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Measurements and Observations of the Toxicological Hazard of Fire in A Metrorail Interior Mock-Up

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Final Report

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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*
James A. Baker, III, *Under Secretary*
Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

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MEASUREMENTS AND OBSERVATIONS OF THE TOXICOLOGICAL HAZARD OF FIRE IN A METRORAIL INTERIOR MOCK-UP

M. M. Birky, A. W. Coats, S. E. Alderson,
J. E. Brown, M. Paabo and B. Pitt[1]

Abstract

Oxygen depletion, carbon monoxide, carbon dioxide, hydrogen chloride and hydrogen cyanide were selected for measurement and identification in Metrorail fire tests.

Male rats exposed to the combustion products were examined for changes in blood chemistry, gross pathology and loss of function. Hydrogen cyanide and carbon monoxide levels in blood were elevated and functional changes were noted.

Key words: Blood; carbon dioxide; carbon monoxide; fire; hydrogen chloride; hydrogen cyanide; oxygen; rats.

1. INTRODUCTION

The major cause of fire fatalities in the United States is inhalation of smoke and toxic gases [1][2]. In the past the assessment of the toxicological hazard has been based on chemical analyses of gaseous products and an optical attenuation measurement for determining the smoke hazard. Review of the fire literature suggests that such an assessment is inadequate to define the toxicological hazard [2]. Based on this information, the only effective method for assessing the inhalation hazard is to expose living organisms to the combustion products and combine the biological information with chemical analyses.

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[1]Johns Hopkins University, School of Hygiene and Public Health. Except for the actual exposure of the animals to fire conditions, all animal work was done at Johns Hopkins School of Hygiene and Public Health. All animal work, wherever done, was carried out under the supervision of B. Pitt of the Johns Hopkins University School of Hygiene and Public Health.

[2]Numbers in brackets refer to the literature references listed at the end of this paper.

Seven fire tests of a proposed Washington Metropolitan Area Transit Authority Metrorail subway car mock-up interior [3] were recently conducted to determine the fire hazard(s) of the materials used in interior construction. These tests were instrumented to measure smoke density, heat flux, temperature and gas production. The test results have for the most part, been reported by Braun [3]. In two of the seven tests, animals were included to determine the toxicological hazard(s) of the products of combustion. It is with the details of these tests, No. 5 and 6, that this report is concerned. Atmospheric data from test No. 7 is also included in order to compare combustion product generation in the 3 tests.

2. EXPERIMENTAL DESIGN

2.1. Description of Mock-up of Metrorail Car Interior

The mock-up (fig. 1) consisted of wall and ceiling sections and three seat frames, one of which was a lateral single and the other two were transverse double seats. The floor was carpeted and the seat cushions were varied from test to test.

2.2. Material Identification

The basic materials that were utilized in fire tests No. 5, 6, and 7 were identified by infrared spectroscopy. X-ray fluorescence was used to identify the presence of those elements which are generally found in fire retardant formulations (table 1, page 8). The X-ray fluorescence measurements were limited to the determinations of Bromine (Br), Chlorine (Cl), Phosphorus (P), and Antimony (Sb). The identification of these elements, however, is not conclusive proof of the presence of a fire retardant, as some of these elements may be found in other additives or in the polymer itself. For example, additives such as blowing agents may contain a halogen; therefore, caution must be used in interpreting the presence of a halogen in a polymer as confirmation of the inclusion of a fire retarding agent.

2.3. Ignition Source

The ignition sources and their locations in the Metrorail mock-up were as follows:

Test No.	Source	Location
5	454 g (16 oz) newspaper	on aisle seat
6	43 g (1.5 oz) paper bag	on aisle seat
7	908 g (32 oz) newspaper	on wall seat

2.4. Animal Exposure and Gas Sampling

A three-inch exhaust line was used to transfer the combustion products from the fire area to a motorized revolving cage which contained three Wistar male rats each weighing approximately 260 grams (see fig. 2). The rats were in separate compartments within the wheel, which rotated at 8 rpm. Prior to the experiment the animals were trained to walk in the wheel in two training sessions a day for five days, each session of five minutes duration. The animals were trained in order to observe any changes in their behavior during exposure to the combustion products. An abdominal-aorta cannula was surgically placed in one animal (each test) two days prior to exposure to provide for the rapid removal of blood samples for carboxyhemoglobin (COHb) determinations. This animal was not trained to walk in the wheel prior to exposure. Since a large blood sample was required for cyanide determination, an animal was sacrificed for this purpose.

Sampling ports were installed just before the interface of the three-inch transfer line at the animal exposure chamber. Sampling for continuous analysis of CO, CO_2, O_2, and HCl, and intermittent sampling of HCN took place at these ports.

