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Source Characterization and Personal Exposure to Methylene Chloride from Consumer Products

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ABSTRACT

A recently completed bioassay, which found methylene chloride (CH_2Cl_2) to be an animal carcinogen, has increased the concern about consumer exposure to this chemical. To provide information on exposures sufficient to conduct a health risk assessment, CH_2Cl_2 source strengths and personal exposures were characterized in a room-size (20 m^3) environmental chamber for representative applications of several paint removers and aerosol finishes as examples of the two major types of consumer products containing CH_2Cl_2. For each product, experiments were conducted at ventilation rates of ~0.5 and ~3 air changes per hour. Altogether, including duplicate experiments, a total of 10 experiments were performed. Both the chamber concentration and the worker's breathing-zone concentration of CH_2Cl_2 were continuously monitored by infrared spectroscopy throughout each experiment. In addition, the source strength of CH_2Cl_2 was determined from product composition and the quantity of product used. Measured personal exposures resulting from the use of paint removers ranged from 1040 to 1200 ppm•h at the high ventilation rate and from 1970 to 2400 ppm•h at the low ventilation rate for work periods of ~90 min. Personal exposures from the use of aerosol finishes ranged from 32 to 35 ppm•h for a single coat of a polyurethane finish and 121 to 124 ppm•h for two coats of a metallic paint for work periods of 23 min or less. Several occupational standards and guidelines for CH_2Cl_2 concentrations were exceeded during experiments with paint removers. When chamber concentrations of CH_2Cl_2 were integrated over the work periods and compared to measured personal exposures, agreement was good at the low ventilation rate but measured personal exposures were higher by 21% at the high ventilation rate. Temporal profiles of CH_2Cl_2 concentrations were calculated from the source strengths, the ventilation rates and the chamber volume using single-equation, mass-balance models. These theoretical concentrations were in good agreement with measured concentrations. Exposure models based upon the concentration models were also developed and then evaluated by comparing theoretical and measured exposures for the experiments. The exposure models appeared to have sufficient accuracy and precision for use in assessment of consumer health risk from the use of consumer products containing CH_2Cl_2.

Key Words: aerosol finish, consumer product, environmental chamber, exposure model, methylene chloride, modeling, paint remover, personal exposure

INTRODUCTION

Methylene chloride or dichloromethane (CH_2Cl_2) is a chemical widely used by consumers in the residential environment. In 1984, domestic production of CH_2Cl_2 in the United States was estimated by the U.S. International Trade Commission to be 607 million pounds (Greek, 1985). Approximately 30% of this CH_2Cl_2 was formulated into paint stripper/removers for both industrial and consumer use. A second major source of consumer exposure to CH_2Cl_2 occurs through its use in a variety of aerosol finishes which accounts for another 20% of CH_2Cl_2 end use.

There is concern about consumer exposure to CH_2Cl_2 from these products since CH_2Cl_2 retained in inhalation is metabolized to carbon monoxide leading to elevated levels of carboxyhemoglobin (Ratney *et al.*, 1974; Stewart *et al.*, 1972). At relatively high exposures, the resulting anoxic stress placed on individuals may pose a health hazard. In addition, a recent National Toxicology Program inhalation bioassay found "clear evidence of carcinogenicity" of CH_2Cl_2 in female rats and in both sexes of mice as well as "some evidence of carcinogenicity" in male rats (National Toxicology Program Board of Scientific Counselors Peer Review Panel, 1985).

Because information about consumer exposures to CH_2Cl_2 from the use of paint removers and aerosol finishes was inadequate, an investigation was undertaken to measure exposures under controlled conditions and to develop a theoretical model from the data which would allow extrapolation of exposures to other conditions. Experiments were conducted with several paint removers and aerosol finishes in a room-size environmental chamber at two ventilation rates. Exposures to CH_2Cl_2 were characterized from continuous measurements of both breathing-zone and chamber concentrations. The source strengths of CH_2Cl_2 were determined for the products and were applied to a single-equation, mass-balance model for predicting exposures. The resulting theoretical exposures were compared to measured exposures.

The base substrates for application of products were 0.74-m^2 (1.22 m x 0.61 m) panels of 1.27 cm thick plywood. For application of paint removers, the panels were painted by roller on one side with a primer coat and two finish coats of an oil-based enamel. Panels for spray paint application were painted with a primer coat only. Unpainted panels were used for polyurethane finish application. All painted substrate panels were concurrently painted and dried at room conditions for over five months prior to use.

Environmental Chamber

Experiments were conducted in a 20-m^3 environmental chamber located in an air-conditioned laboratory. The chamber, illustrated in Figure 1, has interior dimensions of 3.66 m (length) x 2.46 m (width) x 2.23 m (height). All interior surfaces are clad with stainless steel. The walls, floor and ceiling are insulated with a 10-cm layer of high-density polyurethane foam. The door and interior seams are sealed with silicone gasket material. Electrical and plumbing feedthroughs are also sealed. The ventilation rate of the chamber in air exchanges per hour due to natural ventilation is 0.03±0.01 h^{-1}. The chamber is equipped with a single-pass ventilation system. Inlet air is drawn from laboratory room air through a coarse filter by a variable speed blower. Volumetric flow rate is monitored with both orifice-plate and gas-turbine flowmeters (Model 2011-0, Daniel Industries, Inc., Houston, Texas) located in the air inlet downstream of the blower. Air enters the chamber through a diffuser positioned low at one end of a long wall and exits through an outlet located high at the opposite end of the same wall. This configuration is designed to promote mixing within the chamber while approximating typical ventilation patterns in residences. Air is exhausted outdoors. For these experiments, the chamber was operated at either ~0.5 or ~3 h^{-1}.

The volumetric flowrate of ventilation air entering the chamber was continuously monitored throughout each experiment with the gas turbine flowmeter. Calibration of this instrument was checked immediately before and after each experiment by measuring the pressure drop across the orifice-

The IR spectrometers were calibrated using certified-grade CH_2Cl_2 gas standards of 500 and 5000 ppm ±1% in air (Scientific Gas Products, Inc., South Plainfield, N.J.) dynamically mixed with dry air to desired concentrations by an electronic mass-flow-controlled dilution system. Multi-point calibrations over the required analytical range were performed immediately before and after each experiment.

Since toluene, with an analytical wavelength of 13.7 μm, is found in many aerosol finishes, interference by toluene in the analysis of CH_2Cl_2 at 13.3 μm was evaluated. At a CH_2Cl_2/toluene mass ratio of one, no interference in the analysis of CH_2Cl_2 was observed for the instrument used for the chamber sample, while a 5% positive interference was measured for the instrument used for the breathing-zone sample. No correction was made for this interference. Because the IR adsorption bands for water vapor are 2.66, 2.74 and 6.27 μm, water vapor was not expected to interfere. To confirm this, multi-point calibrations were conducted using a closed-loop calibration system over a CH_2Cl_2 concentration range of zero to 665 ppm and humidities ranging from 7 to 83% RH at room temperature. As expected, no interference by water vapor was observed.

The chamber sample was also periodically analyzed for CH_2Cl_2, as well as for other major solvents, with a GC/FID (Model 3700, Varian Instrument Co., Palo Alto, Calif.) equipped with a 10-port heated sample valve, a glass capillary column (SPB-5, 30 m x 0.75 mm ID, 1.0 μm film; Supelco, Inc., Bellefonte, Penn.), and a chromatographic data system (Model 3000K, Nelson Analytical, Inc., Cupertino, Calif.). A portion of the sample gas stream was drawn through a sample loop (0.25 or 0.5 cm^3) at 90 cm^3 min^{-1} regulated by a downstream mass-flow controller. Samples were injected onto the chromatographic column at ~15 min intervals throughout an experiment. Sample loop temperature and pressure at the time of injection were recorded. Gas standards consisting of a mixture of the compounds of interest for a given experiment were prepared in 2-L flasks (Riggin, 1984). These standards were analyzed using the same procedure employed for samples. A multi-point calibration was performed immediately prior to each experiment, and at least one standard was analyzed at the conclusion of each experiment.

and 3.2-cm wide putty knives, cloths, and a thin polyethylene sheet, were taken into the chamber and individually weighed. The polyethylene sheet was placed under the work area. For experiments with aerosol finishes, both the chamber floor and the wall that the panel was positioned against were protected from overspray with an unweighed polyethylene sheet.

After calibrations were completed and the chamber had stabilized at the desired conditions, the worker entered the chamber and the door was sealed. Monitoring of the chamber concentration of CH_2Cl_2 by IR spectroscopy was initiated, and a sample of chamber air for GC-FID analysis was obtained. The worker's activities were monitored through the chamber window and recorded by an observer. At a signal from the observer, the worker put on the breathing apparatus and attached the breathing-zone sampling line. Monitoring of the breathing-zone sample for CH_2Cl_2 was initiated, and the worker began the application procedure.

All products were used according to the manufacturers' instructions printed on the container labels, except for minor deviations in the case of paint remover B. Paint remover B was left undisturbed for times as short as 10 min, rather than the 10-15 min recommended by the manufacturer. The manufacturer also recommended that the stripped surface be washed with a steel-wool pad dipped in a "paint remover wash". This was not done. These deviations were deemed minor and there was no observable difference in the performance of paint remover B relative to paint remover A.

For paint removers, the original container was shaken; a portion of the product was transferred to the 1-L can; and the can and application brush were weighed. Thick coats of product were sequentially applied to the panel surface using single brush strokes in one direction only. The details of the entire paint removal procedure were as follows: (1) paint remover was applied to the first quarter of the panel, the can was covered and the can and brush were weighed; (2) after the remover had remained undisturbed on the first quarter for 10 min, remover was applied to the second quarter of the panel and the can and brush were weighed; (3) softened paint was scraped from the first quarter with the putty knives, and paint scrapings were collected on the polyethylene sheet. This sequence was repeated until each

CH_2Cl_2 was measured as described above just prior to the exit. All sampling and analytical procedures were the same as described for experiments with paint removers.

The work period for experiments with paint removers was defined as the time between the initial pouring of the product into the can and disconnecting the breathing-zone sampling line prior to the worker's exit from the chamber. For experiments with aerosol finishes, the work period was defined as the time between the initial shaking of the product container and disconnecting of the breathing-zone sampling line.

MODELING

A single-equation, mass-balance model which describes the average volume concentration of a pollutant in an enclosed space (Turk, 1963) was used to calculate theoretical temporal concentration profiles of CH_2Cl_2 in the chamber for all experiments. The model has been used in evaluating a variety of indoor air pollution sources (Traynor *et al.*, 1985). It assumes that exfiltrating air and indoor air have the same average pollutant concentrations. The mathematical expression for the change in indoor pollutant concentration is:

$$dC = PaC_o dt + \frac{S}{V} dt - (a + k)Cdt, \qquad (1)$$

where:

- C = indoor pollutant concentration (ppm or mL m^{-3});
- C_o = outdoor pollutant concentration (ppm or mL m^{-3});
- P = fraction of the outdoor pollutant level that penetrates the enclosed space (unitless);
- a = ventilation rate in air changes per hour (h^{-1});
- S = indoor pollutant source strength (mL h^{-1});
- V = volume (m^3);
- k = net rate of removal processes other than ventilation (h^{-1});
- t = time (h).

actively emitting the pollutant. Once product application stops and the source term returns to zero, the pollutant concentration will begin to decay as determined by the pollutant removal rate. A general solution for exposure which covers the periods of both pollutant emission and decay is:

$$\int_0^{t_2} C(t)dt = \int_0^{t_1} C(t)dt + \int_{t_1}^{t_2} C(t)dt$$

$$= \frac{St_1}{(a + k)V} - \frac{C(t_1)}{(a + k)} e^{-(a + k)(t_2 - t_1)} \qquad (5)$$

where the source is emitting at a constant rate from t=0 to $t=t_1$ with constant a and k and then immediately decreases to and remains at zero from $t=t_1$ to $t=t_2$.

