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Sumi, K.; Williams-Leir, G.

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LETHAL EFFECTS OF MATTRESS FIRES

BY

K. SUMI AND G. WILLIAMS - LEIR

ANALYZED

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## LE DANGER MORTEL DES INCENDIES DE MATELAS

### SOMMAIRE

Les morts au cours des incendies sont souvent causées par l'habitude de fumer au lit, et on découvre parfois que seule la literie a brûlé. La combustion du capitonnage de coton allumé ainsi se déroule de façon inhabituelle. Il ne se produit ni flammes ni incandescence, mais de la chaleur et de la fumée.

Les auteurs ont réalisé une série d'expériences dans différentes conditions de ventilation, et ont mesuré les quantités de produits de combustion et les températures.

Ils ont établi des estimations de la durée de survie de l'occupant du lit dans chaque cas, en se fondant sur les données de toxicité publiées; cette durée atteint une heure dans une pièce close ou dans une pièce dont la porte est entr'ouverte de 2 pouces.

Les auteurs ont essayé quelques méthodes simples de défense préventive contre ce danger, et ils les ont trouvées efficaces.

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# LETHAL EFFECTS OF MATTRESS FIRES

by

K. Sumi\*and G. Williams-Leir\*

## ABSTRACT

Fatal fires are often attributed to smoking in bed, and it is found in some cases that the only material consumed is the victim's bedding. The mode of burning of cotton wadding in mattresses ignited in this way is unusual: there is no flame or glow, but heat and smoke are released.

In a series of experiments with varying degrees of ventilation, the products of combustion were measured and the temperature recorded.

On the basis of published information on toxicity, estimates were made of the duration of human survival in each case; this is found to be of the order of one hour either in a sealed room or one where the door is opened 2 in.

Some simple passive defence measures against this type of fire were tested and found effective.

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For a ten-year period ending in 1963 the Division of Building Research compiled statistics on fires in Ontario that resulted in deaths. A first instalment of the conclusions of this study, dealing with clothing and bedding fires, has been published (1) and a future paper will give an account of building fires. One observation from this study is that there are a fair number of fatal fires caused by smoking in bed, say 18 a year in Ontario (population 6 million), and that often in such cases the only material consumed by the fire is the victim's bedding. In about half the cases the victim is over age 50. It seemed desirable to know more about this kind of fire, and to reproduce experimentally the train of events that follow ignition of a mattress.

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\* Research Officer, Fire Research Section, Division of Building Research, National Research Council of Canada.

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Recently the Fire Marshals Association of North America published a resolution (2) dealing with the hazard of fire to old people in nursing homes, stating that the only practical remedy is a sprinkler system. For fires in general this recommendation has merit, but the Association apparently overlooked the mattress fire that results from smoking in bed. It has yet to be established whether sprinklers are a defence against this type of fire. To avoid misapprehension it should be said that very few of the Ontario fatal bedding fires took place in nursing homes; they were mostly in residences and rooming houses.

The experiments to be described consist of two series. In the first, methods of protecting mattresses from ignition by cigarettes were tried. In the second, mattresses were burned in a simulated bedroom to ascertain the mechanism that leads to the deaths of the occupants, and how quickly it acts.

## SERIES I

### Materials

Old cotton mattress cut into 6-in. squares  
Cotton sheeting, 3.8 oz/sq yd  
Polyethylene sheet, 0.010 in. thick, clear  
Vinyl sheet (polyvinyl chloride), 0.008 in. thick, clear  
Wool blanket scraps, 13 oz/sq yd, used previously for  
experiments on laundering  
Wool blanket received from a hospital  
Mixture blanket: 75 per cent wool, 25 per cent orlon, 13.2 oz/sq yd  
Heavy cotton twill, stated to have been treated with a commercial  
launderable fire retardant and then washed 12 times  
Similar but untreated heavy cotton twill  
Cigarettes of various brands, with and without filters.

All materials were conditioned to equilibrium with 15 per cent RH and 73° F before use.

### Method

The mattress section was placed on an asbestos board in a fume cupboard. The forced ventilation was turned down to the minimum setting. Various combinations of the materials were placed on the mattress, the cigarette was lit, the cupboard window lowered to a 1-in. opening, and the result awaited.

Trials were made to examine the effect of layers of sheeting below and above the cigarette. One layer above prevents the cigarette from rolling, and one layer both below and above make little difference to the severity of the test. This arrangement was consequently adopted as standard.

## Results

The mattress alone or with the standard sheeting arrangement ignited consistently. Polyethylene softened, perforated and shrank away from the hole, permitting ignition of the mattress. Vinyl sheeting prevented ignition, as did both samples of woollen blanket. The orlon mixture blanket also prevented ignition, but the scorch beneath it was more pronounced than that beneath a pure wool blanket.

The treated cotton twill prevented ignition, but the similar untreated twill did not.

The differences between kinds of cigarette did not seem to be important. Half a cigarette was usually sufficient for ignition; in the event that ignition did not result, the experiment was repeated with a whole cigarette.

The mode of burning of a mattress ignited in this way is interesting, and different from that of the more common kinds of fire. A combustion front spreads out slowly in all directions through the material. No flame or visible glow appears and the material is not entirely consumed, but progress is shown by blackening of the material and the release of heat and smoke. Measurements show that the combustion front progresses at a speed of about 0.38 cm per minute.

## SERIES II

### Experimental Details

The experiments were conducted in a simulated bedroom, which was an 8-ft cube. A mattress was placed on a simulated bed 2 ft above the floor and a cigarette lighted and placed horizontally on it.

Gases were sampled for analysis from a collector positioned directly above the mattress, 1 ft from the ceiling. Figure 1 is a flow chart of the analysis apparatus. The gases were pumped into a 5-gal reservoir by means of an air pump capable of delivering at a rate of 3 cfm, then sent through appropriate devices for analysis for carbon dioxide, carbon monoxide, and oxygen. Water vapor and other condensable combustion products were removed by means of filters and traps prior to measurement. Infrared absorption gas analysers were used for carbon dioxide and carbon monoxide determination. The full-scale ranges were 0 to 5 per cent CO<sub>2</sub> and 0 to 0.3 per cent CO; response times were 0.5 sec to 90 per cent of final reading and rated accuracies were  $\pm 1$  per cent of full scale. The two instruments were connected to potentiometer-type recorders. Because of the limited range of the CO analyser, a dilution system using air was set up by which concentrations up to 0.3 per cent could be determined. A constant temperature bath was used to eliminate the error on the sampled gas-air mixing ratio that could be caused by differences in temperature. Figures 2 and 3 give the measured concentrations of carbon monoxide and dioxide.