3. EXPERIMENTAL RESULTS

3.1. Analytical Measurements

Carbon monoxide (CO), carbon dioxide (CO_2), and oxygen (O_2) concentrations were determined from the same sampling stream. Non-dispersive infrared techniques were used for measurement of CO and CO_2, and a polarographic oxygen cell was used for the measurement of O_2. The results of these measurements for experiments 5, 6, and 7 are shown in figures 3, 4, and 5.

Hydrogen chloride (HCl) concentrations were determined by collecting the combustion products in distilled water and monitoring this solution with an ion-specific electrode. The sampling rate was two liters per minute for the duration of the experiment. No HCl was detected in the atmosphere in these experiments at the lower limit of detectability which was 50 ppm. In experiment 5 (table 1) the seat was a PVC-covered chlorinated rubber. Since only the seat cushion and cover were involved in the fire and the volume of the mock-up was quite large, high concentrations of HCl were not found. In experiments 5 and 6 the wall did not get involved in the fire, thus explaining the absence of HCl.

In experiment 7, the wall was involved. However, the concentration of HCl did not reach the level detectable with the apparatus. This was apparently due to the fact that the experiment was terminated before substantial quantities of the wall material had burned.

The atmosphere containing combustion products was also sampled sequentially for hydrogen cyanide (HCN). The products were collected in 0.1 N sodium hydroxide at a sampling rate of 250 cc/min. The solution was analyzed for cyanide according to a modification of the procedure reported by Valentour [4]. The results of these measurements are shown in figure 6. The presence of atmospheric HCN was detected in experiments 6 and 7. No atmospheric HCN was detected in experiment 5. This was due to the absence of nitrogen-containing polymers in the fire. In experiment 6, the source of HCN is attributed to the polyurethane seat cushion. In experiment 7, the HCN is due to the acrylonitrile present in the PVC-acrylic wall section.

3.2. Biological Measurements

In order to assess the overall toxicological hazard from a test fire in a Metrorail car, the gas measurements were correlated with animal behavior and blood chemistry in two of the tests. The animals were exposed for the entire time of the experiments. In experiment 5, this was 13 minutes and in experiment 6, this was 12 minutes.

Male Wistar rats (206 g) were used in all the exposures. The rats exposed in experiment 5 showed no deviation from the behavioral patterns exhibited during the pre-test training sessions. The rats exposed in experiment 6 were obviously incapacitated to some degree as their ability to walk in the wheel was severely curtailed. Post-exposure blood samples were taken at various time intervals following the cessation of the tests, from which COHb measurements were made. These data are summarized in table 2 (page 9) for rats No. 1 and 2 in each test. Rat No. 3 was returned to Johns Hopkins University for short-term observation after each test. No long-term observations were made.

Blood chemistry included COHb and cyanide determinations. Carboxyhemoglobin determinations were done according to the spectrometric technique developed by Small, et al. [5]. The analytical procedure for determining blood cyanide was a two-step procedure consisting of a microdiffusion technique [6] for separating cyanide from the blood followed by gas chromatographic determination of the cyanide [4]. In experiment 6, the blood sample was divided into 2 parts, each portion treated separately.

As noted in table 2, blood samples for cyanide and COHb determinations were obtained 10 minutes post exposure in the sacrificed animal. The rate of release of COHb from rats has been measured by Packham [7]. His data suggested that in 10 minutes the COHb will decrease about 20% if there is no pulmonary damage.

The effect of the delay time on cyanide (CN) concentrations in the bio-system is more difficult to assess. Data obtained by Pettigrew and Fell [8] on rats which were injected with cyanide intraperitoneally, suggest that the half-life of the cyanide was 15 to 20 minutes. These data should be interpreted with caution because of the different method of exposure. In any event, the actual blood cyanide level immediately after exposure may have been somewhat higher than reported.

3.3. Correlation of Analytical and Biological Results

In order to correlate the carbon monoxide measurements with the COHb determinations, the CO measurements were approximated with an average value for a specified time period of the test to give the same dose. In experiment No. 6 (fig. 4) the CO concentration to which the rats were exposed was approximately 200 ppm for a period of 5 minutes. This dosage (product of concentration and time) has approximately the equivalent effect as the measured time dependent concentration. Carboxyhemoglobin levels as a function of CO concentration and time for rats were determined by Hofmann and Oettel [9]. According to their data, this approximated dosage should lead to a COHb level of 5%. The measured level was 12%. This difference can be attributed to the fact that Hofmann and Oettel's results were obtained on rats at rest as opposed to forced exercise as in the fire experiments.

A literature search on the dosage of hydrogen cyanide, administered to rats by inhalation that produces a given toxicological effect, shows that various authors are not in agreement. Moss et al. [10] report that the minimum lethal atmospheric level of HCN is about 50 ppm. At this level, incapacitation occurred in 3 minutes and death in 8 minutes. No blood measurements were given. More recent data reported by Lynch [11] yields a 5 minute LC_{50} (lethal concentration for 50% of animals) of 720 ppm. Again no blood cyanide levels were reported. A similar, unpublished study using rats, reports a 5 minute LC_{50} of 480 ppm with large variation in blood cyanide measurements suggesting there is either a large variation in blood levels from a given dose, or that the analytical results were in error. In any event, correlation of the environmental concentration of hydrogen cyanide in experiment 6 with blood levels could not be made with any certainty at this time.