RESULTS AND DISCUSSION

Product Composition

The percent weight compositions of the components of the four products are shown in Table 1. The compositions of the volatiles in paint removers are averages of three or four analyses; all other compositions are averages of duplicate analyses. Precision estimates are shown as standard deviations. As determined by our analysis, the percent weight composition of the volatile fraction of the metallic paint was 136%. For purposes of comparison, the percent weight compositions of the volatile compounds from the analysis of this product were multiplied by one minus the fractional composition of non-volatiles and divided by 1.36 to yield a total weight composition of 100% for the product. The relatively low precision and the inaccuracy in the analysis of the volatile compounds in the aerosol finishes were due, in part, to the small sample aliquots which were difficult to weigh accurately and which may not have been uniformly representative of the contents of the product containers. By our analyses, the two aerosol

atmospheric conditions, to limited humidity control and to differences in respiration and perspiration rates. The highest respiration and perspiration rates occurred during the use of paint removers because of the physical exertion of scraping paint. The result was high water vapor concentrations which, in low ventilation rate experiments, decayed slowly.

CH_2Cl_2 Concentrations

Quantitative data for CH_2Cl_2 were obtained by GC/FID from the periodic analyses of the chamber sample. All of the concentrations measured with GC/FID during the experiments were compared to concentrations measured concurrently with the IR spectrometer used for the chamber sample. The relationship between the two variables was defined with Bartlett's three-group method for regression (Sokal and Rohlf, 1969) which is an appropriate method when both variables are subject to measurement error. Concentration of CH_2Cl_2 measured by GC/FID, Y, was related to concentration measured by IR spectroscopy, X, by the equation $Y = 1.31X - 40.8$. The good fit of the regression line to the data was indicated by a 95% confidence interval of 1.30-1.32 for the slope. When the relationship between the variables was examined by product type, the concentrations were related by the equation $Y = 1.29X - 5.8$ for experiments with paint removers and by the equation $Y = 1.17X - 27.7$ for experiments with aerosol finishes. The better agreement between the analytical methods with aerosol finishes was due, in part, to the relatively low concentrations in these experiments.

Attempts to identify the source(s) of the difference between the analytical methods were unsuccessful. As a check on the accuracy of the IR data, the IR spectrometers were calibrated using the alternate method of injecting liquid standards into a closed-loop calibration system. Calibration curves obtained by this method were identical to those obtained by the dilution of the calibration gas standards. Because (1) these calibrations agreed, (2) the GC/FID was calibrated by a less direct method, and (3) the IR spectroscopic data were conservative, concentrations of CH_2Cl_2 in air measured by IR spectroscopy were used throughout this paper except where noted.

The peak chamber concentrations of CH_2Cl_2 produced by the use of paint removers were high and ranged from 950 ppm (Experiment 1) to 3000 ppm (Experiment 4). Peak breathing-zone concentrations averaged approximately 30% higher than peak chamber concentrations, reaching a maximum of 3300 ppm in Experiment 4.

However, it must be noted that these concentrations are specific to the chamber volume, the chamber ventilation rate and the amount of product used. In actual practice, the concentrations produced by consumer use of these products will depend upon variations in these parameters.

Ideally, the concentrations of CH_2Cl_2 in these experiments should be evaluated against established indoor air quality guidelines or standards. However, there are no non-occupational indoor air quality guidelines for CH_2Cl_2 . Because of this lack, concentrations of CH_2Cl_2 in this study were compared to occupational air quality standards. Such a comparison may not be appropriate due to differences in the composition of the population that is exposed, occupational versus consumer (Albert, 1983). Nevertheless, the comparison is useful because it lends perspective to the observed concentrations. The U.S. Occupational Safety and Health Administration (OSHA) has set occupational standards for CH_2Cl_2: 500 ppm for the 8-h time-weighted average concentration; and 1000 ppm for the acceptable ceiling concentration with a maximum exposure of 5 min in any 2 h but never to exceed 2000 ppm (U.S. Government, 1985). The Threshold Limit Values (TLV) for CH_2Cl_2 are 100 ppm for the 8-h time-weighted average concentration (TLV-TWA) and 500 ppm for the 15 min time-weighted average concentration (TLV-STEL), not to be repeated more than four times per day with at least 60-min between exposures (American Conference of Governmental Industrial Hygienists, 1984). It should be noted that there currently is a proposal to delete the TLV-STEL for CH_2Cl_2. It should also be noted that these guidelines were developed on the basis of acute health effects (American Conference of Governmental Industrial Hygienists, 1980) and do not reflect recent bioassays which have shown evidence of carcinogenicity.

As illustrated by Figures 2 and 3, both the 100-ppm and 500-ppm concentration levels were exceeded in all experiments involving the use of

integrating the temporal profiles of breathing-zone concentrations over the previously defined work periods. For these calculations, breathing-zone concentrations during the periods of stratification measurements (~4 min duration) were averages of the breathing-zone concentrations immediately preceding and following those measurements, rather than the concentrations from the stratification measurements. The personal exposures are shown in Table 3 along with the durations of the work periods and the masses of products and CH_2Cl_2 used. Exposures to CH_2Cl_2 were considerably higher from the use of paint removers than from the use of the aerosol products due to the longer work periods and the greater masses of CH_2Cl_2 used. The highest personal exposures (1970 and 2400 ppm·h) occurred as the result of paint remover use at the low chamber ventilation rate. Between the two aerosol finishes, application of two coats of the metallic paint resulted in the highest personal exposures; however, these exposures were approximately a factor of 10 lower than the personal exposures from the use of paint removers. The variation in personal exposures between duplicate experiments was 7% for the paint remover and 2% for the metallic paint.

Additionally, to determine whether chamber concentrations could be used to estimate personal exposures, the temporal profiles of chamber concentrations were integrated over the work periods to produce chamber exposures, and these were compared to the measured personal exposures (Table 3). At high ventilation rates, measured personal exposures were consistently higher than chamber exposures by an average of 21%, while at low ventilation rates, the two exposures were equivalent in three of four experiments. The mean of the ratio of personal exposure to chamber exposure for high ventilation rate experiments (1.21 ± 0.06, $n=6$) was compared to this ratio for low ventilation rate experiments (1.05 ± 0.08, $n=4$) with a Student's t-test and found to be significantly different ($t=2.48$, $0.05>P>0.02$).

The good agreement of personal exposures to exposures estimated from chamber concentrations in the low ventilation rate experiments presumably resulted from the relatively good mixing of air that occurred because of the long residence times for chamber air under these conditions. At higher ventilation rates, the air in the chamber may have been less well mixed,

volatile compounds. This large injection was followed by the slower evaporation of compounds as the finishes dried, but this release was relatively minor.

Initially, the chamber concentration of CH_2Cl_2 in the experiments with aerosol finishes was determined by the amount of product that was used in the first application and by the volume of the chamber. The ventilation rate had little effect on this concentration, since there was insufficient time during the application period for the concentration to decay by flushing the chamber. Because the experimental work periods were short, the exposures occurred predominantly while concentrations were near their peak values and not during the more prolonged decay periods when the effects of ventilation were important. Thus, despite ventilation rates that were higher by a factor of 5.8, the exposures estimated from the chamber concentrations in the high ventilation rate experiments averaged 71% of the exposures in low ventilation rate experiments. The personal exposures in the high rate ventilation experiments averaged 83% of those in the low ventilation experiments. As these percentages indicate, ventilation was not very effective at reducing exposures to CH_2Cl_2 from aerosols finishes when the work period was short.

CH_2Cl_2 Source Strengths

For each experiment with aerosol finishes, the source strength of CH_2Cl_2 was calculated from the mass of product used, the percent weight composition of CH_2Cl_2, and the time and duration of product use (Appendix B).

Both time-averaged and time-dependent source strengths of CH_2Cl_2 were calculated for each experiment with paint removers. First, the mass of product used in an experiment was determined from the weights of the containers, all tools, and the polyethylene sheet, as follows: (1) the initial weights of the tools and the sheet were subtracted from their final dry weights to yield the weight of the paint that was removed from the chamber; (2) the weight of the paint was subtracted from the total weight of all items at the exit from the chamber, and this difference was subtracted from the total initial weight of all items to yield the weight of product

source strengths with time among the five experiments, the variations are not large and all experiments are generally characterized by the regular application of product and stripping of paint.

Modeling

The mass balance model (Equation 2) was used to predict theoretical chamber concentrations of CH_2Cl_2 for each minute of each experiment. For experiments with paint removers, these calculations were made using both time-averaged source strengths and time-dependent source strengths calculated to the nearest minute. Source strengths calculated to the nearest minute were also used to predict theoretical concentrations for experiments with aerosol finishes. An outdoor pollutant concentration (C_o) of zero was used in all calculations, since CH_2Cl_2 concentrations in chamber air before the work period began and in laboratory air immediately prior to the worker's exit from the chamber were less than 10 ppm. The net rate of removal processes other than ventilation, k, was determined to be 0.07 $\pm$0.02 h^{-1}, the average difference between the calculated and the mechanical ventilation rates for the uniform portions of the decay periods of the four low ventilation rate experiments. The temporal profiles of theoretical concentrations for Experiments 2, 4, and 6 are shown in Figures 6 - 8. Figures of theoretical concentrations for all experiments are presented in Appendix C.

The temporal profiles of theoretical chamber concentrations of CH_2Cl_2 were integrated over the work periods to produce theoretical estimates of exposures. For experiments with paint removers, the integral solution of Equation 4 was used to calculate exposures from the time-averaged source strengths. These theoretical exposures are compared in Table 4 with the exposures derived from the measured chamber concentrations.

The theoretical exposures and the measured chamber exposures for experiments with paint removers were compared with paired Student's t-tests. The exposures derived from the theoretical estimates of concentrations based on the time-dependent source strengths were not significantly different from the chamber exposures ($t=2.29$, $0.10>P>0.05$). However, the exposure

This compares to the measured reductions to 71% for chamber exposures and the measured reductions to 83% for personal exposures.

For aerosol finishes, the good agreement between average theoretical and measured exposure reductions with ventilation rate is due, in part, to offsetting errors. For experiments with the metallic paint, the theoretical exposures underestimated the chamber exposures by 15%, and for experiments with the polyurethane finish, the theoretical exposures were as much as 30% higher than the chamber exposures. These discrepancies may have resulted from differences in drying times for the two products and from inaccuracies in the GC/FID analyses of product compositions which were previously discussed. The combined effects of product drying times and accuracies of the product analyses were evaluated by comparing the percent weight compositions of the volatile components in aerosol finishes to the respective percent weight compositions of the volatile components in chamber air. These comparisons are made in Table 5 using the quantitative GC/FID data for the three components: aliphatic hydrocarbon propellant; CH_2Cl_2; and toluene. For both products, the propellant was more predominant in chamber air than in the product. In addition, for the polyurethane finish, the percent weight composition of CH_2Cl_2 was considerably reduced in chamber air relative to the composition of CH_2Cl_2 in the product.

If it is assumed that the GC/FID analyses of the products and of CH_2Cl_2 in air were accurate, the observed enrichment of the propellant in chamber air relative to the aerosol products may have been due to differences in the vapor pressures of the components. The propellant, which exists only as a gas at room conditions, would have immediately entered the air while the other components which are liquids and vapors at room conditions would have evaporated from the substrate panels at rates which relate to their vapor pressures (e.g., Bennett and Myers, 1974). The fact that the propellant was most enriched and CH_2Cl_2 was depleted in the experiments with the polyurethane finish may have been due to the relatively slow drying time for this product and possible inhibition of CH_2Cl_2 evaporation due to the formation of a surface layer of polymer.

Experiments were conducted with two individual products of both paint remover/strippers and aerosol finishes at chamber ventilation rates of ~0.5 and ~3 h^{-1}.

When paint removers and aerosol finishes were applied to identical areas during simulated typical use, the resulting CH_2Cl_2 concentrations were higher, by far, with paint removers because of the larger amounts of CH_2Cl_2 used. While occupational guidelines may not be directly applicable to residential use of consumer products for reasons stated previously, it is notable that concentrations of CH_2Cl_2 in experiments with paint removers quickly exceeded occupational guidelines. It should also be noted that these guidelines were developed on the basis of acute health effects and do not reflect recent animal studies which have shown evidence of carcinogenicity. Although the experiments were conducted with a limited range of ventilation rates in a single chamber volume and only while stripping a single size and type of substrate, the results strongly suggest that concentrations of CH_2Cl_2 produced by paint removers are likely to be significant under many conditions of use. Concentrations of CH_2Cl_2 resulting from the use of aerosol finishes are also strongly dependent upon the conditions of use and, in some instances, could be higher than those observed in these experiments. In addition, aerosol finishes often contain relatively large percentages of compounds other than CH_2Cl_2 (e.g., toluene), and the health risks from these compounds should also be considered.