Oxygen concentrations were determined by a direct reading instrument of the magnetic susceptibility type. The instrument had a full-scale range of 0 to 25 per cent oxygen and a rated accuracy of  $\pm 1$  per cent of full scale. Figure 4 gives the oxygen concentrations. The three instruments for gas analysis were calibrated against appropriate gas mixtures of known composition.

Temperature recordings were made by means of a chromel-alumel thermocouple located near the "gas collector" and connected to a millivolt potentiometer. Smoke measurements were made (except for the first experiment) by placing a smoke meter under the bed. Figures 5 and 6 give temperatures and smoke densities.

The smoke meter was roughly the same as that used in the "St. Lawrence Burns"(3). A further measure of smoke was provided by visual observation of a 100-watt bulb on the far wall about 8 ft from the window, with a switch outside.

The rate of progress of combustion was observed by drawing circles on the mattress before each experiment and timing the spread to each circle as long as visibility permitted. Cotton, spring filled mattresses were used. After the first trial it was apparent that one-half of a mattress (cut transversely) was sufficient. Experiments 2 to 5 were therefore conducted using one half of a mattress each.

The experimental conditions were as follows:

- No. 1: Trial run with Mattress A.
- No. 2: Mattress B; the gases that passed through the CO<sub>2</sub>, CO and O<sub>2</sub> analysers were returned to the room. Ventilation was reduced to a minimum by sealing any openings to the room with adhesive tape.
- No. 3: Mattress B; the gases were discharged outside.
- No. 4: Mattress C; gases discharged outside. Door position was fixed to provide an opening of 1 in.
- No. 5: Mattress C; gases discharged outside. Door position was fixed to provide an opening of 2 in.

### Results

In Experiment 2 the ventilation was minimal and appears to have limited the development of the fire. In Experiment 3 the slight extra ventilation caused by sampling gas and not returning it to the room seems to have produced higher concentrations of CO<sub>2</sub> and CO. In both, the ratio of CO to CO<sub>2</sub> remained roughly at 1 to 10. The CO production was in good agreement with what would be expected from a fire spreading radially through a 3-in. layer of cellulose of the observed density (0.065 gm/cm<sup>3</sup>) at the observed rate (0.38 cm/min). Most of the heat of combustion was lost by convection to the walls.

Experiments 4 and 5, with the door opening fixed at 1 and 2 in. produced more vigorous combustion and higher temperatures but lower concentrations of combustion products. To understand this it should be remembered that loss of gases in Experiments 2 and 3 was negligible, but that heat loss from the gases in the room was substantial in all experiments.

The correlation between visibility of the lamp and smoke density below it was poor: with the door closed a fairly homogeneous smoke mixture was gradually attained by convection; with it open the inflow was fast enough to maintain clear air below the bed.

In the development of these mattress fires two regimes may be distinguished:

- I "Smouldering": Radius of burning area increasing linearly with time: system controlled by rate of propagation through wadding.
- II "Free-burning": Rate of increase proportional to size of fire.

Experiments 2 and 3 never went beyond Regime I. No. 2 reached a limit, presumably imposed by air supply.

Experiments 4 and 5 switched to Regime II between 65 and 80 min when the temperature at the thermocouple was 40 to 45°C. In Experiment 5, flames were detected at 84 min (110°C), and may have been present throughout Regime II since visual observation was handicapped by the smoke. The fires were extinguished before they were limited by their air or fuel supplies.

### Survival

It is important to know how long anyone could live under the conditions obtaining in the test room and what factors would eventually be responsible for his death.

To estimate duration of survival it is necessary to know the quantities of the toxic factors present, and to know also how these factors separately and together influence survival. The quantities were measured by the methods described above, and information on survival from the literature is discussed in Appendix A. It must be appreciated that products of combustion other than those measured were present and might well reduce a victim's survival period.

If the equation for this is correct, then with the concentrations of carbon monoxide and carbon dioxide found in Experiment 3 the lethal condition would be reached in 67 min. The same condition would be reached in 73 min without the CO<sub>2</sub> but with the same concentrations of CO.

This is the situation with no ventilation. At the end of this time the temperature rise would be no more than about 15 Celsius degrees, so that heat would not contribute much to the lethal effect, nor would it open a

sprinkler head. Neither would oxygen deficiency be serious.

With 2 in. of door opening, exposure to the reduced concentrations of carbon monoxide would not be lethal until 86 min. When CO<sub>2</sub> and heat are allowed for, this becomes 80 min. All these estimates are upper limits and would be accurate only if there were no synergism; it is unlikely that synergism is in fact absent.

Figure 7 shows the accumulating effect of the toxic influences, as indicated by Equation 4 of Appendix A.

To summarize this speculation on toxicity, if with no ventilation a victim's endurance is exhausted in about 70 min, and with a door ajar by 2 in. in about 80 min, it may be concluded that the ventilation makes only an unimportant difference to a victim's period of survival.

At time 70 min, temperatures adjacent to the sprinkler head had risen from their initial values by 11, 17, 16 and 35 Celsius degrees in Experiments 2 to 5. Thus if they had each started from 20°C, and given that the lowest standard rating for sprinklers is 135°F or 57°C (4), it is clear that a sprinkler would operate too late to save life in this kind of fire.

## CONCLUSIONS

Anyone who ignites a mattress and does not wake within 70 to 80 min will probably not survive; his death will have been due primarily to the effects of carbon monoxide, but partly to those of carbon dioxide and heat. If it is not feasible to discourage or prevent people from smoking in bed, an effective defence measure is to place a layer of protective material between sheets and mattress. Among effective materials are woollen blankets, certain types of plastic sheeting, cotton cloth treated with a commercial launderable fire retardant, and the materials examined by Hammack (5). These will not prevent charring damage to a mattress, but should prevent ignition. Which is most suitable will be determined by considerations other than their fire properties.

Automatic sprinklers, though well-established as a defence against many other types of fire, will not alone serve to defend life against mattress fires.

REFERENCES

1. Williams-Leir, G. Deaths From Clothing and Bedding Fires. Can. J. Public Health, Oct. 1967.
2. Resolution of Fire Marshals Association of North America, 17 May 1965; Fire J., 59, 24, Sept. 65.
3. Shorter, G.W. and others. The St. Lawrence Burns. National Fire Protection Association Quarterly, 53, 4, Apr. 1960, p. 300.
4. National Fire Protection Association Standard for the Installation of Sprinkler Systems No. 13, p. 84, 1965.
5. Hammack, J.M. Cigarette Ignition of Bedding. Fire J. 59, 9, May 65.