In test 6, the average cyanide level from measurements on the two blood fractions was 0.14 μg/ml. This level is considered sub-lethal; however, as indicated above, the relationship between atmospheric levels and blood levels in rats has not been established.

4. CONCLUSION

The deviation from the learned behavior of the animals in experiment 6, coupled with significant blood CO and CN content is evidence that a toxicological hazard definitely resulted from the combustion of the particular polyurethane cushions used in fire test No. 6. The decreased capacity of the animals to maintain their position in the rotating cage confirms this conclusion. The hazard arose from the cushioning, rather than some other portion of the seat assembly, as evidenced by the absence of similar observed effects in Tests 5 and 7.

5. REFERENCES

[1] Birky, M. M., Review of Smoke and Toxic Gas Hazard in Fire Environment, Paper presented at the University of Edinburgh (Oct. 1975).

[2] Zikria, B. A., Weston, G. C., Chodoff, M. and Ferrer, M. M., Smoke and Carbon Monoxide Poisoning in Fire Victims, J. of Trauma, Vol. 12, No. 5, 641-646 (1972).

[3] Braun, E., A Fire Hazard Evaluation of the Interior of WMATA Metrorail Cars, Nat. Bur. Stand. (U.S.) NBSIR 75-971.

[4] Valentour, James C., Aggarawal, Va. and Sunshine, Irving, Sensitive Gas Chromatographic Determination of Cyanide, Analytical Chemistry, Vol. 46, No. 7, 924-925 (1974).

[5] Small, K. A., Radford, E. P., Fragier, J. M., Rodkey, F. L. and Collision, H. A., A Rapid Method for Simultaneous Measurement of Carboxy and Methemoglobin in Blood, J. Appl. Physiol., Vol. 31, 154-160 (1971).

[6] Feldstein, M. and Klendshoj, N. C., The Determination of Cyanide in Biological Materials, J. Lab. Clin. Med., Vol. 44, 166 (1954).

[7] Packham, S. C., Behavior and Physiology: Tools for the Assessment of Relative Toxicity, Paper presented at 17th National Cellular Plastics Conference on Safety and the Product Liability (Nov. 18-20, 1974).

[8] Pettigrew, A. R. and Fell, G. S., Microdiffusion Method for Estimation of Cyanide in Whole Blood and Its Application to the Study of Conversion of Cyanide to Thiocyanate, Clinical Chemistry, Vol. 19, No. 5, 466-491 (1973).

[9] Hofmann, H. T. and Oettel, H., Comparative Toxicity of Thermal Decomposition Products, Modern Plastics, Vol. 46, No. 10, 98-100 (1969).

[10] Moss, R. H., Jackson, C. F. and Seiberlich, J., Toxicity of Carbon Monoxide and Hydrogen Cyanide Mixtures, Arch. Industrial Hygiene Occup. Med., Vol. 4, 53-64 (1951).

[11] Lynch, R. D., On the Non-Existence of Synergism Between Inhaled Hydrogen Cyanide and Carbon Monoxide, Fire Research Note No. 1035 (May 1975).

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TABLE 1.

METRORAIL MATERIAL IDENTIFICATION
USED IN FIRE TESTS 5, 6, & 7

TEST NO.	DESCRIPTION	INFRARED	X-RAY FLUORESCENCE			
			P	Cl	Br	Sb
5	Black Foam-Seat Cushion	Chlorinated Rubber		++		+
5	Seat Cover (Blue)	Polyvinyl Chloride (Plasticized)	+	++		+
5	Wall Panel	PVC-Acrylic		++		
6	Orange Foam - Seat	Polyurethane	+	+	++	
6	Wall Panel	PVC-Acrylic		++		
7	Seat	Cement-Asbestos	Not Analyzed			
7	Wall Panel	PVC-Acrylic		++		

TABLE 2.

BLOOD CYANIDE AND COHb RESULTS

EXPERIMENT NO.	RAT NO.	ELAPSED TIME IN MIN	% COHb	CN ug/ml	COMMENTS	LUNG PATHOLOGY (WET/DRY RATIO)
5	1*	10	4.6		Soot in Trachea	
		29	3.3			
		75	1.3			
	2**	10	3.7	0.01	Background Level	3.85:1
	3***				No Significant Pathology	
6	1*	6	12.2			
		12	10.2			
		26	8.0			
		65	4.2			
	2**	10	6.4	0.14	Average of 2 Samples Excess Mucous Some Soot	3.75:1
	3***				No Significant Pathology	