The measured chamber concentrations of CH_2Cl_2 were integrated to provide estimates of personal exposure. These estimates agreed closely with the measured personal exposures when the ventilation rate was low. However, when the ventilation rate was high, the measured personal exposures averaged 21% higher than estimated exposures. Although some vertical stratification of concentrations occurred for both product types at both ventilation rates, this stratification did not appear to affect exposure estimates.

Exposures to CH_2Cl_2 were reduced by increasing the ventilation rate. However, the observed effect of ventilation rate on exposures was non-linear. When paint removers were used, increasing the ventilation rate by approximately a factor of five only reduced exposures derived from chamber

exposure by increased ventilation were predicted with good accuracy by application of the exposure model which uses the time-averaged source strength, indicating that the model can be used for other product use scenarios to predict reductions in exposure with ventilation increases.

Both models appeared to have sufficient accuracy and precision for use in the estimation of consumer exposure to CH_2Cl_2 from the use of consumer products containing CH_2Cl_2. A field validation to confirm the applicability of the exposure models to the residential environment is currently underway. This study will examine the effects of variations in volume, ventilation patterns and rates, and product use patterns on the predictive capabilities of the models.

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Table 1. Composition of products by weight

	PERCENT WEIGHT COMPOSITION (%)					
	Paint Removers		Metallic Paint		Polyurethene Finish	
Component	A	B	Manufact.	Our Analysis	Manufact.	Our Analysis
Non-volatile	3.6±0.1[a]	2.8±0.1	8.6	9.8±0.1	26.9	21.4±0.0
Aliphatic HC	--	--	35.0	31.7±4.4	23.3	33.2±4.2
Propellant Methanol	P[b]	P	--	--	--	--
Ethanol	7.5±0.5	--	--	--	--	--
Isopropanol	--	9.4±0.5	--	--	--	--
CH_2Cl_2	83.0±5.9	86.6±4.0	26.3	25.8±4.0	20.8	26.9±3.4
Toluene	--	--	30.1	32.7±2.8	--	6.8±3.4
Xylenes	P	--	--	--	--	--
Aliphatic HC Thinner	--	--	--	--	28.9	P
TOTAL	>94.1	>98.8	100	100[c]	99.9	>88.3

[a]Precision estimates are ±1 standard deviation.

[b]P=present but not quantified

[c]By analysis percent composition of volatiles was 136%; percent compositions of individual volatiles were normalized to yield 100% total weight composition.

Table 3. Personal and chamber exposures to CH_2Cl_2

Product[a]	Exp. No.	Total Vent. Rate (h^{-1})	Work Period (min)	Mass used Product[b] (g)	Mass used CH_2Cl_2 (g)	Personal Exposure (ppm·h)	Chamber Exposure (ppm·h)	Pers.Exp./ Chamber Exp. (%)
PR-A	1	3.19	90	316[c]	262[c]	1040	889	117
	5	0.62	86	325	270	1970	1970	100
PR-B	2[d]	3.23	89	363	314	1120	921	122
	3[d]	3.20	91	389	337	1200	1010	119
	4	0.63	88	385	333	2400	2350	102
MP	6[d]	3.10	23	151	38.9	124	103	120
	7[d]	3.12	21	161	41.6	121	103	118
	8	0.54	23	150	38.6	160	137	117
PF	10	3.11	10	72.8	19.6	31.6	23.9	132
	9	0.53	14	58.5	58.5	35.2	35.5	99.2

[a]PR=paint remover; MP=metallic paint; PF=polyurethane finish

[b]Average density of paint removers was 1.18 g cm^{-3}.

[c]Approximate value since some product was spilled during application

[d]Duplicate experiments

Table 5. Percent weight compositions of propellant, CH_2Cl_2, and toluene in chamber air

Component	PERCENT WEIGHT COMPOSITION (%) Metallic Paint		Polyurethane Finish	
	Product	Chamber air[a]	Product	Chamber Air[a]
Aliphatic HC Propellant	31.7±4.4[b]	39.4±2.0	33.2±4.2	48.8±0.8
CH_2Cl_2	25.8±4.0	25.2±1.3	26.9±3.4	12.1±0.6
Toluene	32.7±2.8	25.6±1.2	6.8±0.4	6.0±0.3
TOTAL	90.2	90.2	66.9	66.9

[a]Percent compositions normalized to the total percent compositions of the three components in the product

[b]Precision estimates are ±1 standard deviation.

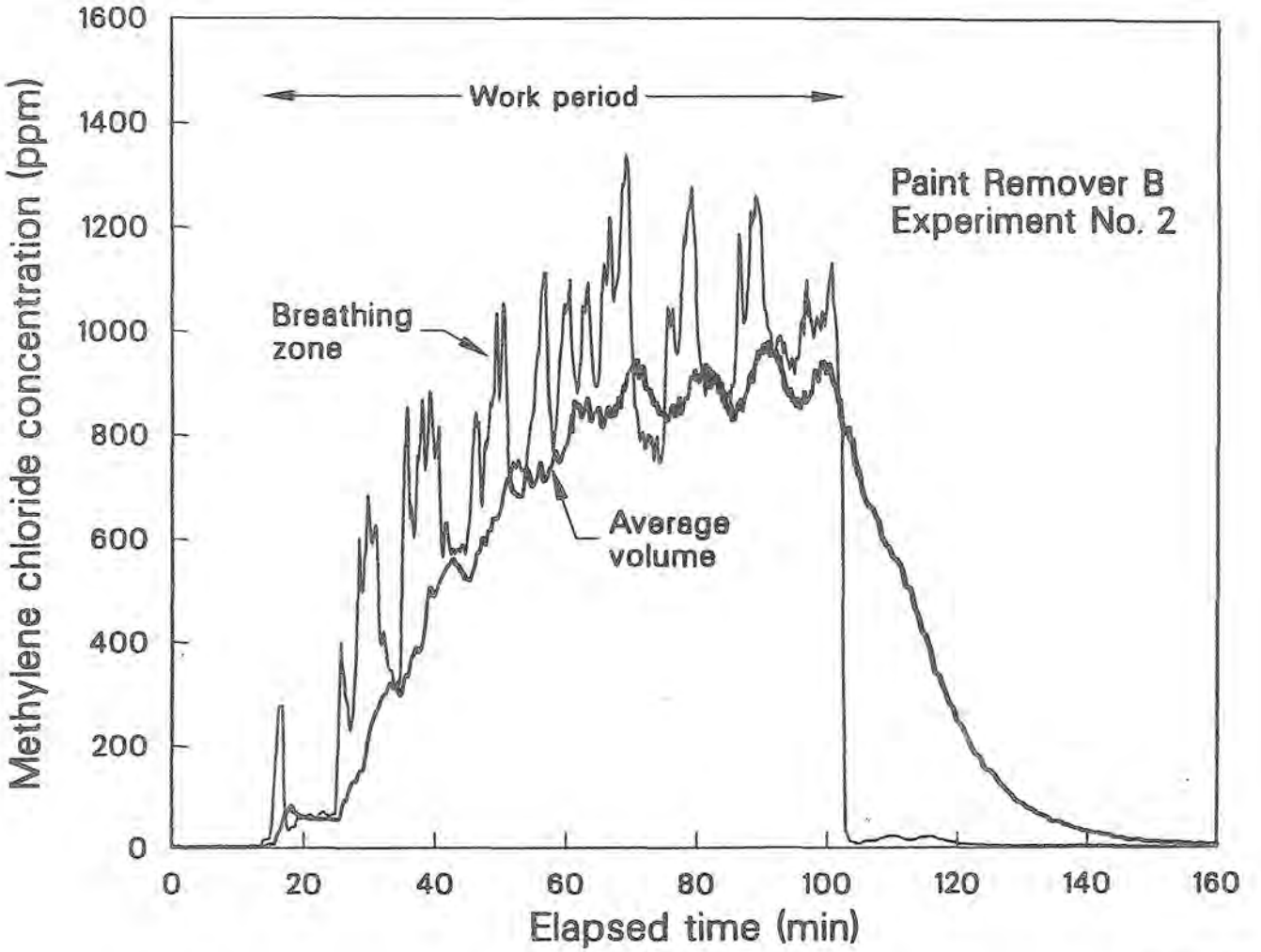
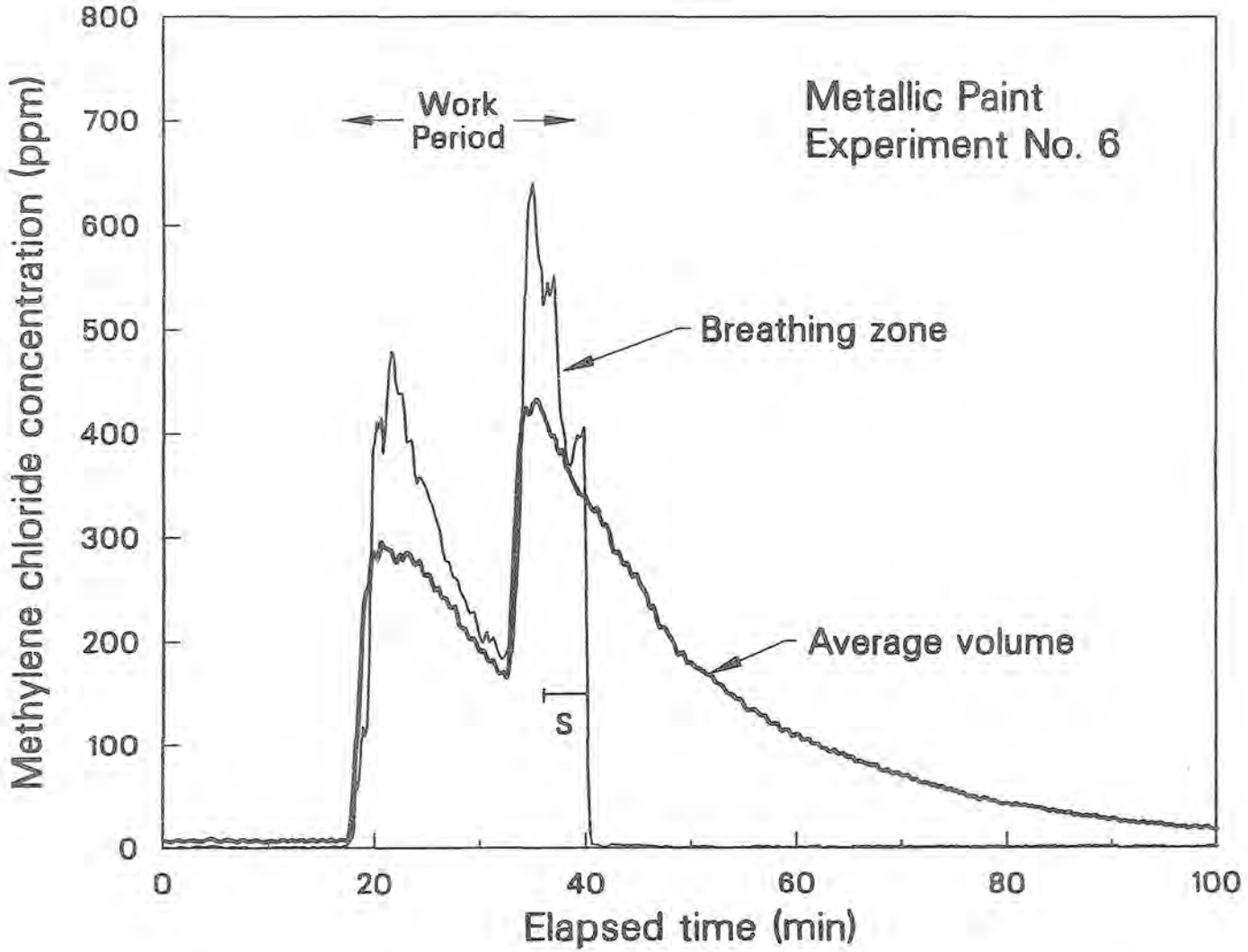


Figure 2. Temporal profiles of chamber and breathing-zone concentrations of CH_2Cl_2 during Experiment 2 with paint remover B at a ventilation rate of 3.23 h^{-1}. Duration of work period is shown above curves. At end of work period, breathing-zone sampling line was switched to laboratory air external to chamber.



XCG 861-7056

Figure 4. Temporal profiles of chamber and breathing-zone concentrations of CH_2Cl_2 during Experiment 6 with metallic paint at a ventilation rate of 3.10 h^{-1}. Duration of work period is shown above curves. Period of vertical stratification measurement (S) using breathing-zone sampling line is shown below curves. At end of work period, breathing-zone sampling line was switched to laboratory air external to chamber.