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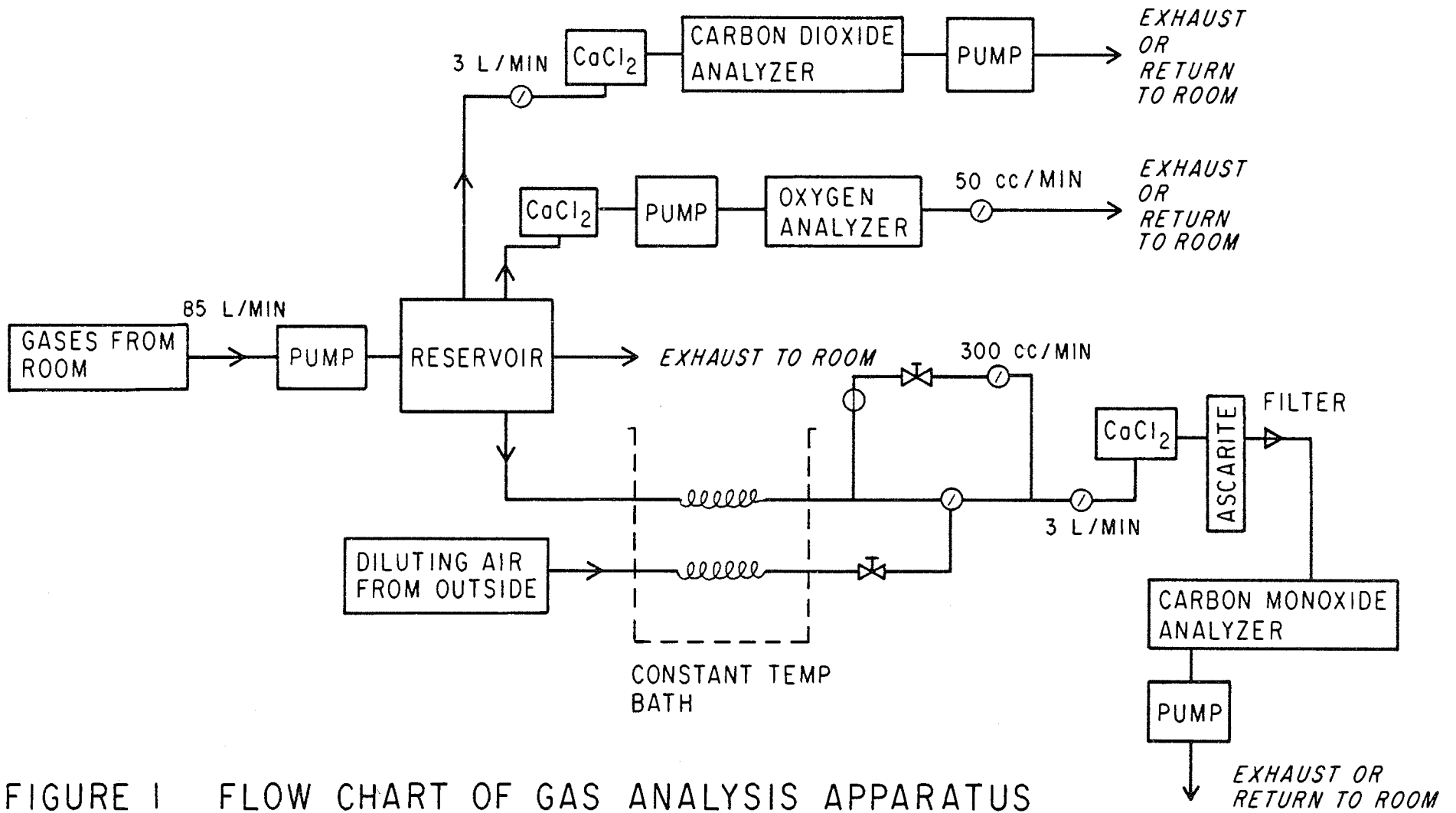