*Cannulated
** Sacrificed
*** to Johns Hopkins University for Observation

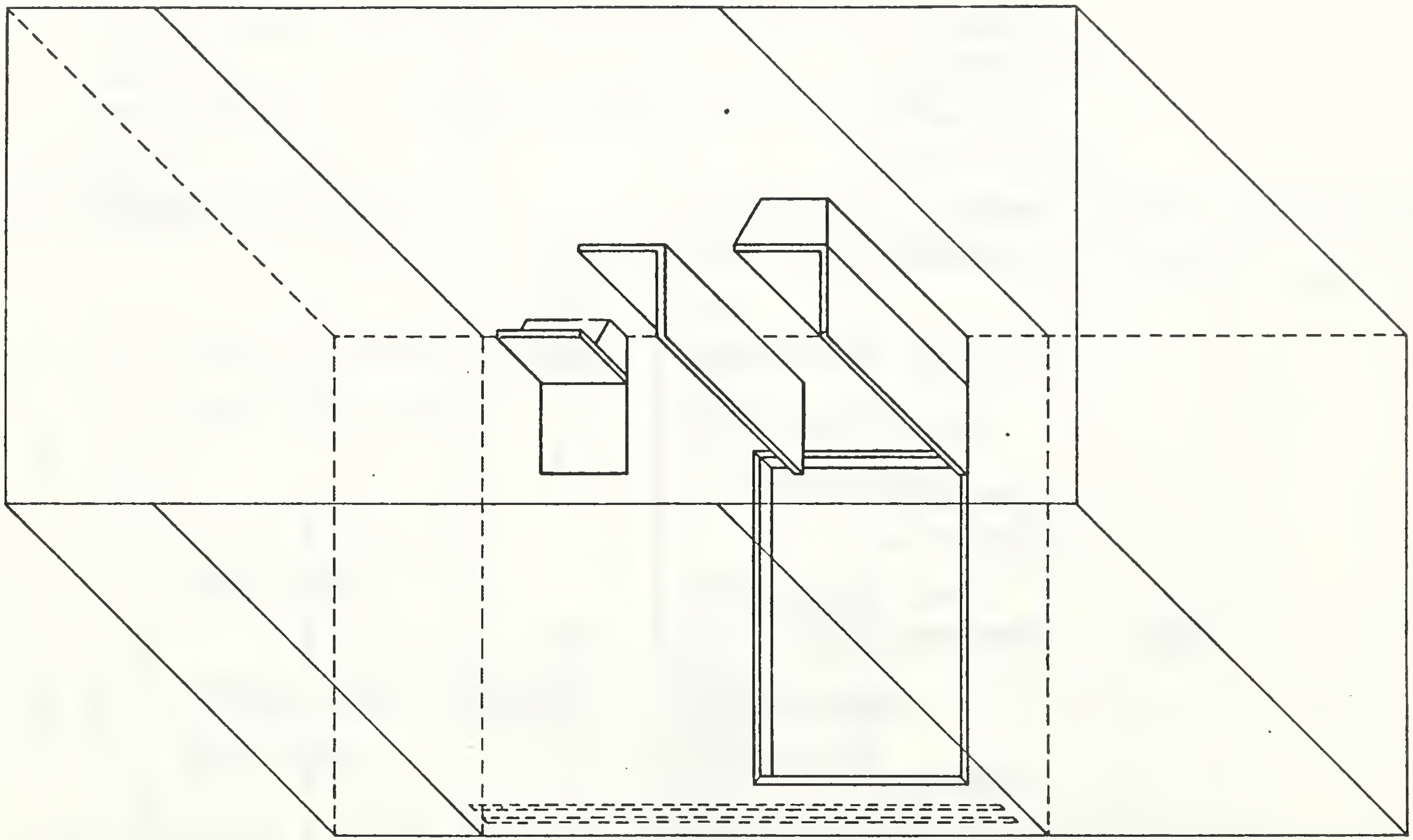

Figure 1. Metrorail Car Mock-up.