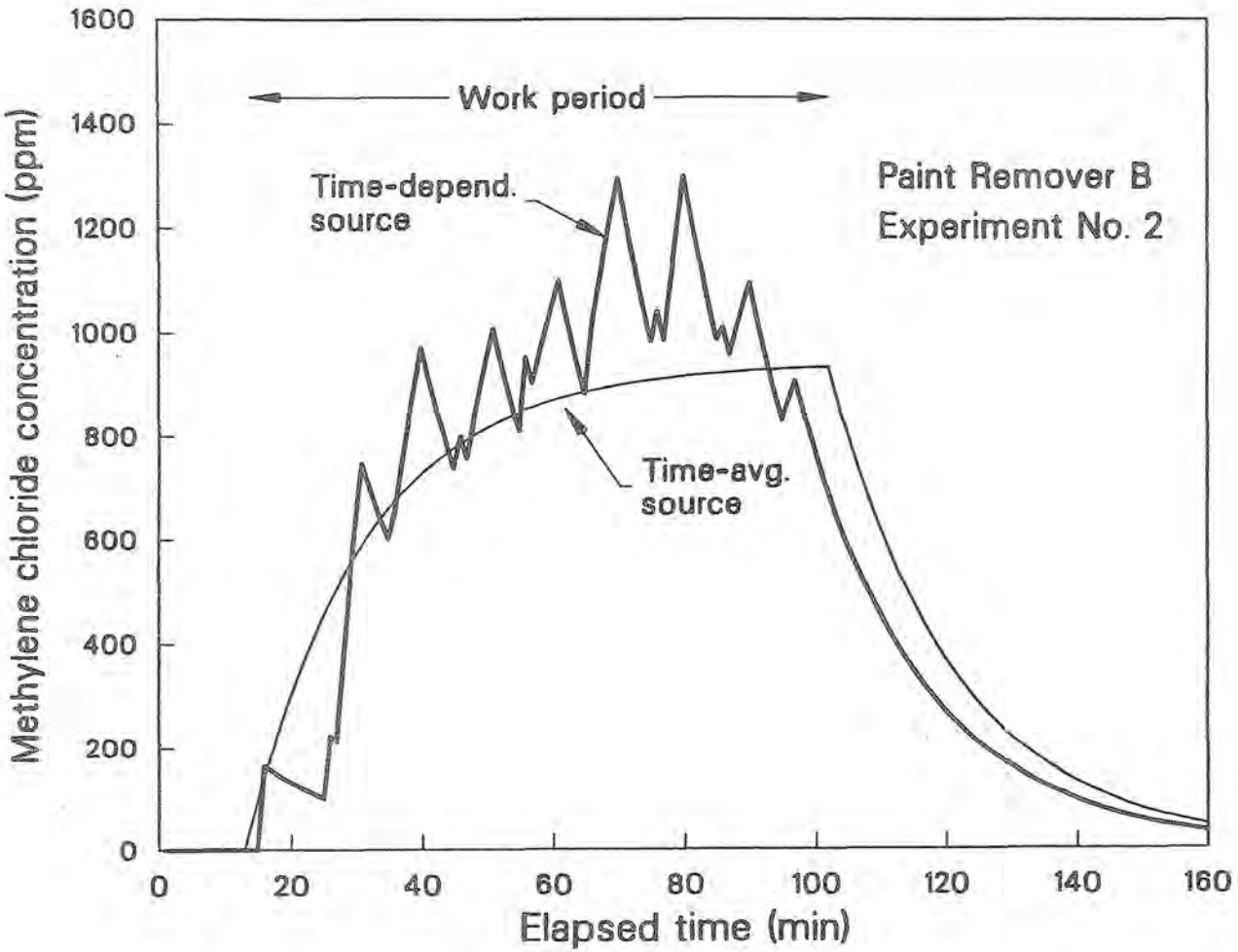


Figure 6. Temporal profiles of theoretical chamber concentration of CH_2Cl_2 for Experiment 2 with paint remover B at a ventilation rate of $3.23\ h^{-1}$. Concentrations were calculated using both time-dependent and time-averaged source strengths. Duration of work period is shown above curves.

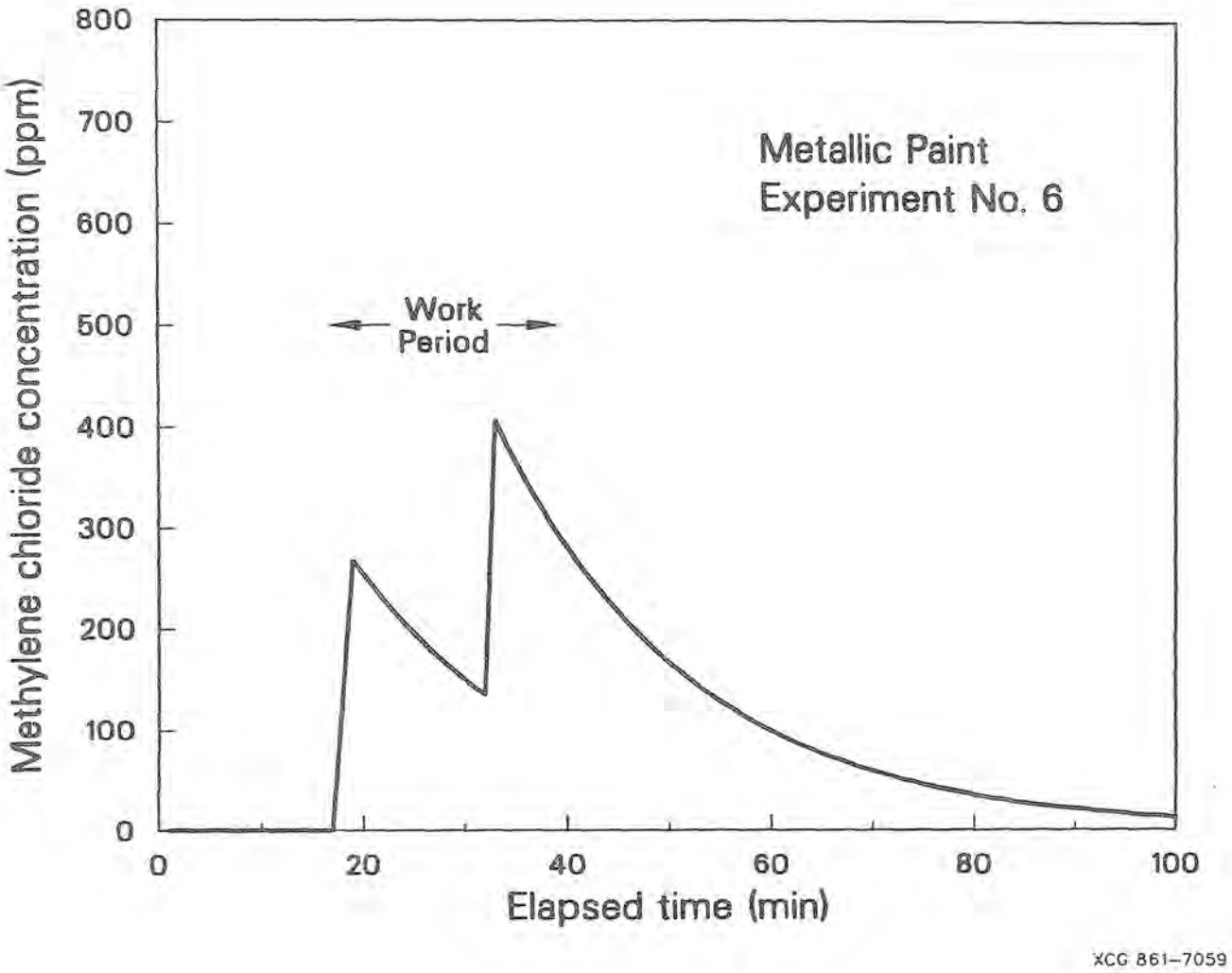


Figure 8. Temporal profile of theoretical chamber concentration of CH_2Cl_2 for Experiment 6 with metallic paint at a ventilation rate of $3.10\ h^{-1}$. Duration of work period is shown above curves.

APPENDIX A

Temporal profiles of chamber and breathing-zone concentrations of CH_2Cl_2 for experiments with paint removers and aerosol finishes at two ventilation rates.

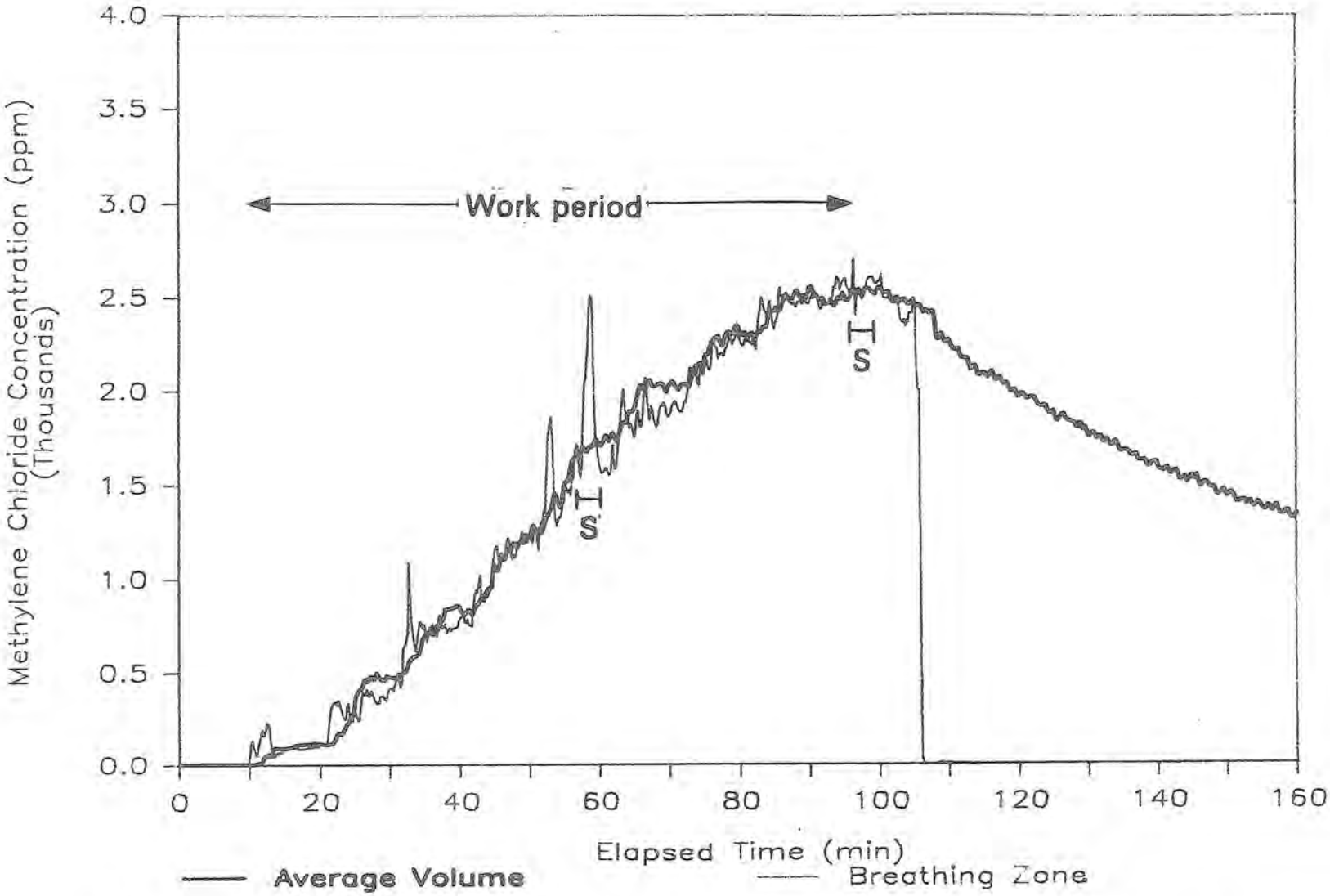


Figure A-2. Temporal profiles of chamber and breathing-zone concentrations of CH_2Cl_2 during Experiment 5 with paint remover A at a ventilation rate of 0.62 h^{-1}. Duration of work period is shown above curves. Periods of vertical stratification measurement (S) using breathing-zone sampling line are shown below curves. At end of work period, breathing-zone sampling line was switched to laboratory air external to chamber.