FIGURE 1 FLOW CHART OF GAS ANALYSIS APPARATUS

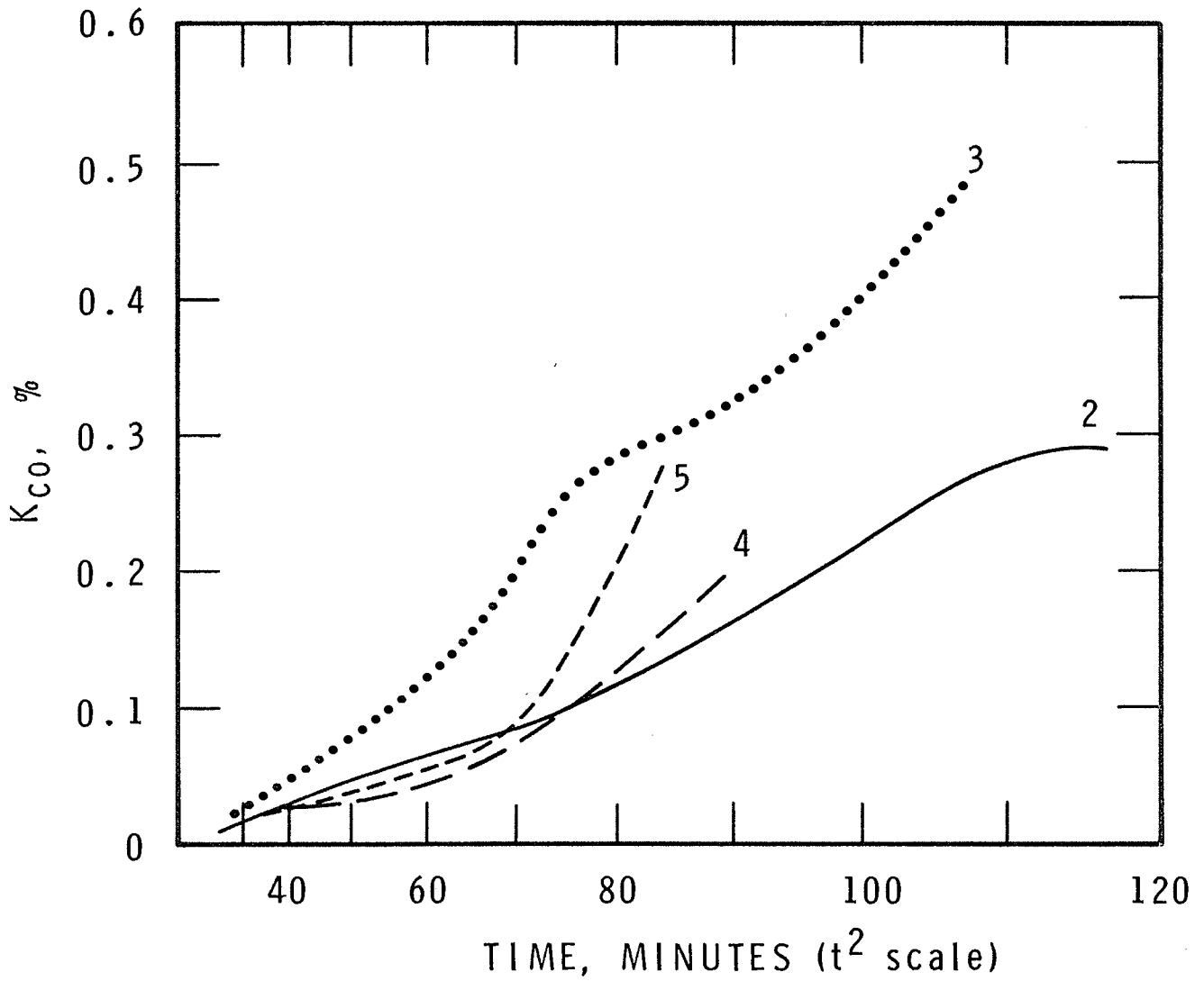


FIGURE 2  
CARBON MONOXIDE CONCENTRATION

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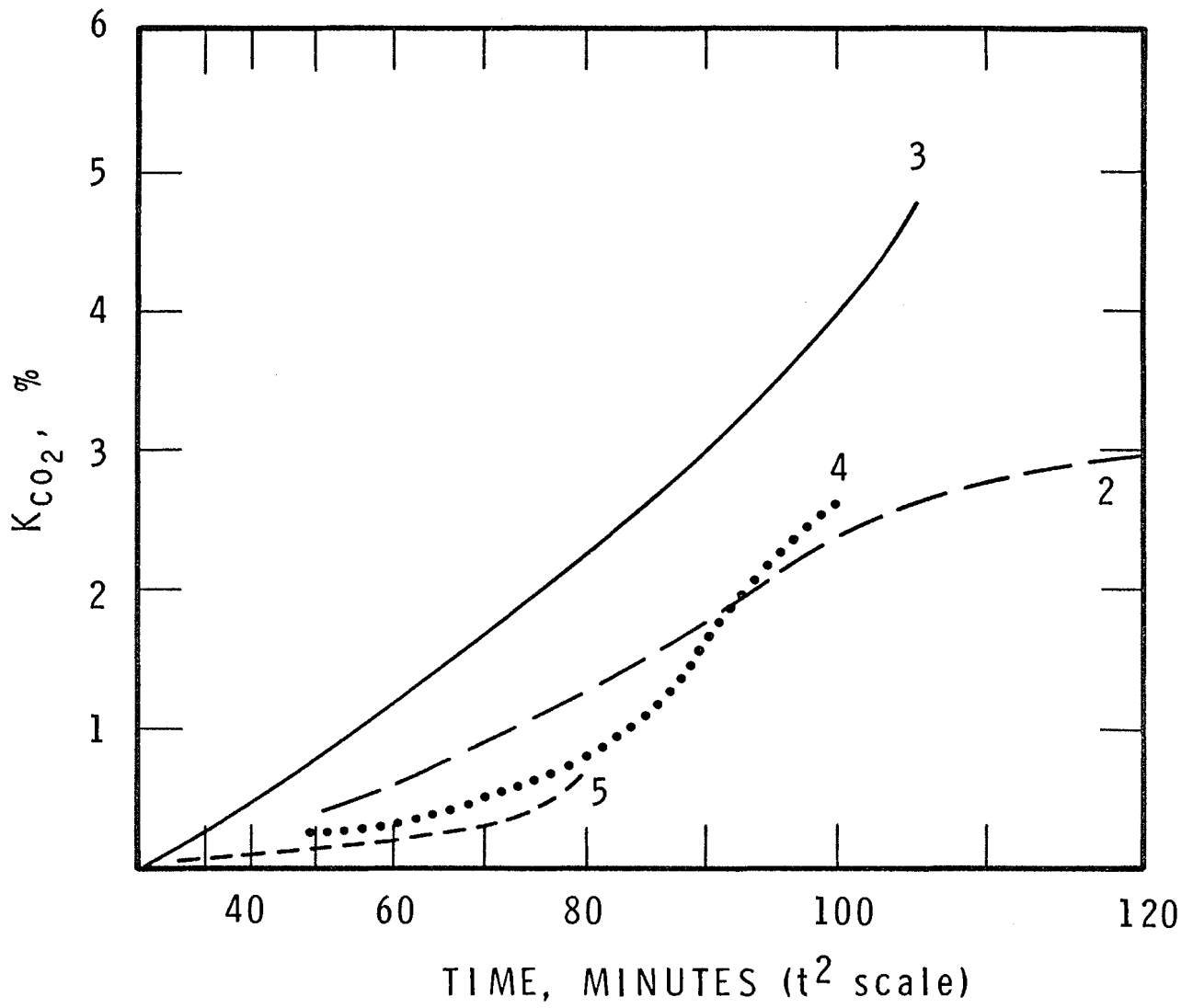