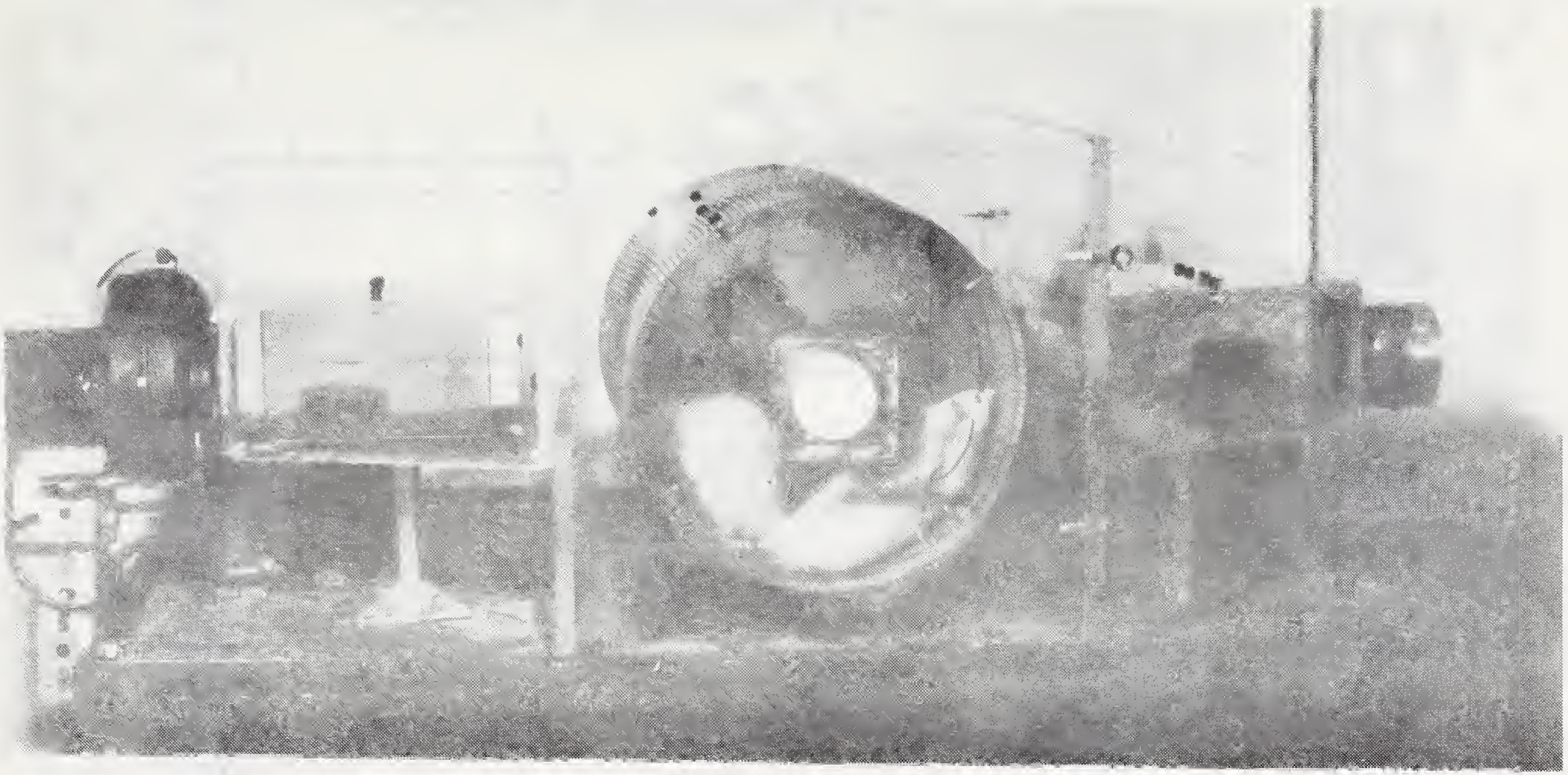

Figure 2. Motorized Rotating Wheel.