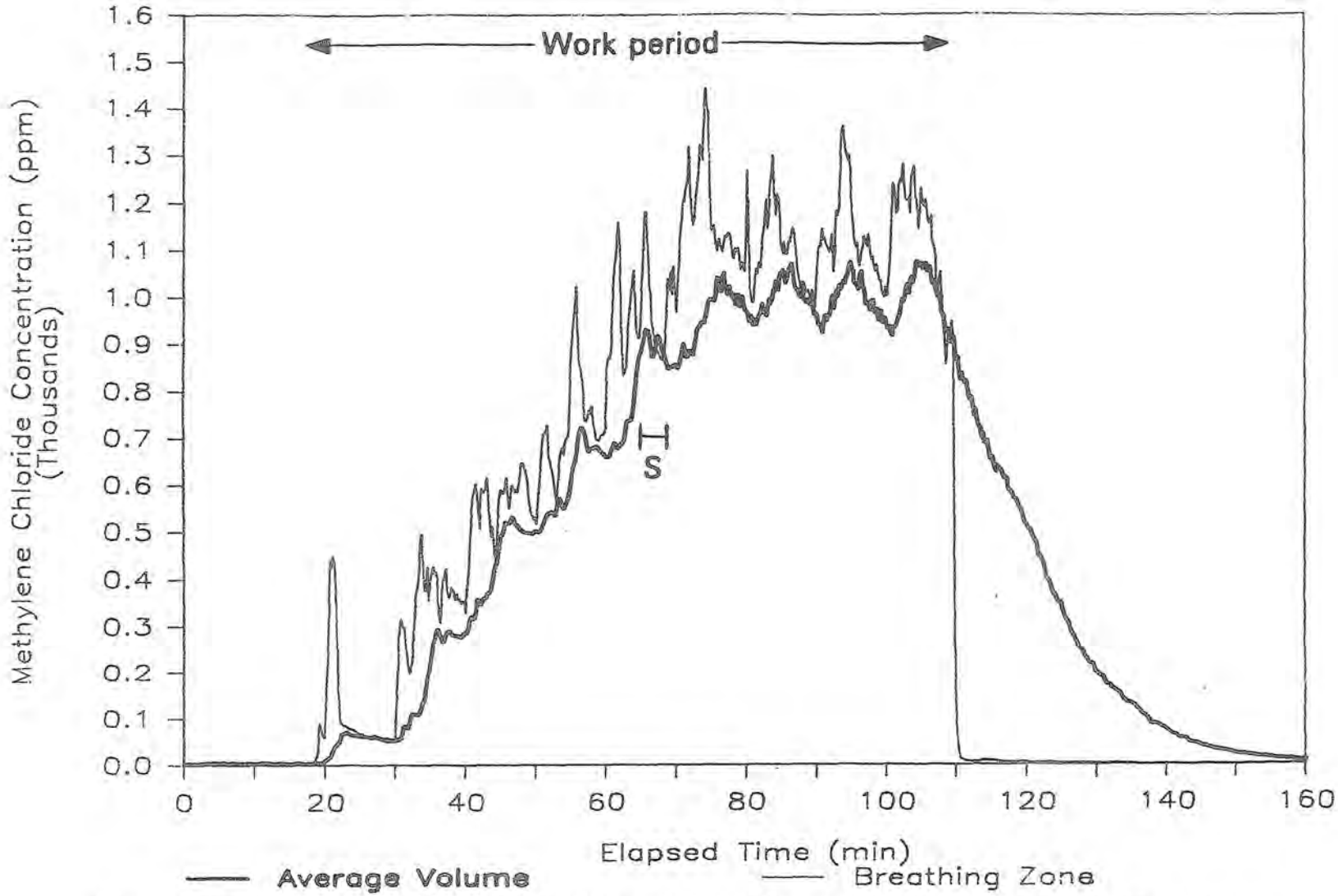


Figure A-4. Temporal profiles of chamber and breathing-zone concentrations of CH_2Cl_2 during Experiment 3 with paint remover B at a ventilation rate of 3.20 h^{-1}. Duration of work period is shown above curves. Period of vertical stratification measurement (S) using breathing-zone sampling line is shown below curves. At end of work period, breathing-zone sampling line was switched to laboratory air external to chamber.

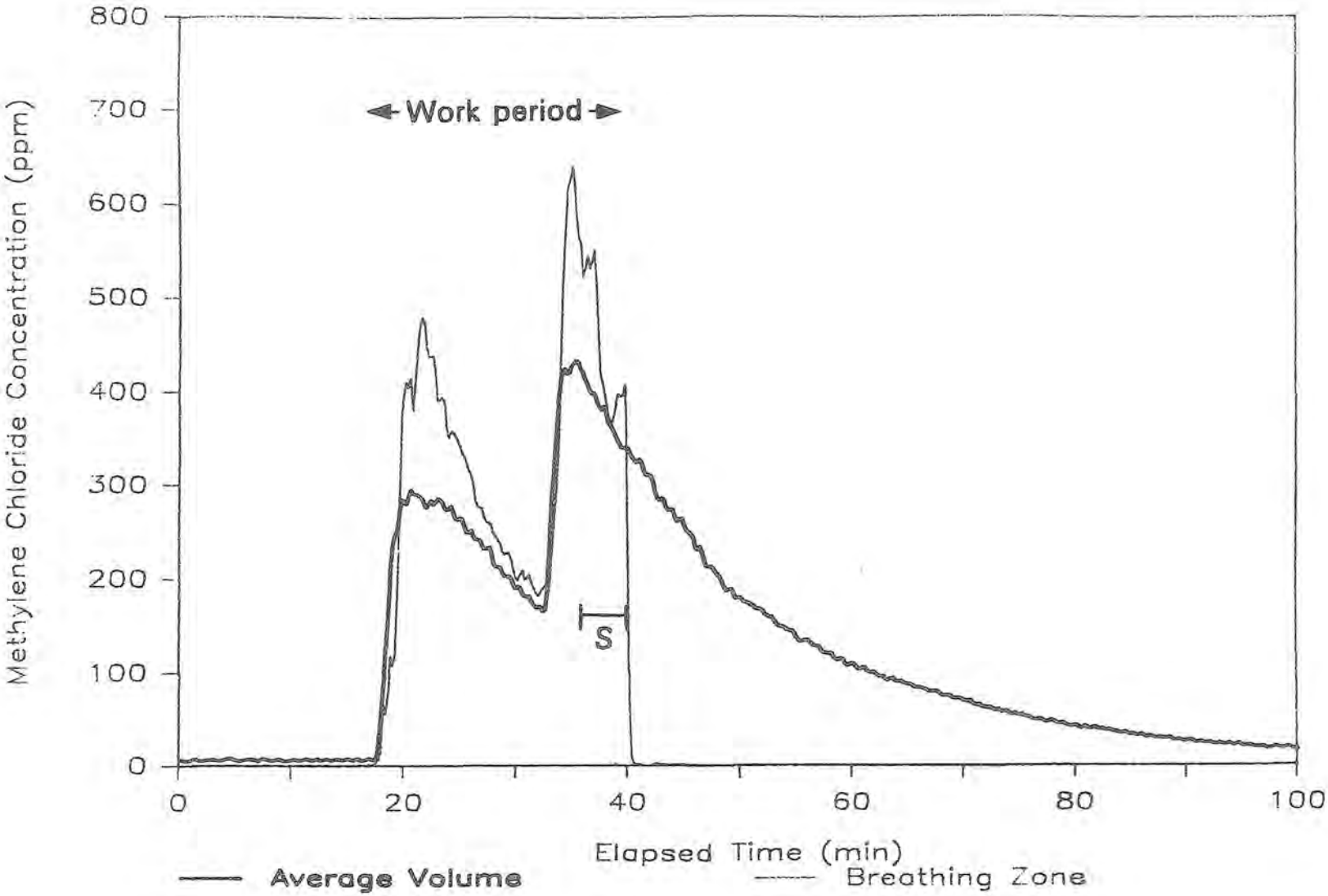


Figure A-6. Temporal profiles of chamber and breathing-zone concentrations of CH_2Cl_2 during Experiment 6 with metallic paint at a ventilation rate of 3.10 h^{-1}. Duration of work period is shown above curves. Period of vertical stratification measurement (S) using breathing-zone sampling line is shown below curves. At end of work period, breathing-zone sampling line was switched to laboratory air external to chamber.

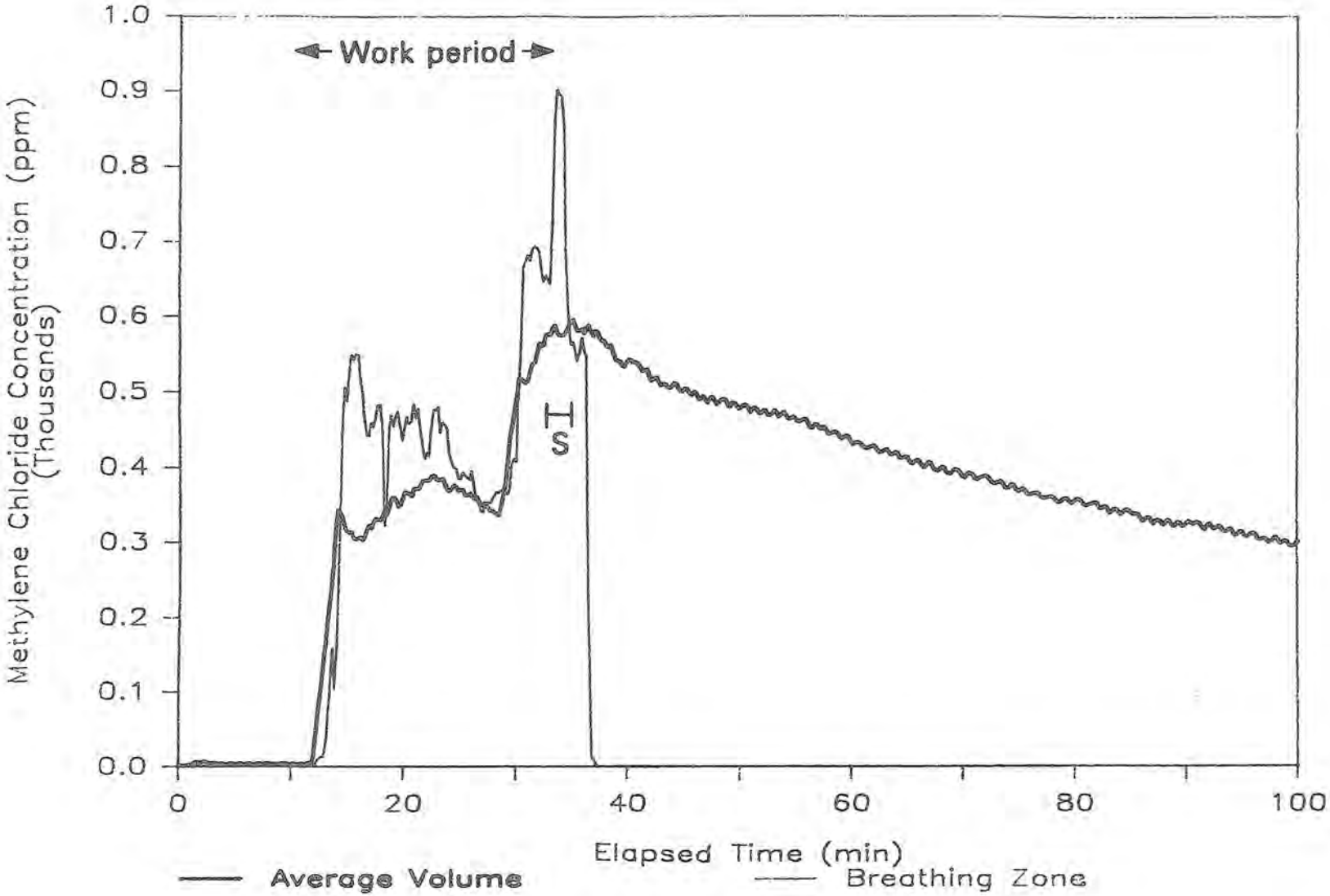


Figure A-8. Temporal profiles of chamber and breathing-zone concentrations of CH_2Cl_2 during Experiment 8 with metallic paint at a ventilation rate of 0.54 h^{-1}. Duration of work period is shown above curves. Period of vertical stratification measurement (S) using breathing-zone sampling line is shown below curves. At end of work period, breathing-zone sampling line was switched to laboratory air external to chamber.

