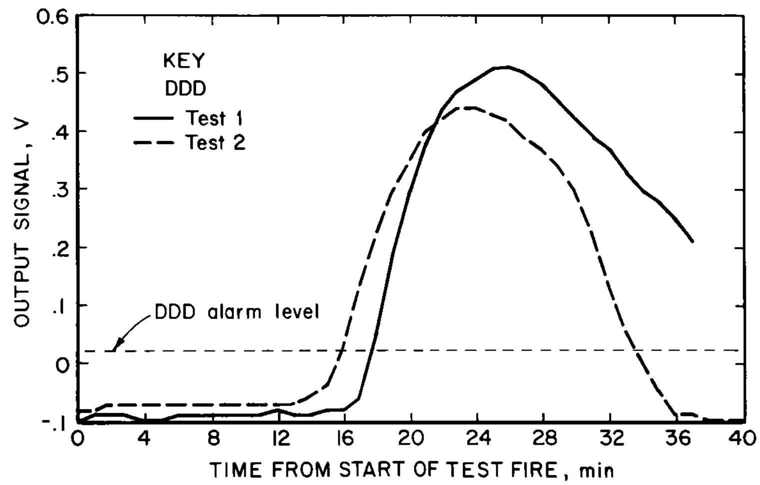


**Figure 6.—Output voltages of diesel-discriminating smoke detector (DDD) during two test fires.**

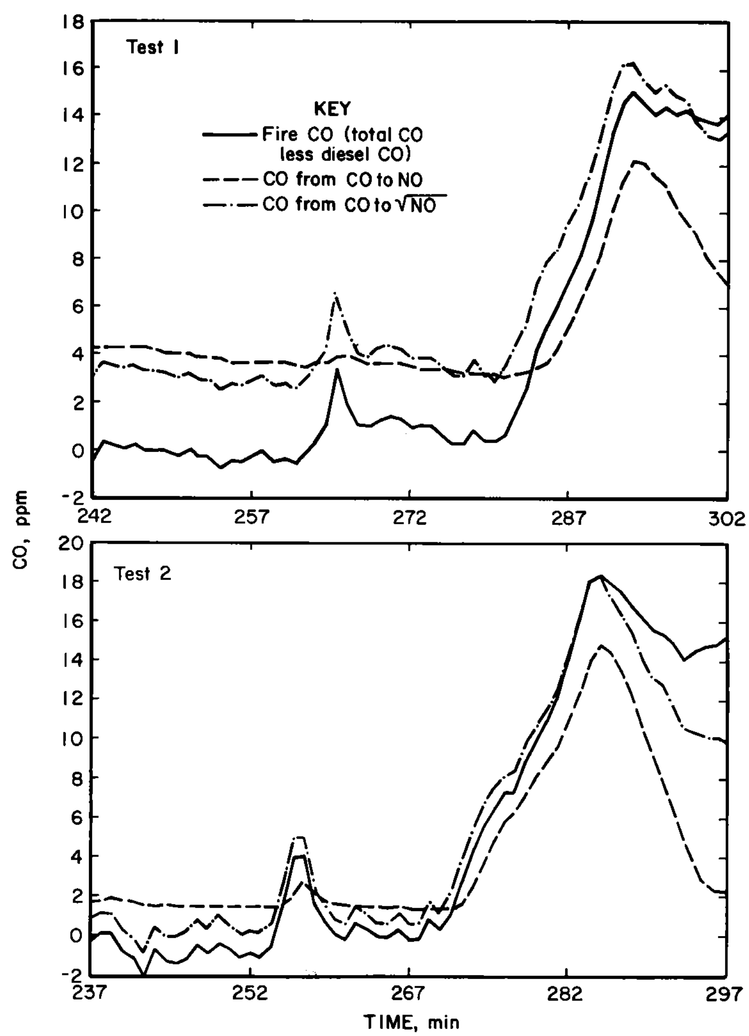


**Figure 7.—Comparison of CO-corrected levels for CO-to-NO and CO-to-$\sqrt{NO}$ ratios with actual fire-produced CO.**

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