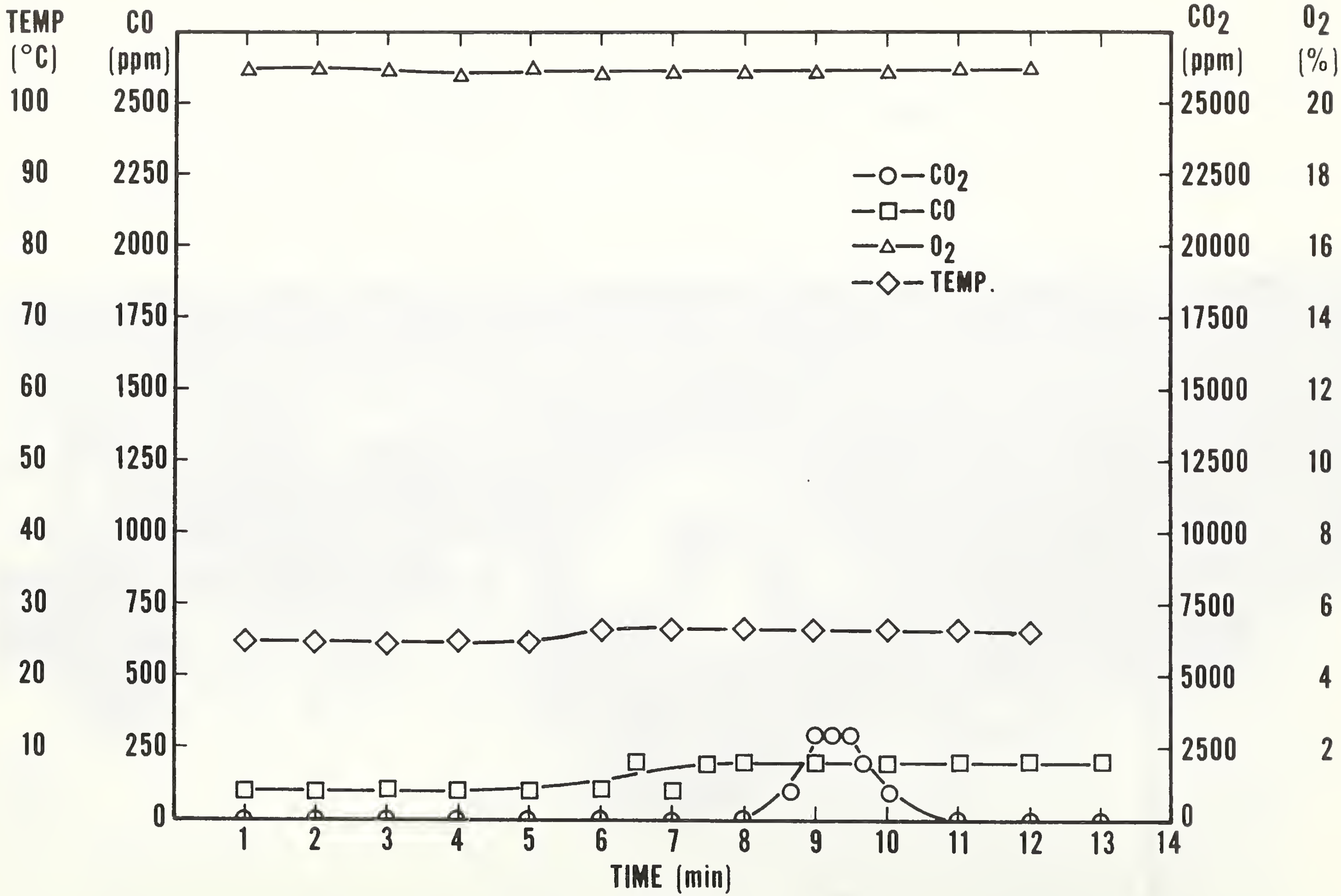

Figure 3. Metro Subway Test No. 5 - PVC over Chlorinated Rubber Cushion.