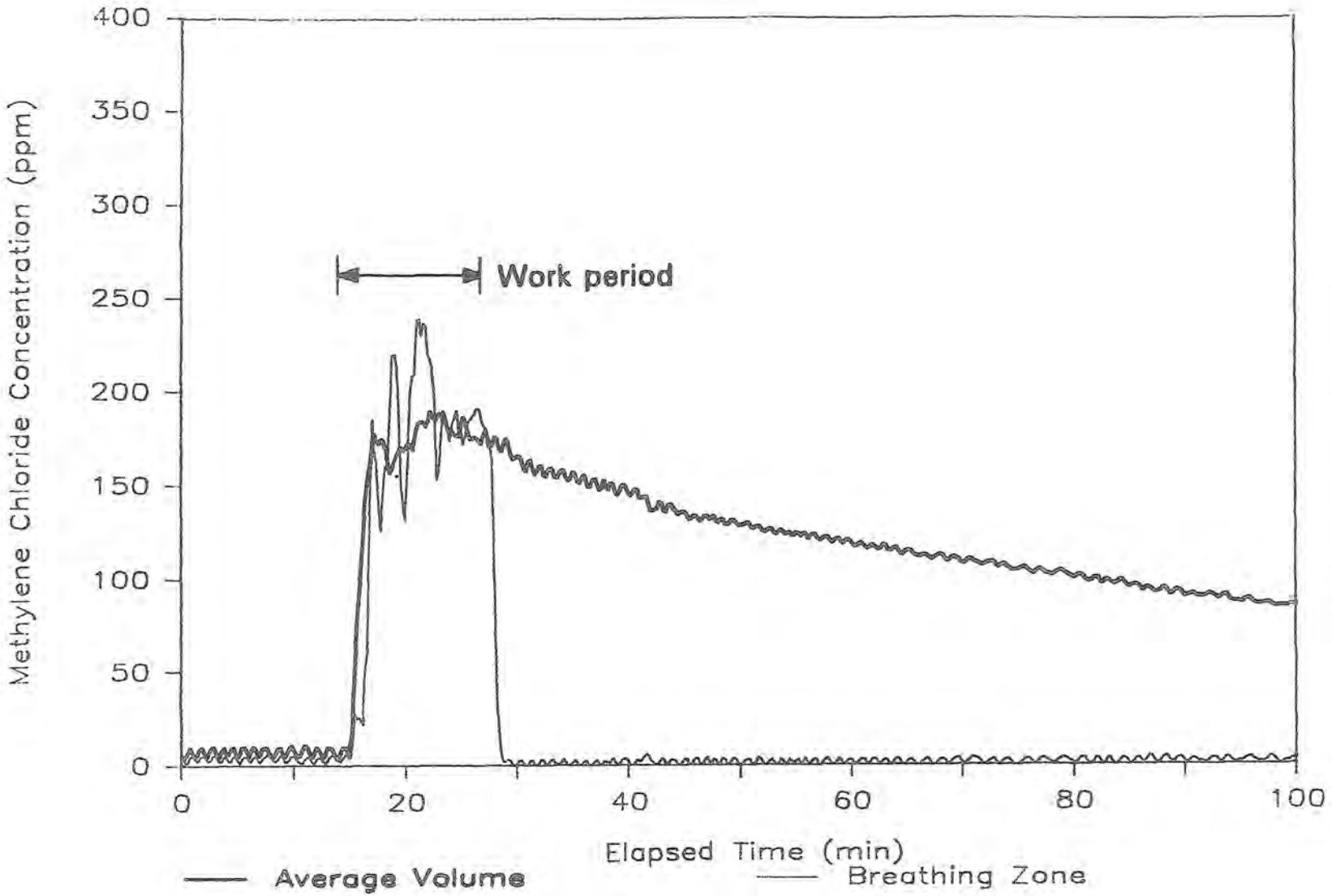


Figure A-10. Temporal profiles of chamber and breathing-zone concentrations of CH_2Cl_2 during Experiment 9 with polyurethane finish at a ventilation rate of 0.53 h^{-1}. Duration of work period is shown above curves. At end of work period, breathing-zone sampling line was switched to laboratory air external

APPENDIX B

Source strengths of CH_2Cl_2 for experiments with paint removers and aerosol finishes at two ventilation rates.

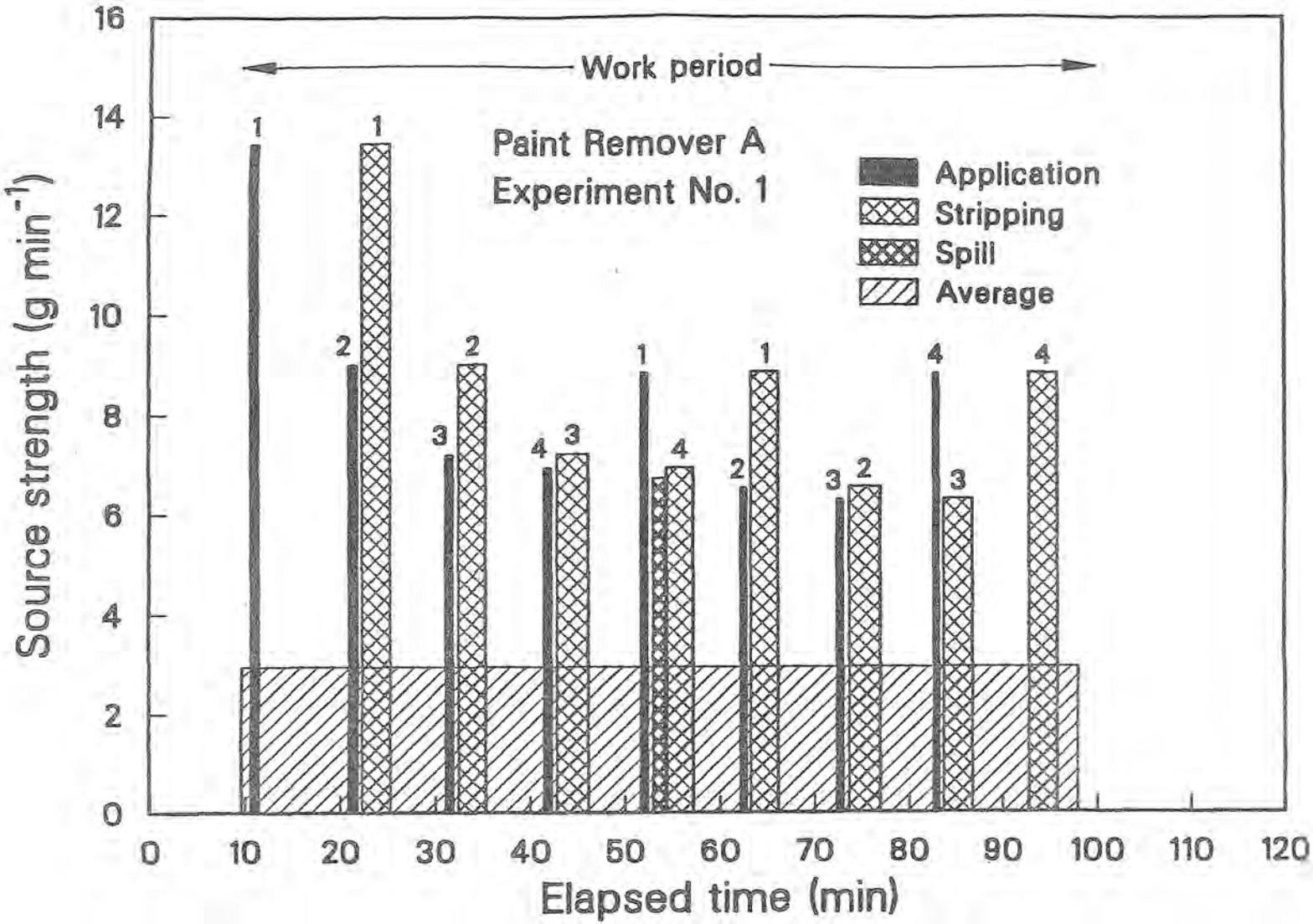
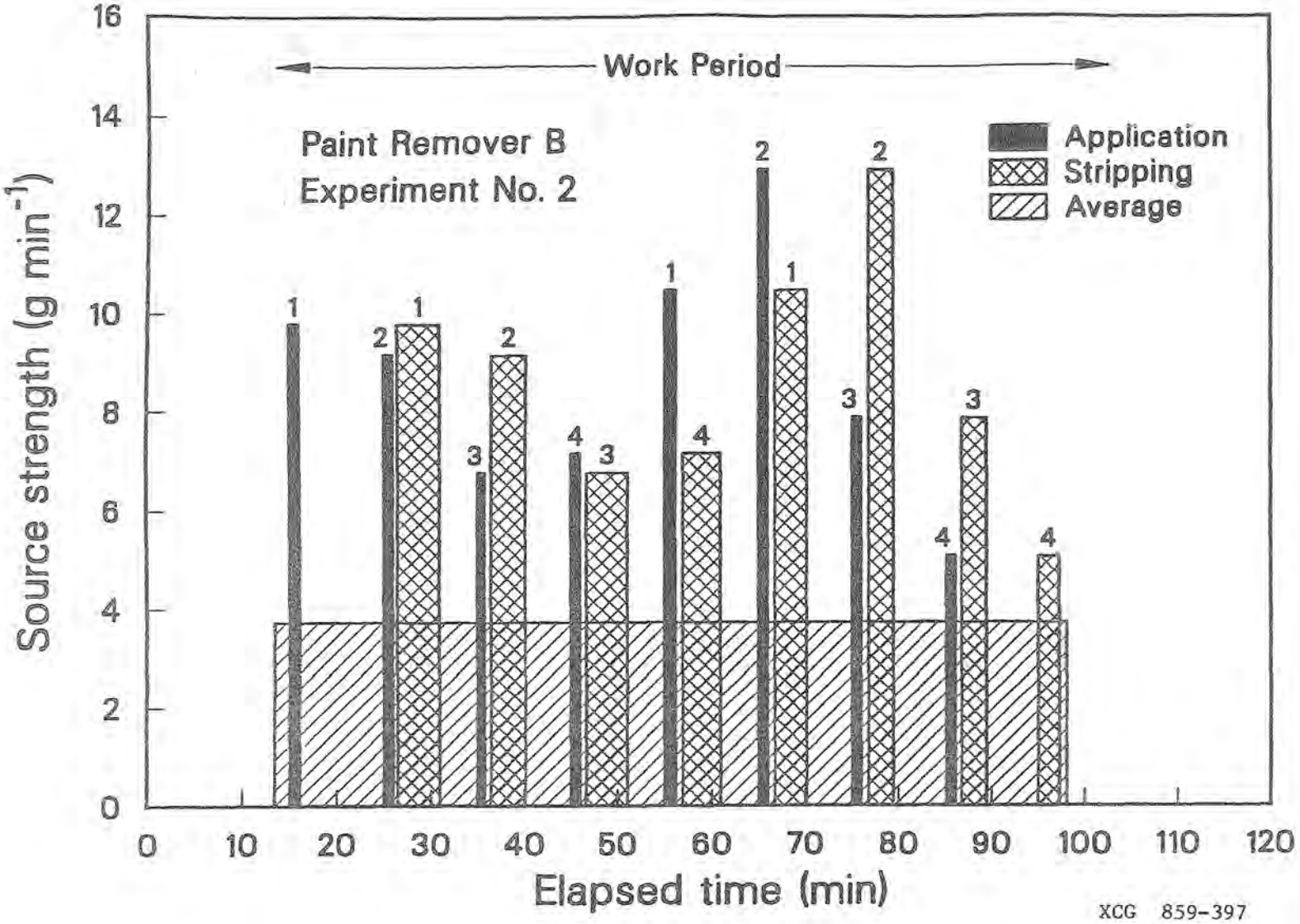


Figure B-1. Estimated time-dependent source strength of CH_2Cl_2 along with time-averaged source strength for Experiment 1 with paint remover A. The quarter of the panel to which an application or stripping event applies is identified above the representation of that event. The time-averaged source strength is for period between initial pouring of product into secondary container and wiping of panel at conclusion of stripping.