FIGURE 3  
 CARBON DIOXIDE CONCENTRATION

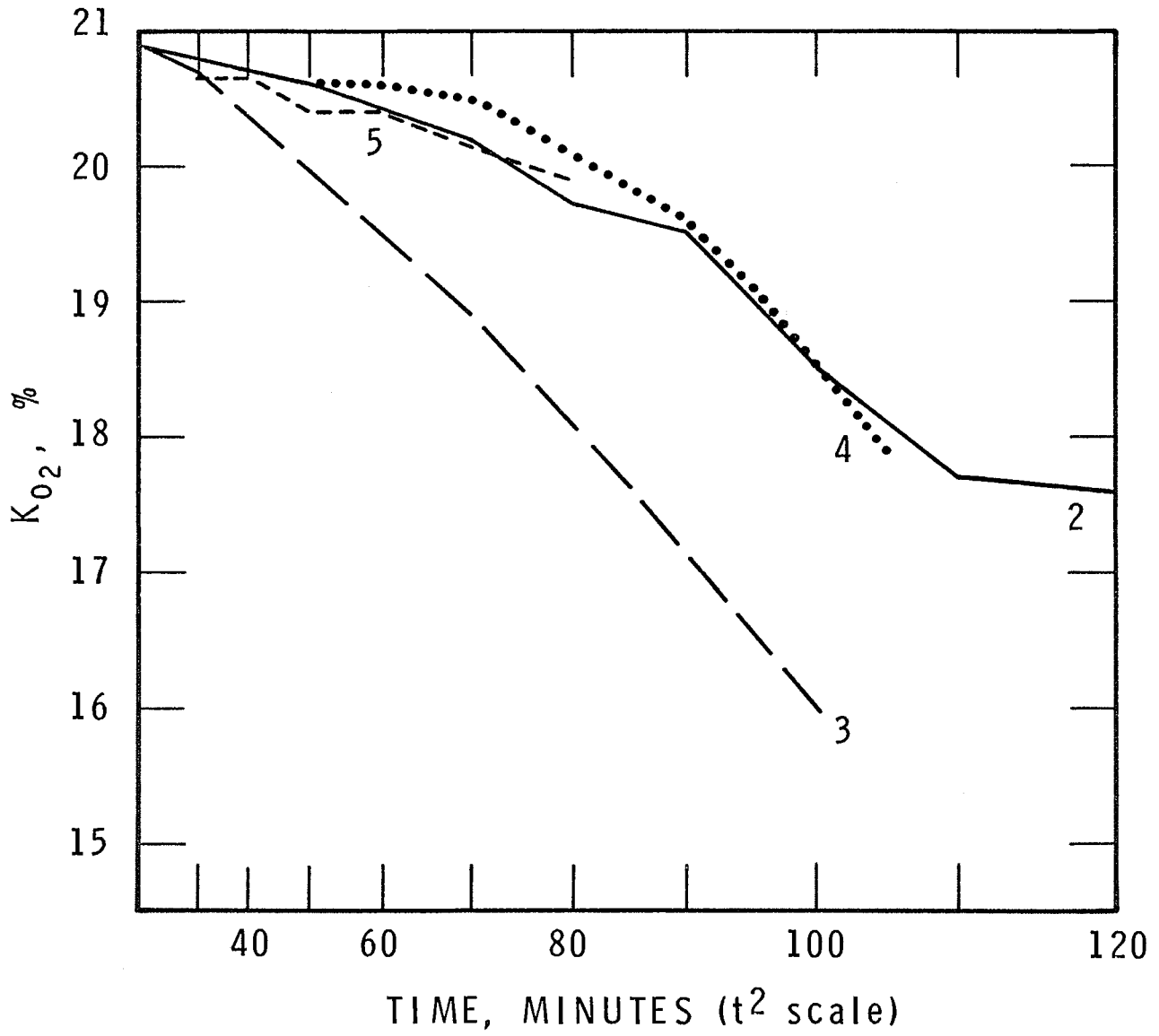


FIGURE 4 OXYGEN CONCENTRATION

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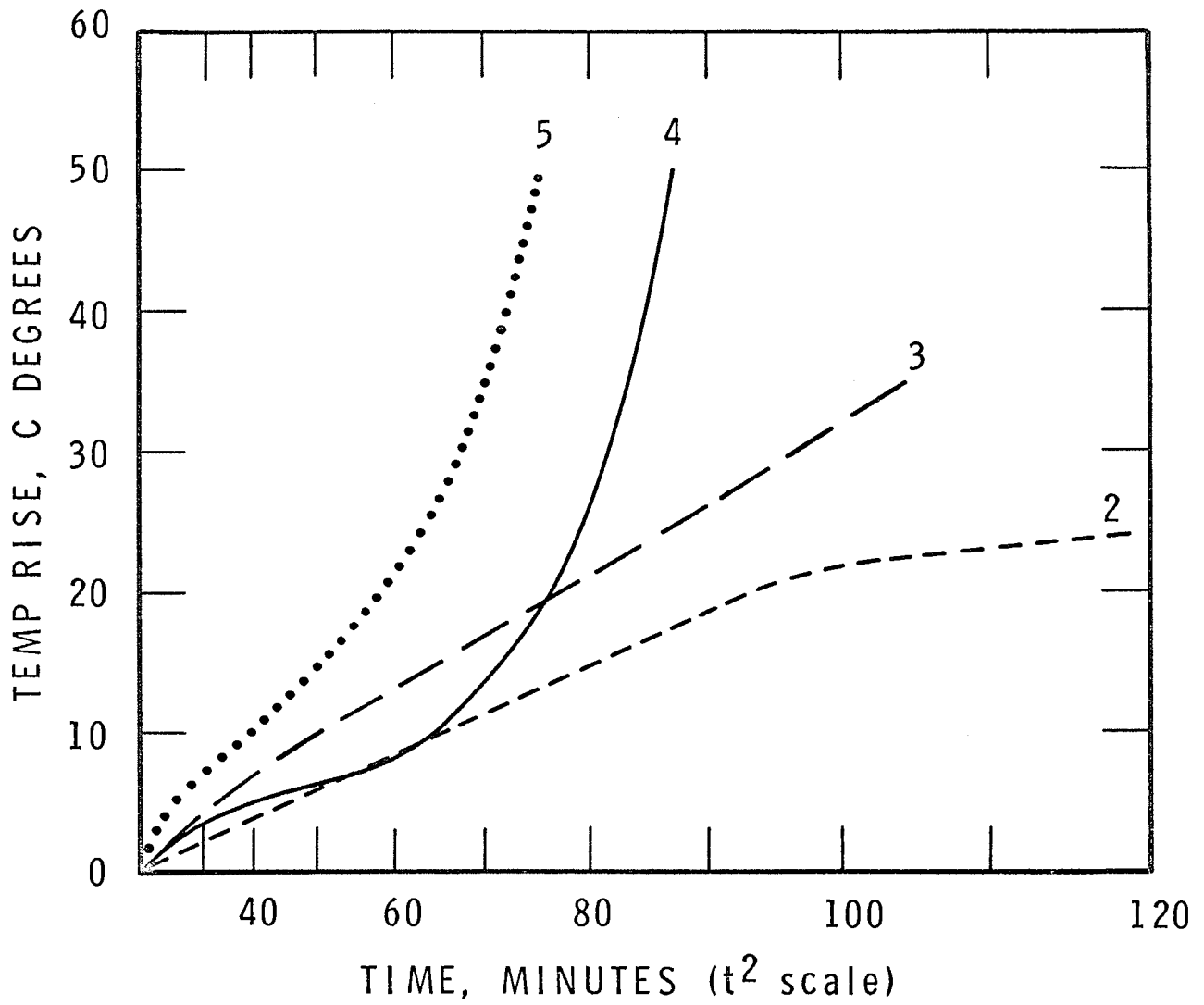