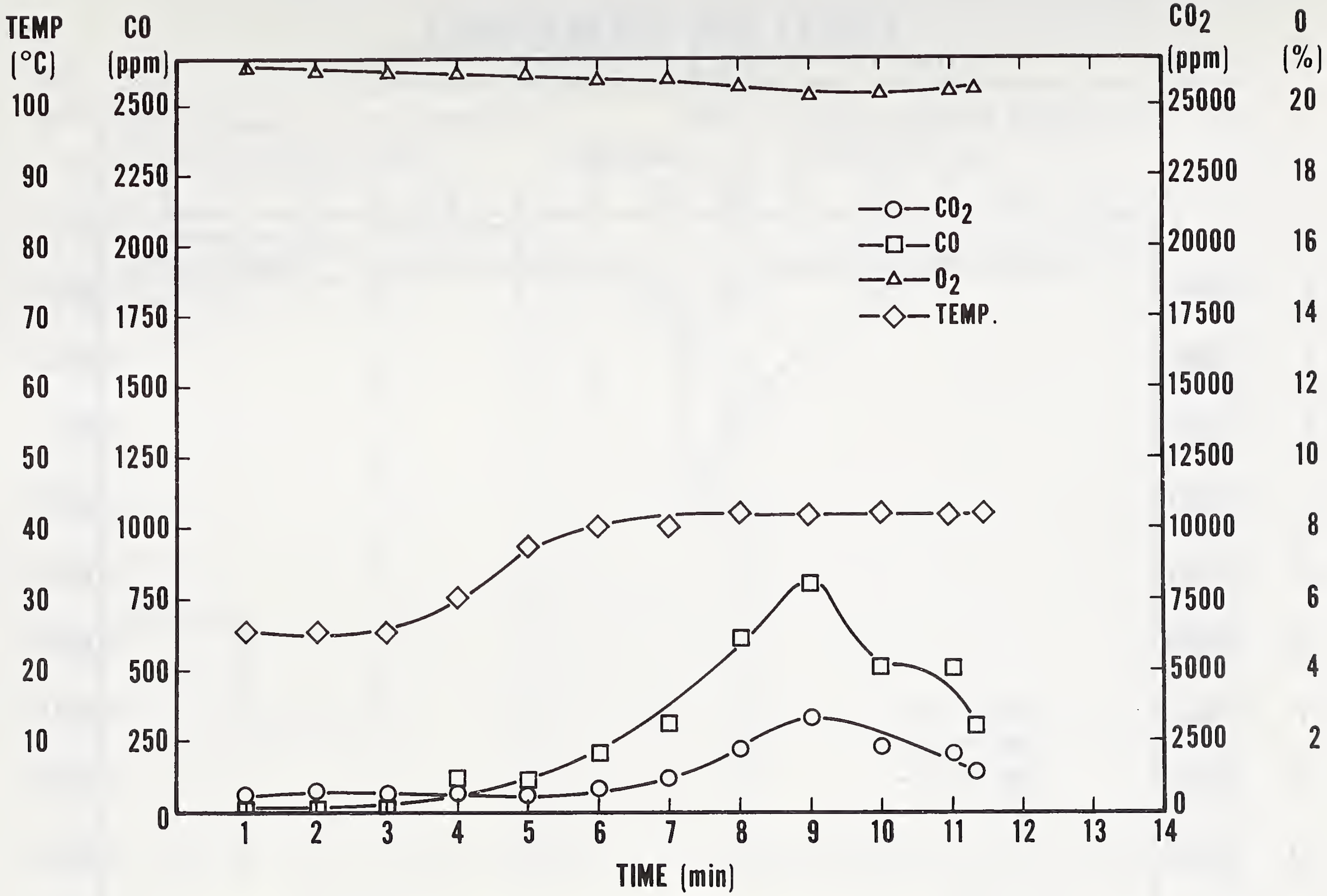

Figure 4. Metro Subway Test No. 6 - Self-Skinning F.R. Polyurethane Seat & PVC-Acrylic Wall.

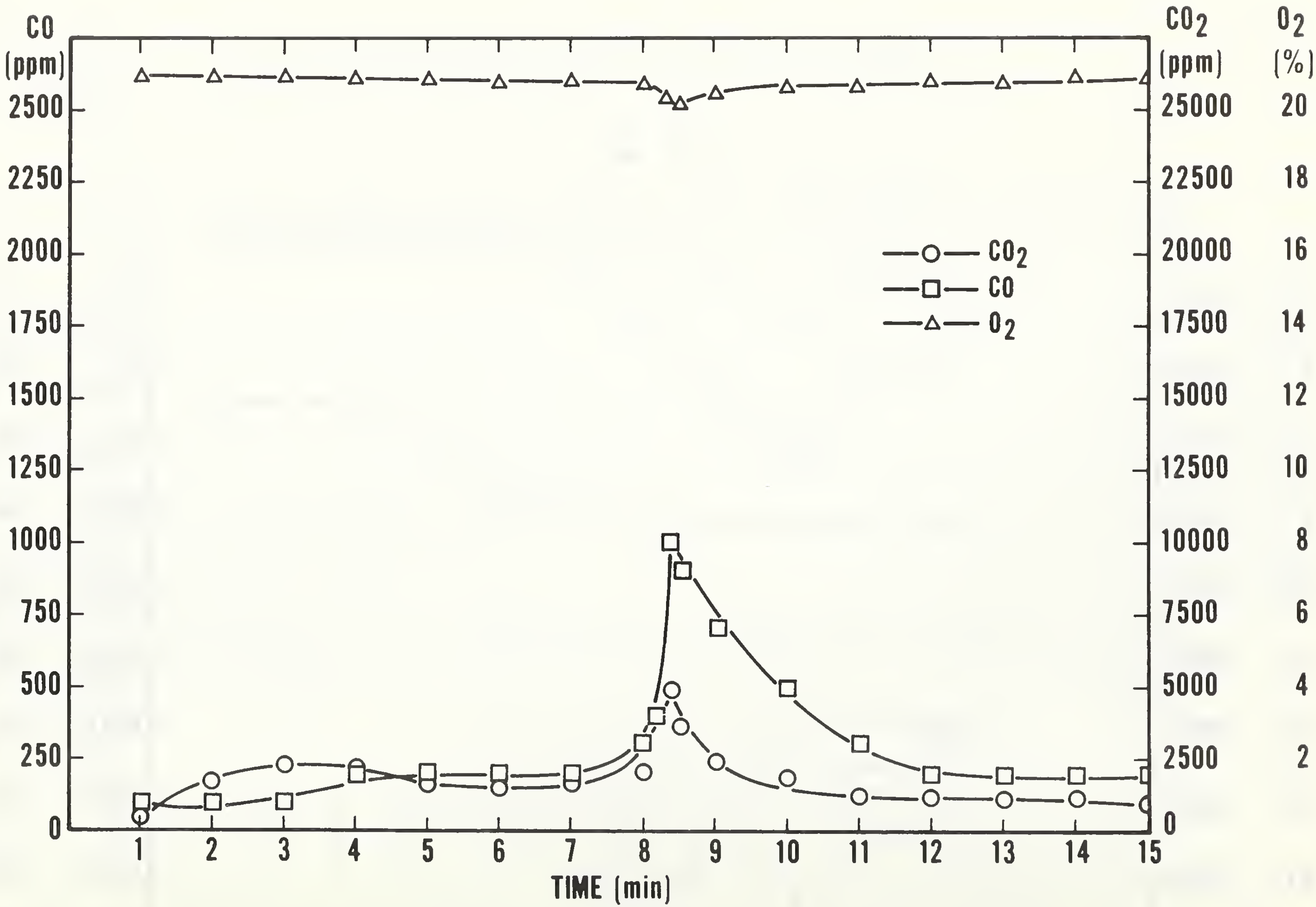

Figure 5. Metro Subway Test No. 7 - Cement-Asbestos Board Seat & PVC-Acrylic Wall.