XCG 859-397

Figure B-3. Estimated time-dependent source strength of CH_2Cl_2 along with time-averaged source strength for Experiment 2 with paint remover B. The quarter of the panel to which an application or stripping event applies is identified above the representation of that event. The time-averaged source strength is for period between initial pouring of product into secondary container and wiping of panel at conclusion of stripping.

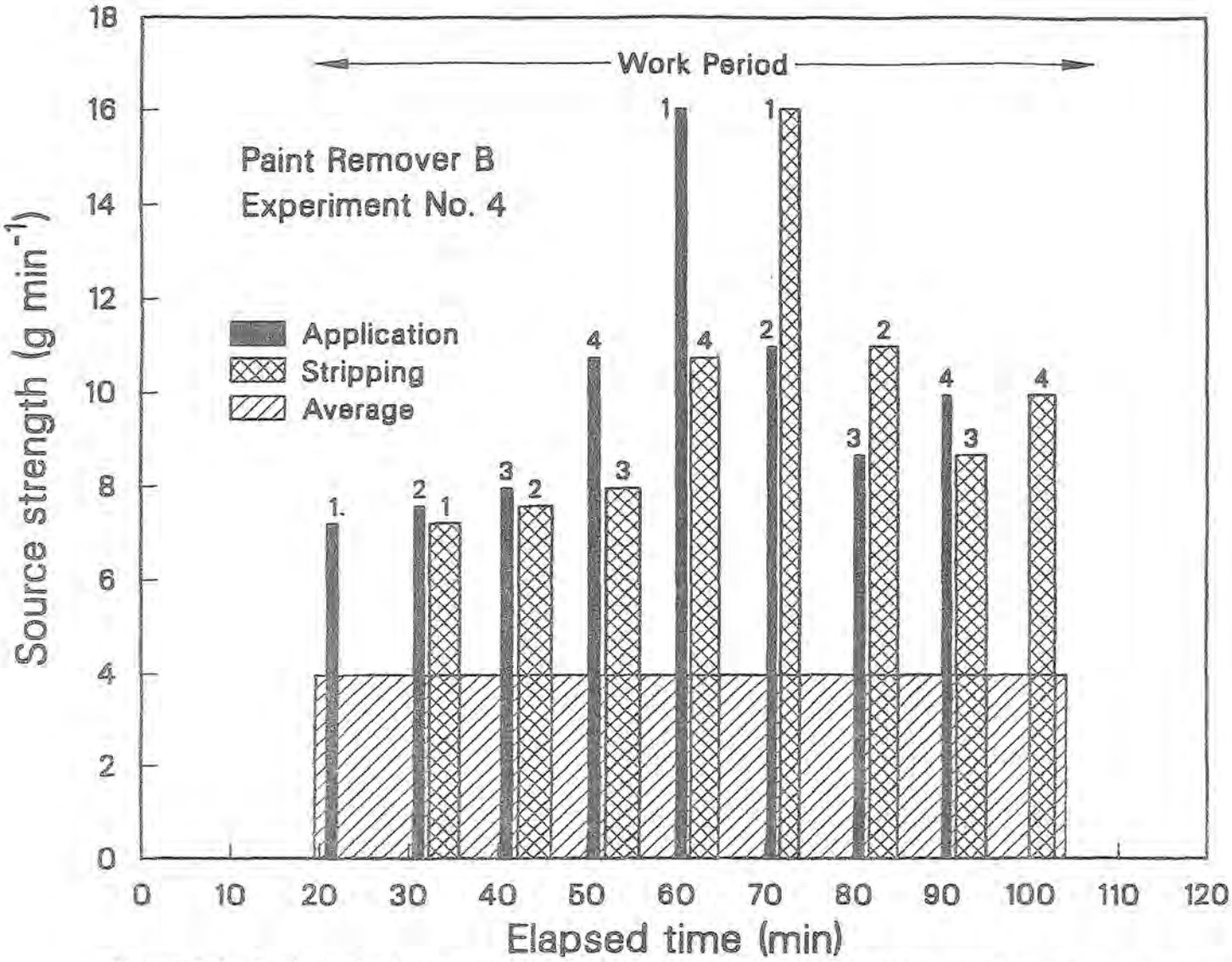


Figure B-5. Estimated time-dependent source strength of CH_2Cl_2 along with time-averaged source strength for Experiment 4 with paint remover B. The quarter of the panel to which an application or stripping event applies is identified above the representation of that event. The time-averaged source strength is for period between initial pouring of product into secondary container and wiping of panel at conclusion of stripping.

APPENDIX C

Temporal profiles of theoretical chamber concentration of CH_2Cl_2 for experiments with paint removers and aerosol finishes at two ventilation rates.

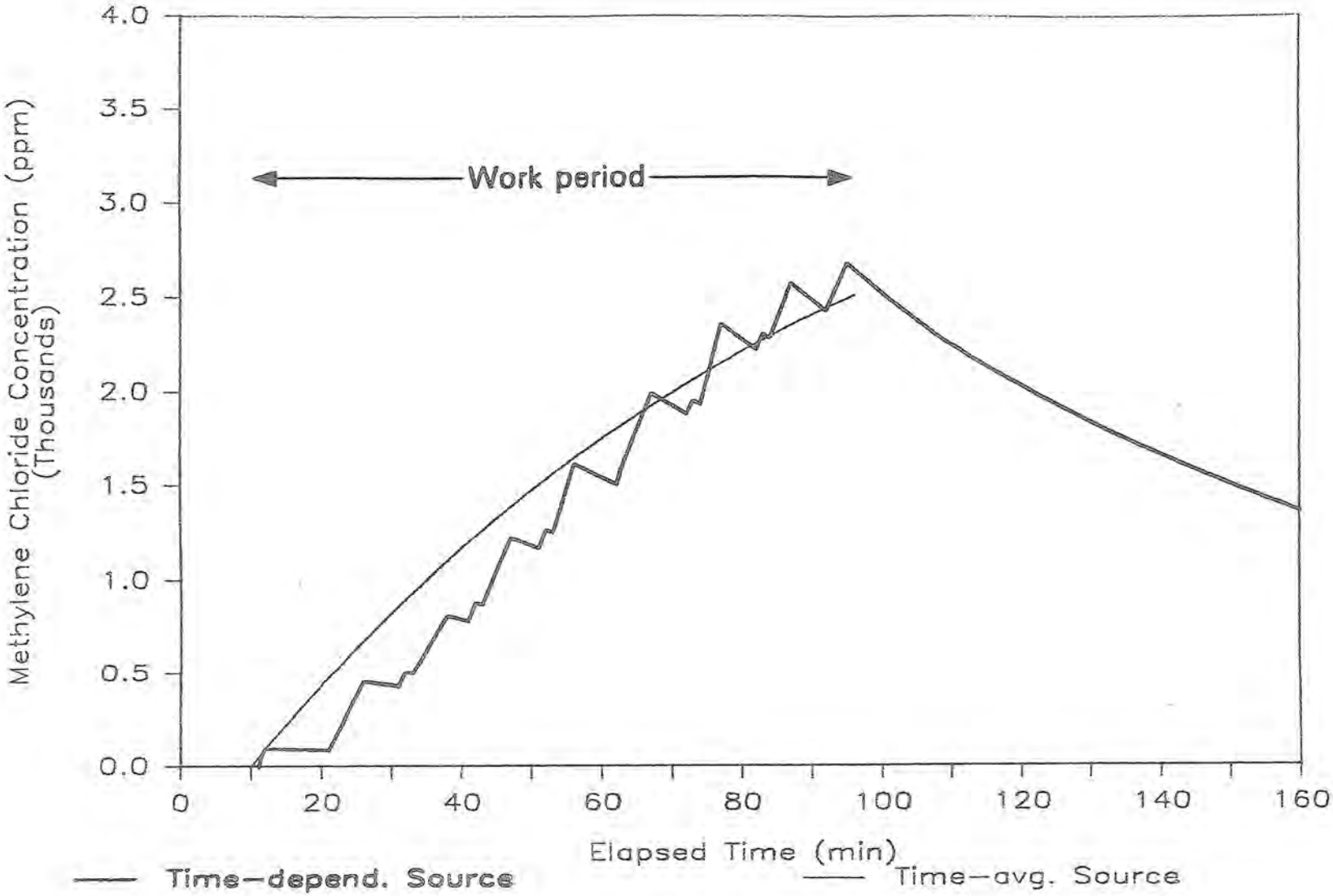


Figure C-2. Temporal profiles of theoretical chamber concentration of CH_2Cl_2 for Experiment 5 with paint remover A at a ventilation rate of 0.62 h^{-1}. Concentrations were calculated using both time-dependent and time-averaged source strengths. Duration of work period is shown above curves.

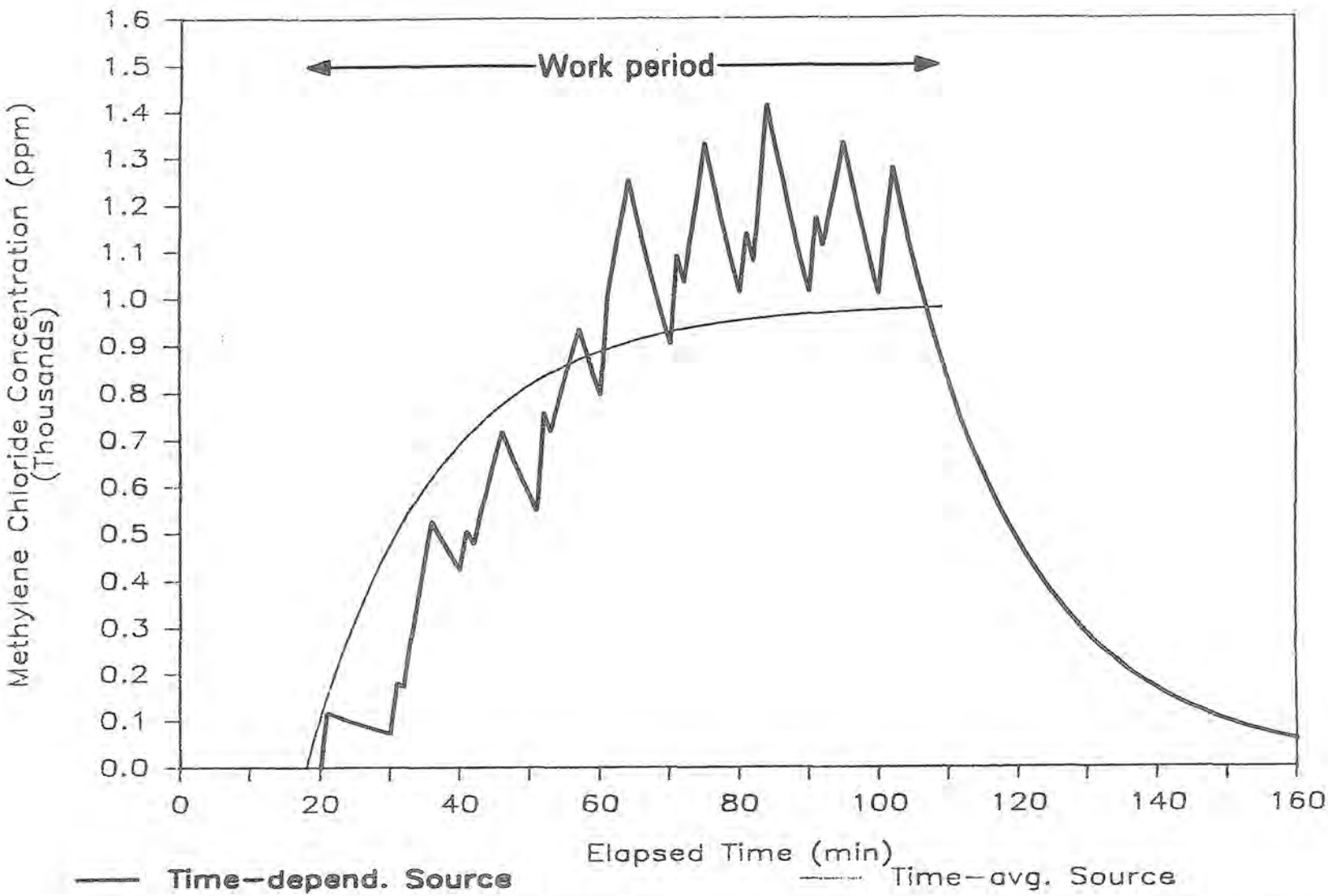


Figure C-4. Temporal profiles of theoretical chamber concentration of CH_2Cl_2 for Experiment 3 with paint remover B at a ventilation rate of 3.20 h^{-1}. Concentrations were calculated using both time-dependent and time-averaged source strengths. Duration of work period is shown above curves.