FIGURE 5  
 TEMPERATURE RISE, NEAR CEILING

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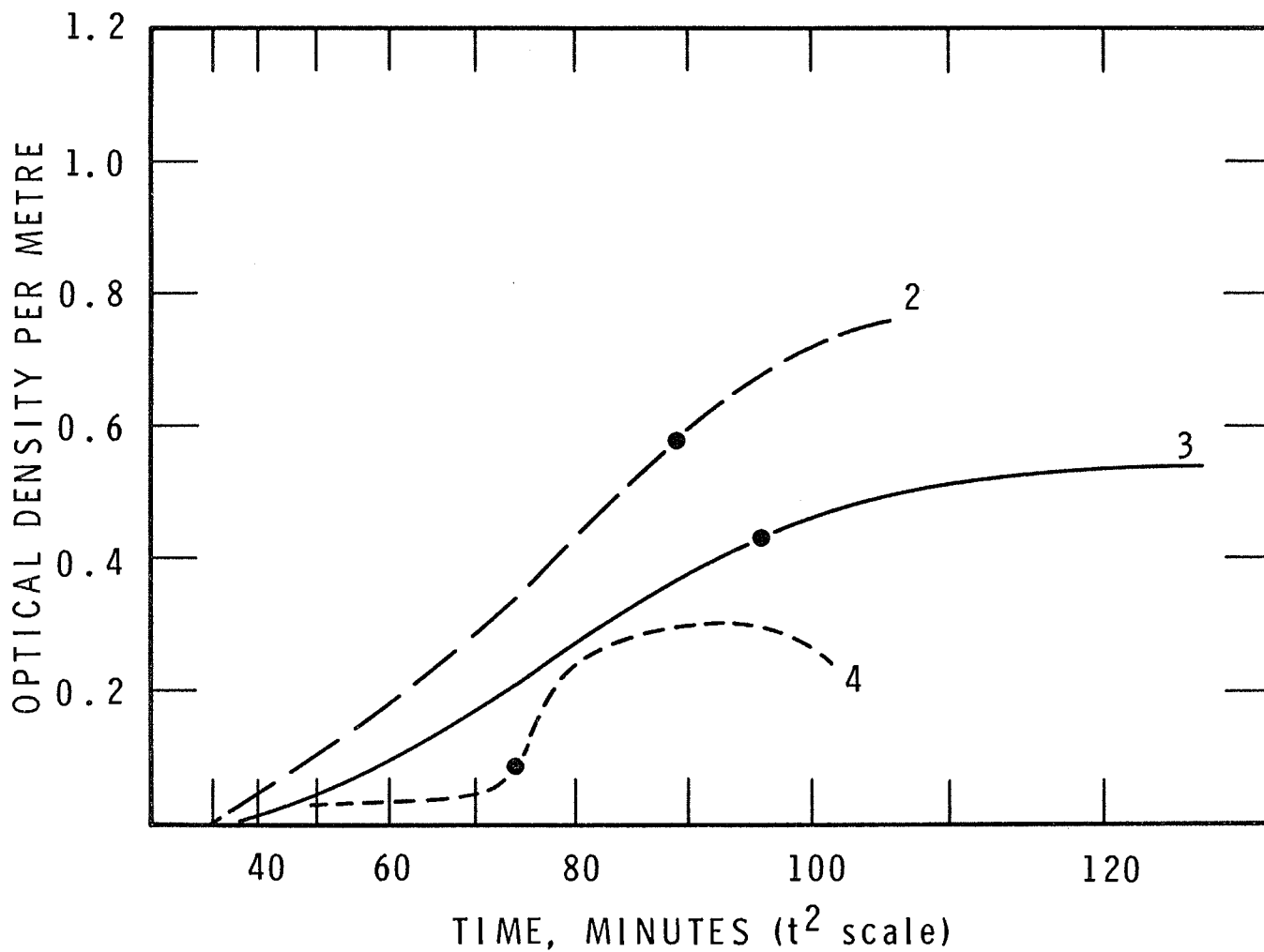


FIGURE 6

SMOKE DENSITY NEAR FLOOR  
 (Lamp above bed visible until ● )