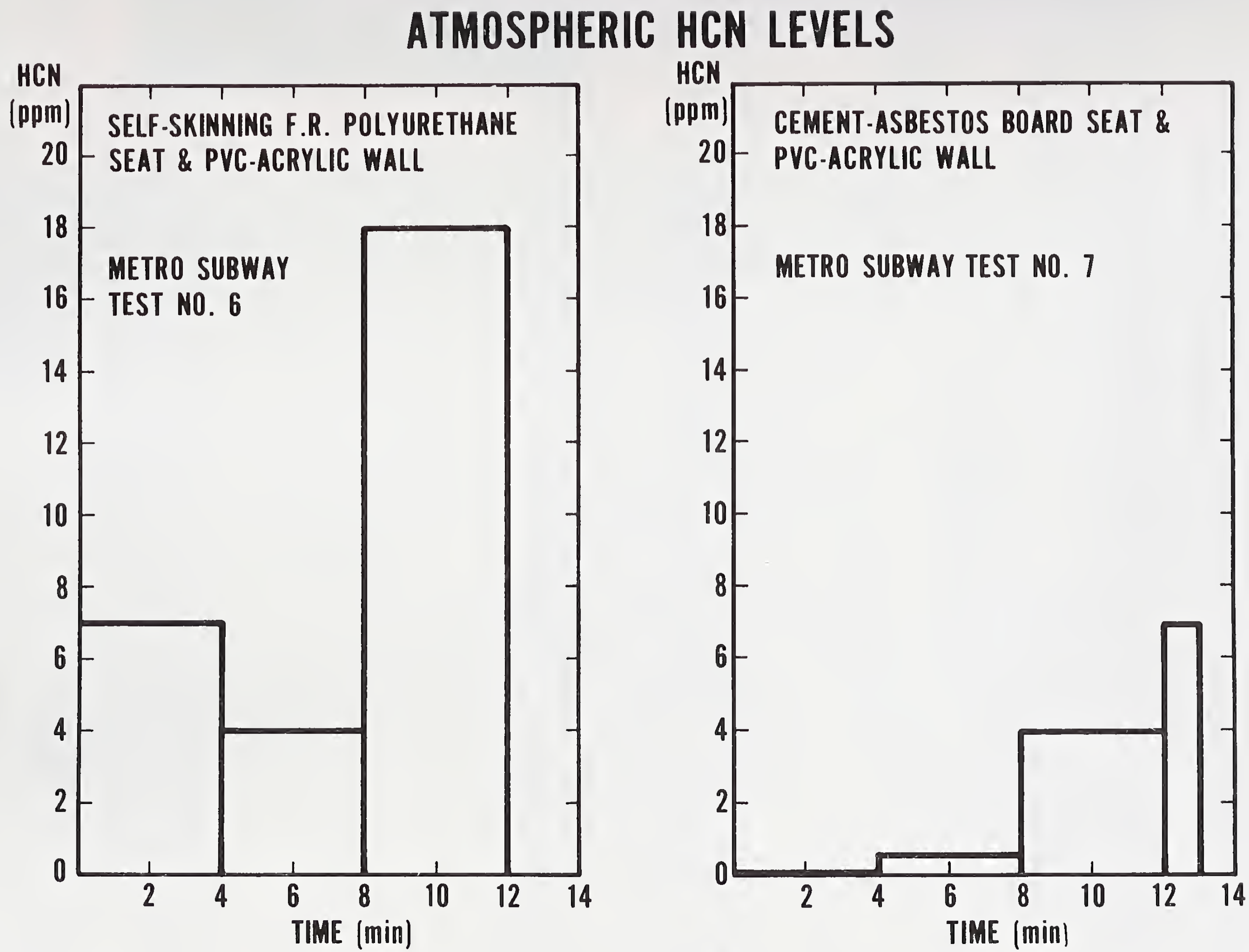

Figure 6. Atmospheric HCN Levels for Metro Subway Tests No. 6 and 7.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

Oxygen depletion, carbon monoxide, carbon dioxide, hydrogen chloride and hydrogen cyanide were selected for measurement and identification in Metrorail fire tests.

Male rats exposed to the combustion products were examined for changes in blood chemistry, gross pathology and loss of function. Hydrogen cyanide and carbon monoxide levels in blood were elevated and functional changes were noted.

17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons) Blood; carbon dioxide; carbon monoxide; cyanide; fire; hydrogen chloride; hydrogen cyanide; oxygen; rats.

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