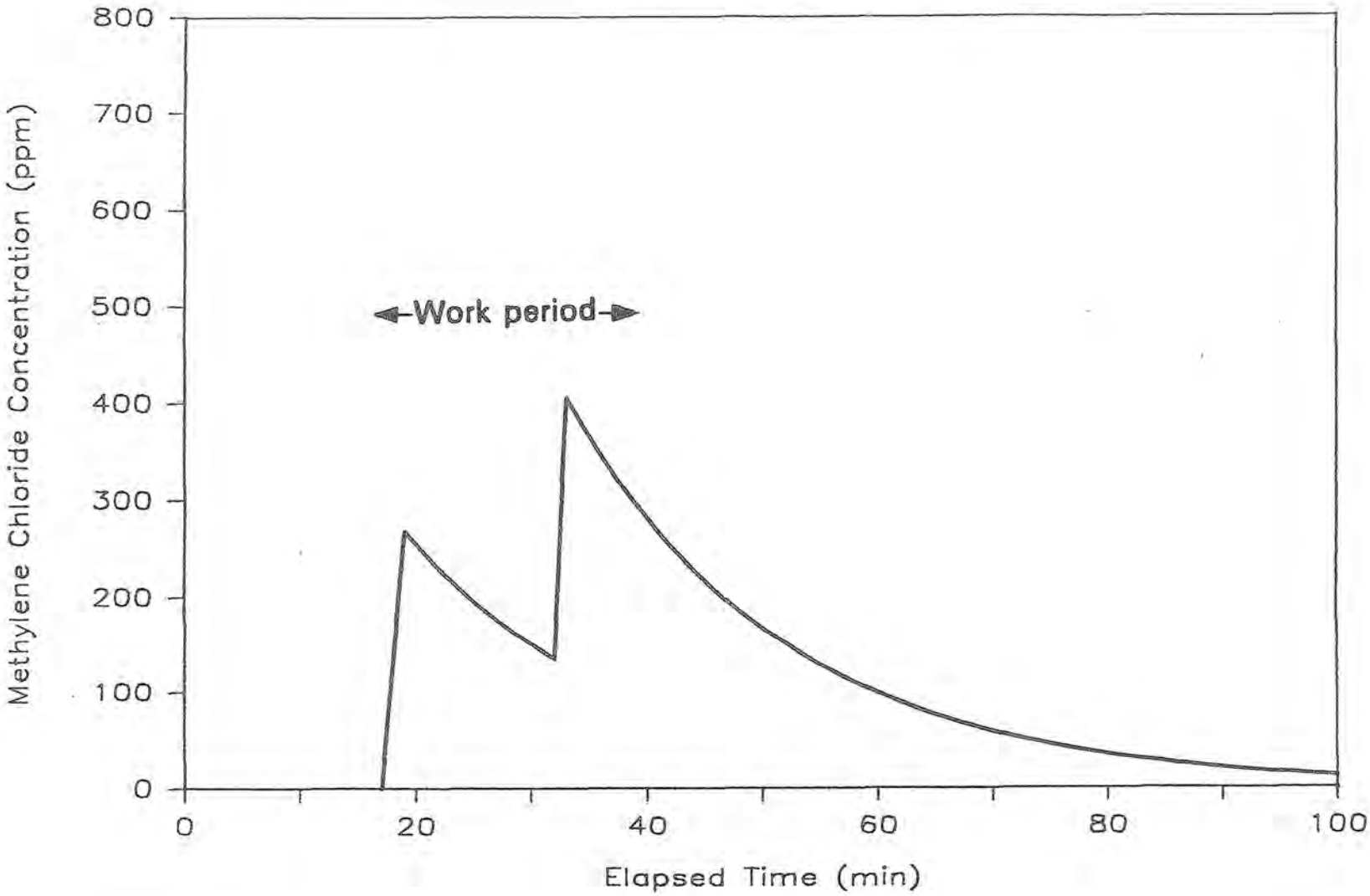


Figure C-6. Temporal profile of theoretical chamber concentration of CH_2Cl_2 for Experiment 6 with metallic paint at a ventilation rate of 3.10 h^{-1}. Duration of work period is shown above curve.

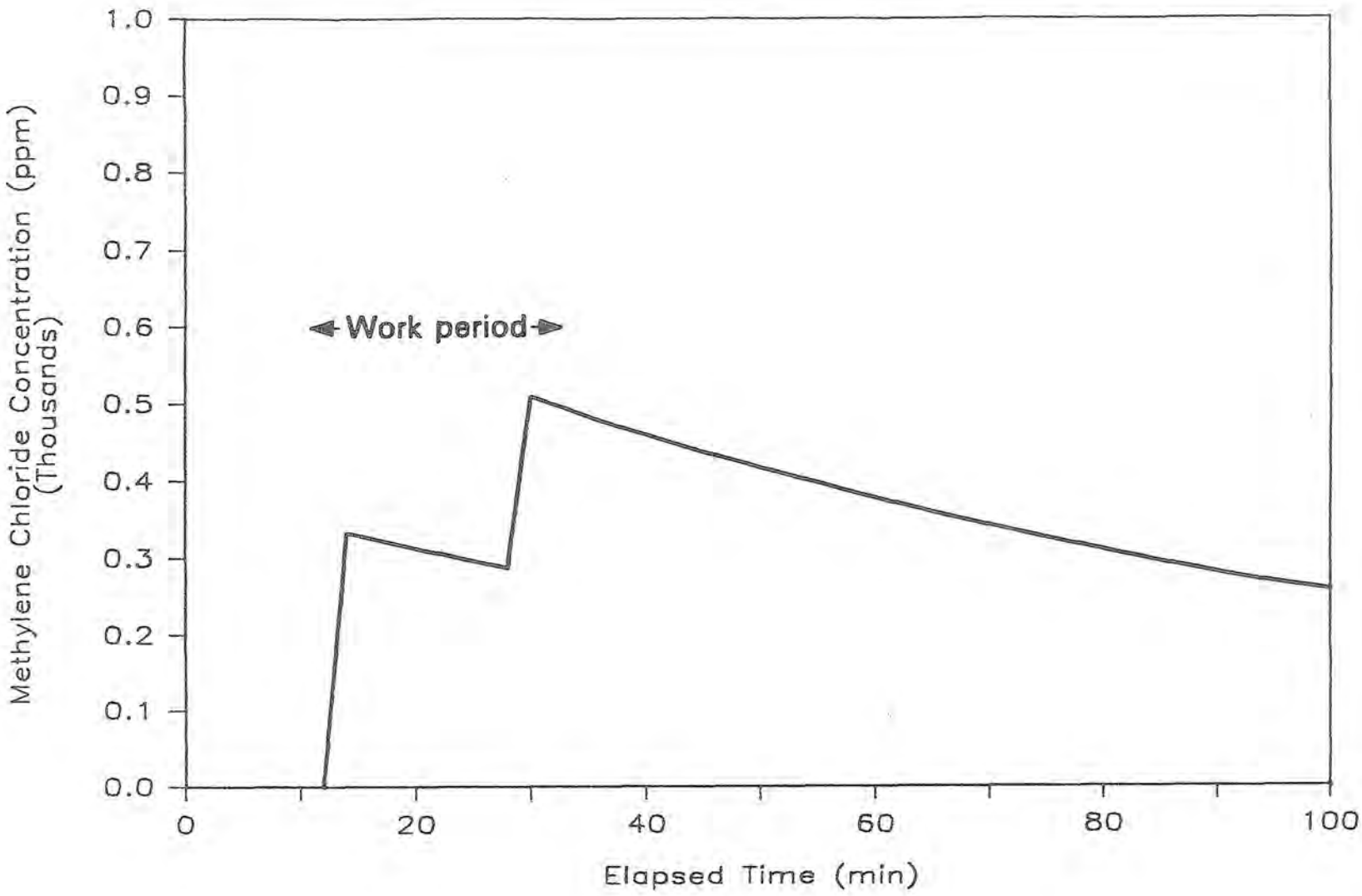


Figure C-8. Temporal profile of theoretical chamber concentration of CH_2Cl_2 for Experiment 8 with metallic paint at a ventilation rate of 0.54 h^{-1}. Duration of work period is shown above curve.

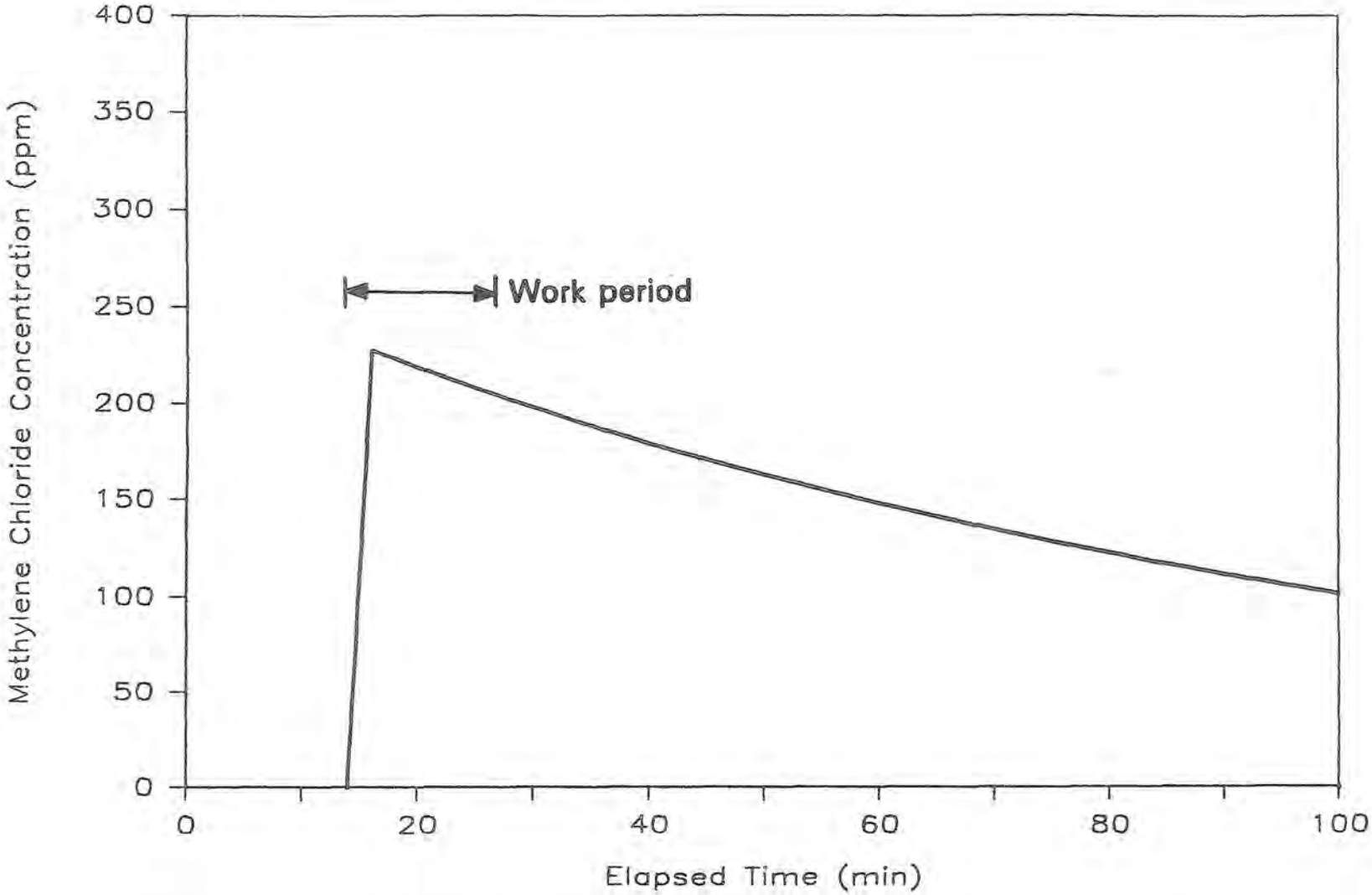


Figure C-10. Temporal profile of theoretical chamber concentration of CH_2Cl_2 for Experiment 9 with metallic paint at a ventilation rate of 0.53 h^{-1}. Duration of work period is shown above curve.