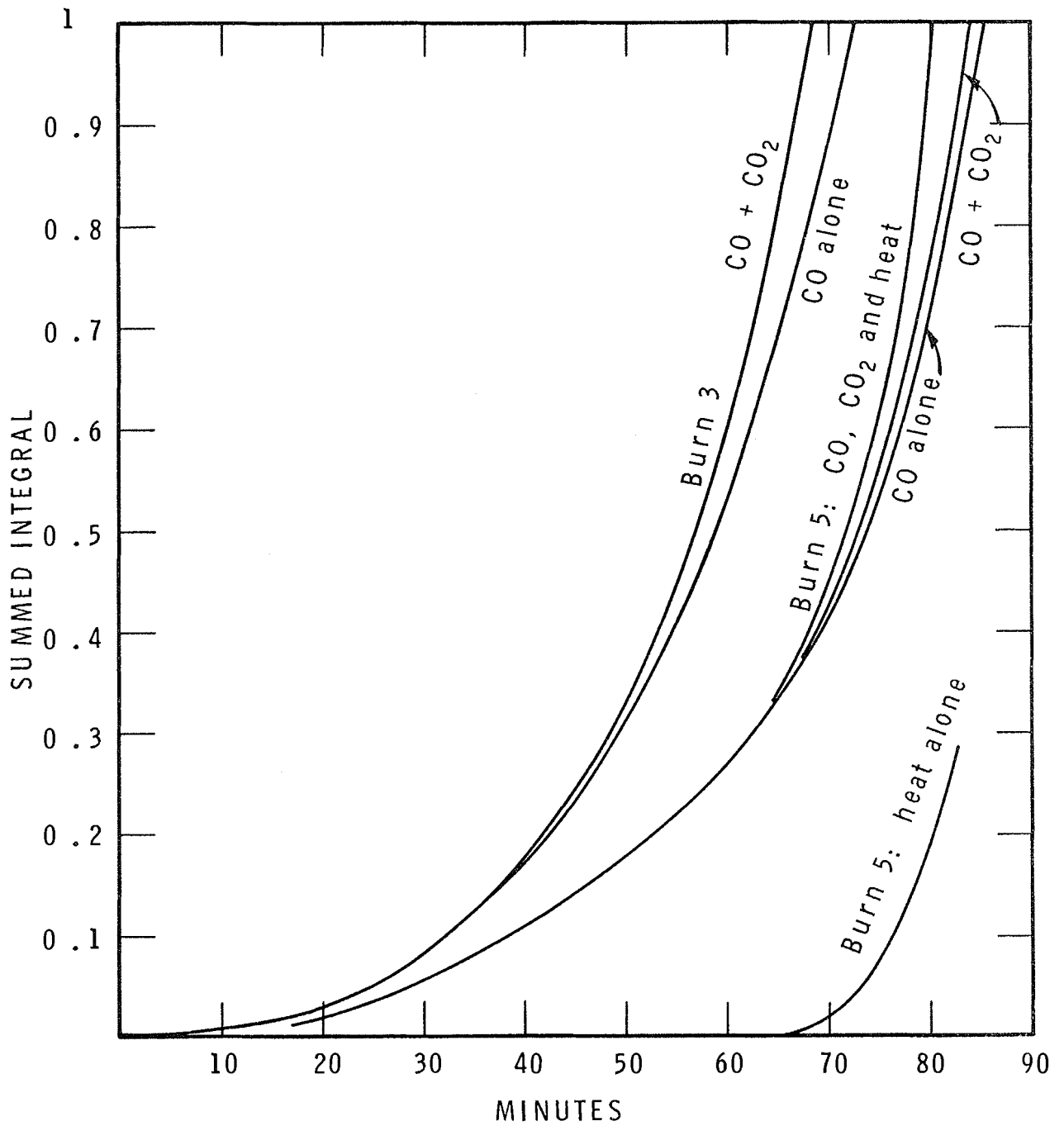


FIGURE 7

TOXIC EFFECT AND ITS COMPONENTS, NUMERICALLY INTEGRATED

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## APPENDIX A

The duration of human survival under extremely adverse conditions is related to the severity of those conditions; the more severe the conditions the shorter the survival. Quantitative data are scanty and it is not to be expected that any precise relation can be found.

The chemical asphyxiant, carbon monoxide, as far as is known, is the worst single hazard of those to which the victim is exposed. Others include heat, carbon dioxide, oxygen deficiency, and the effects of certain products of incomplete combustion such as aldehydes. Henderson and Haggard (A-1) state that a dangerous condition exists when the product of concentration of CO in per cent and exposure time in minutes equals 9. It seems reasonable to take half this exposure as sufficient to prevent the victim from escaping in time. This may be generalized for varying concentrations as follows (A-2):

$$\int_0^T \frac{K_{co} dt}{4.5} = 1 \quad (1)$$

where  $K_{co}$  is the concentration of carbon monoxide (per cent)

$T$  is the maximum time available for escape (minutes)

Up to a certain concentration of carbon dioxide, the body is unharmed because it can maintain normal conditions in the lungs by an automatic increase in breathing. Similarly the body adjusts to heat by sweating. Presumably any excess over the tolerable level can be integrated in the same way as with carbon monoxide, for which the tolerable level is very low.

Pryor and Yuill (A-3) have recently collected the data shown in Figures A-1 and A-2; these make it possible to assign numerical values to the constants in equations for survival time analogous to Equation (1):

For carbon dioxide (A-4, A-5),

$$\int_0^T \frac{(K_{co2} - 5.7) dt}{30} = 1, \quad K_{co2} > 5.7 \quad (2)$$

Similarly for the temperature of still dry air, in Celsius degrees (A-6, A-7):

$$\int_0^T \frac{(\theta - 45) dt}{1600} = 1, \quad 45 < \theta < 120 \quad (3)$$

If two or more insults to the body are offered together, we may say they are additive if:

$$\sum_{k=1}^n \int_0^T \frac{(X_k - c_k) dt}{b_k} = 1 \quad (4)$$

where  $X$  is the measure of the  $k$ -th insult

$c_k, b_k$  are constants.

This provides a means of estimating survival time if it can be assumed that the effects of heat and toxic gases are additive. In practice, synergism probably is present in many cases; for example, the presence of  $\text{CO}_2$ , by increasing respiration, will accelerate the uptake of any substance with high affinity for hemoglobin, such as  $\text{CO}$ , that may be present. Rasbash recently pointed out (A-8), that this effect should be calculable for  $\text{CO}_2$  and  $\text{CO}$  together:

$$\int_0^T \frac{K_{\text{co}} C_{\text{co2}} dt}{4.5(C_{\text{co2}} - K_{\text{co2}})} = 1, \quad K_{\text{co2}} < C_{\text{co2}} = 5.5.$$

## REFERENCES

- A-1 Henderson, Y. and H. W. Haggard, Noxious Gases and the Principles of Respiration Influencing Their Action, 2nd ed., Reinhold 1943, p. 168.
- A-2 Minchin, L. T. Mild Carbon Monoxide Poisoning as an Industrial Hazard. Industrial Chemist, 30, No. 355, Aug. 1954, p. 381-5.
- A-3 Pryor, A. J. and C. H. Yuill. Mass Fire Life Hazard. SWRI Project 03-1726, Contract N228 (62479) 68665. OCD Work Unit 2537A.
- A-4 Roth, E. M. Space Cabin Atmosphere, Part 2, Fire and Blast Hazards. NASA-SP48, 1964.
- A-5 Pesman, G. J. Appraisal of Hazards to Human Survival in Aircraft Crash Fires. NACA Tech. Note 2996, Sept. 53.

- A-6 Buettner, Konrad. Heat Transfer and Safe Exposure Time for Man in Extreme Thermal Environment. ASME paper 57-SA-20. June 1957.
- A-7 Blockley, W. V. and C. L. Taylor. Studies of Human Tolerance for Extreme Heat. Report NCREXD-696-113A, USAF, Wright-Patterson AFB, Ohio, Nov. 1948.
- A-8 Rasbash, D. J. Private communication.

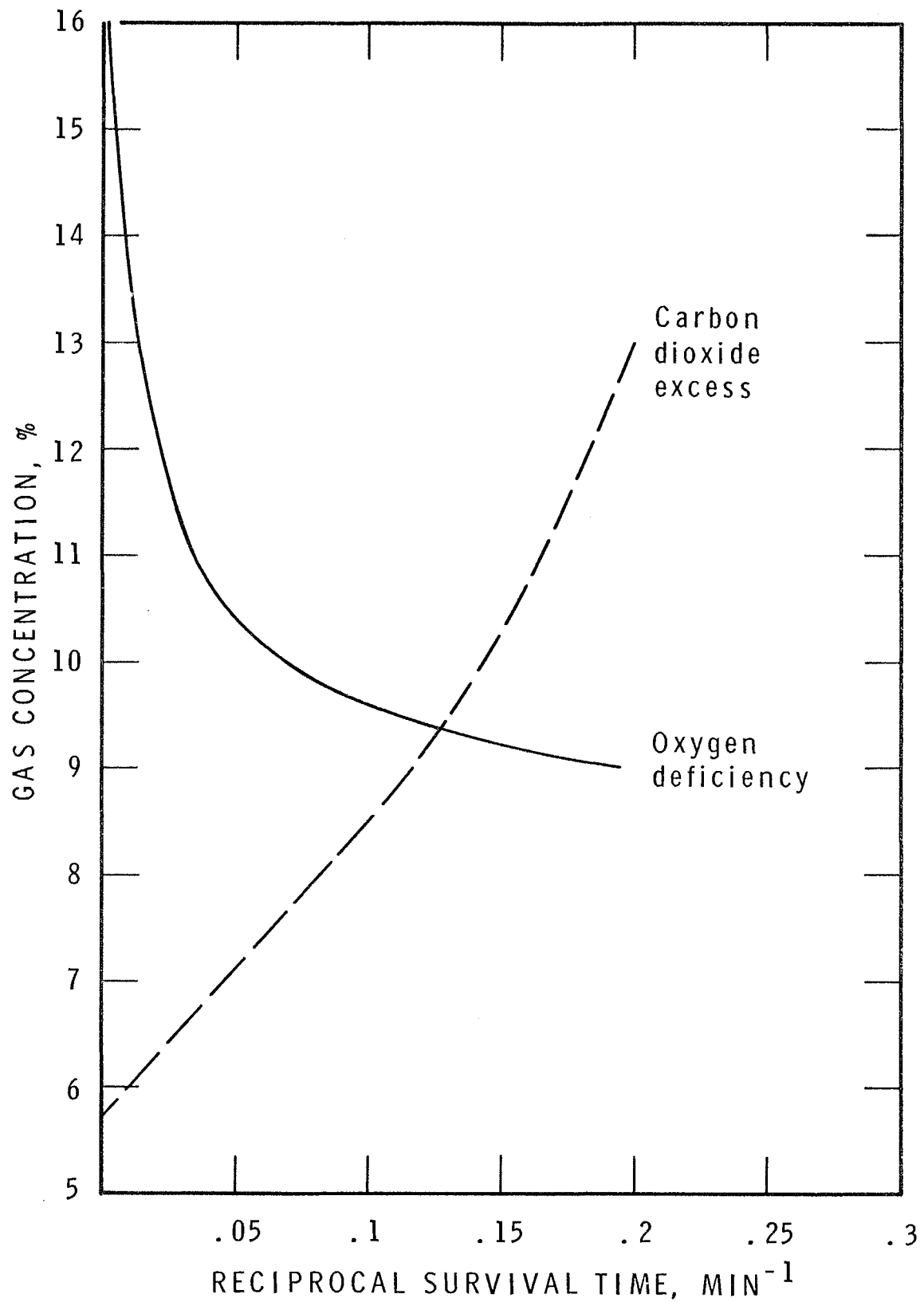


FIGURE A-1  
 HUMAN SURVIVAL IN UNNATURAL ATMOSPHERES  
 (Ref: Pryor & Yuill)

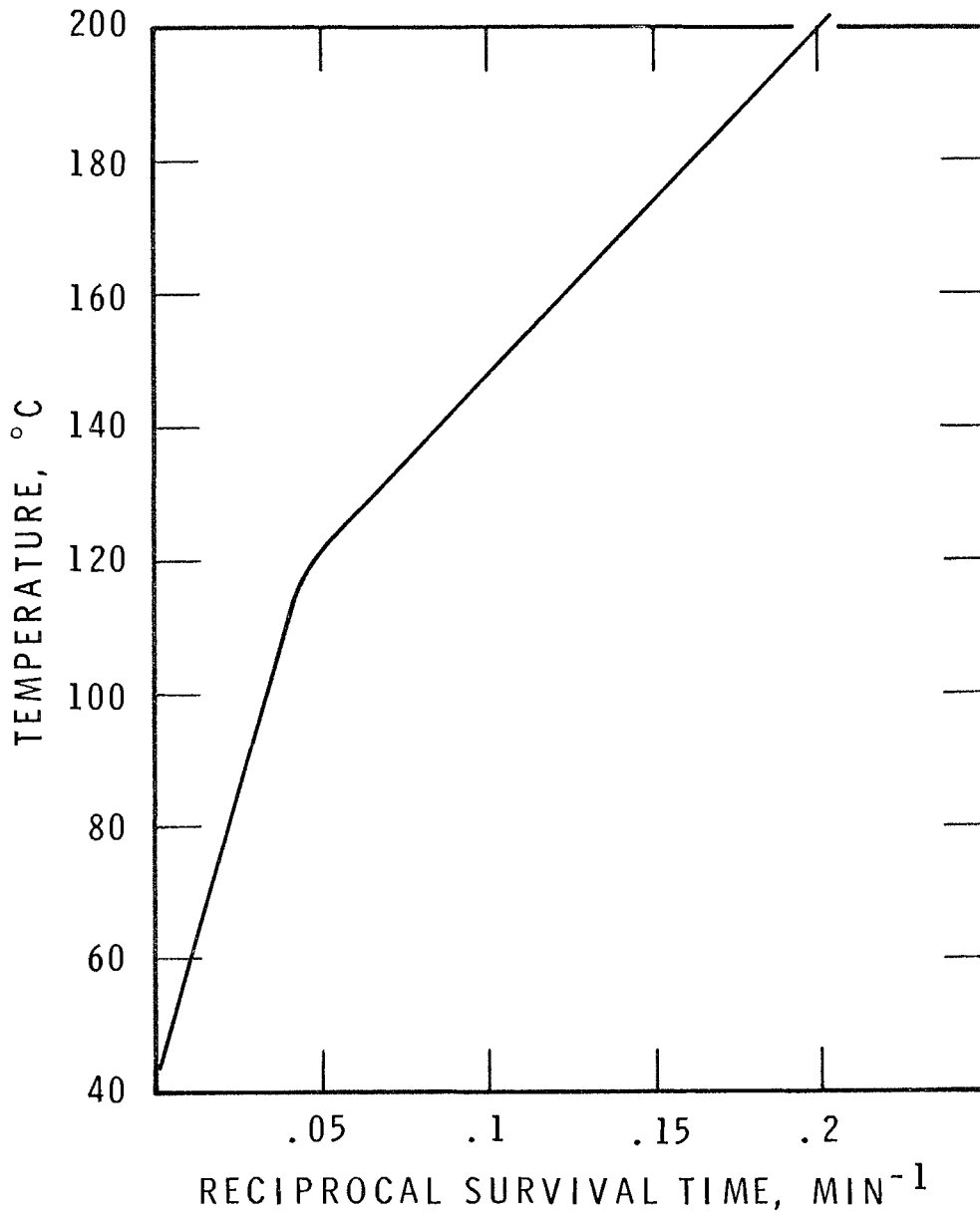


FIGURE A-2  
HUMAN SURVIVAL IN STILL DRY HEAT  
(Ref: Pryor & Yuill)

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