CHARACTERIZATION OF EMISSION RATES AND EMISSION FACTORS FOR THREE MANUFACTURING PROCESSES

BY

SHERYL A. MILZ
B.S., The Ohio State University, 1985
M.S., The Ohio State University, 1987

THESIS

Submitted as partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Public Health Sciences
in the Graduate College of the
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THE UNIVERSITY OF ILLINOIS AT CHICAGO
Graduate College
CERTIFICATE OF APPROVAL

March 3, 1994

I hereby recommend that the thesis prepared under my supervision by

Sheryl A.Milz

entitled Characterization of Emission Rates and Emission Factors for Three Manufacturing Processes

be accepted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

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This thesis is dedicated to my husband, John F. Milz.

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Although the plant at which this project took place wishes to remain anonymous, I thank management and labor for their courtesy and helpfulness.

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LIST OF ABBREVIATIONS

C	Concentration
D	Eddy diffusivity
erfc	Error function complement
F	Air cleaner efficiency
g/hr	Grams of contaminant per hour
h	Height
k	Mixing factor
mg/hr	Milligrams of contaminant per hour
mg/m^3	Milligrams of contaminant per cubic meter of air
m^3/min	Cubic meters per minute
n	Number of samples
OTVD	Open-top vapor degreaser
p	Statistical significance
ppm	Parts per million
PIXE	Proton Induced X-Ray Emissions
Q or q	Volumetric flow rate
r_n	Radius of hemisphere
R	Indoor sink removal rate
r	Correlation coefficient
r^2	Coefficient of determination
S_{av}	Ten-minute Miran average emission rate
S_{box}	Box model emission rate
S_{cms}	Completely mixed space model emission rate
S_{mb}	Experimental mass balance emission rate
S_{tp}	Two-point diffusion model emission rate
S_1	Ten-minute Miran1 emission rate

LIST OF ABBREVIATIONS (Continued)

t	Time
TCA	1,1,1-Trichloroethane
u	Velocity
V	Volume
z	Resulting value from z-test
w	Width
$\mu g/m^3$	Micrograms of contaminant per cubic meter of air
η	Efficiency

SUMMARY

Industrial hygiene field tests were conducted at a manufacturing plant in December, 1990 and in March, 1991. Air concentrations were collected for contaminants in three process areas. The three processes included a copper plating line, 1,1,1-trichloroethane vapor degreasers, and wave soldering lines utilizing molten lead baths. Two days of sampling were devoted to each process. The sampling strategy consisted of taking one-hour simultaneous samples at five or more different locations in each process area. In addition, worker and process activity was observed and recorded over each one-hour interval.

The purpose of the study was to use the collected sampling data to calculate emission rates of pollutant release for each process area. Emission rates have the dimensions of mass released per unit time. The emission rates could then be compared with source activities and other process conditions to develop emission factors. Emission factors are expressions of the ratio of emissions to some easily defined source activity over a certain time interval, including changes in process settings or materials which may affect emission rates.

Sampling at the degreasers for 1,1,1-trichloroethane was performed by drawing air through charcoal tubes with calibrated personal sampling pumps and analysis by gas chromatography. Copper, lead, and other elements were collected onto polycarbonate filters with calibrated personal and area sampling pumps in the other two process areas. The filters were analyzed by Proton Induced X-Ray Emission analysis.

SUMMARY (Continued)

The sampling method and strategy yielded 12 one-hour sampling intervals (runs) over two consecutive days in each process area. Ventilation measurements were also carried out in each space. The concentration and ventilation measurements were transformed to emission rates by using a pollutant mass balance in interior space. The particular form of the mass balance model chosen for each area depended on the nature of the particular space being characterized.

The calculated average emission rate for each one-hour interval was then compared to the source activities (e.g., throughput, process conditions) during the same interval. In each process area, at least one positive relationship existed between the emission rates and the activity factors. These relationships indicate that this is a useful approach to characterizing emission rates and activity factors for copper plating, degreasing, and wave soldering processes.

I. INTRODUCTION

A. Rationale

The strength and nature of indoor emissions are often the most significant determinants of indoor air quality (1). In addition, physical properties of the contaminant, ventilation characteristics of the workroom, and the proximity of the worker to the emission sources define worker exposure. However, actual worker exposure is often expressed only as the average contaminant concentration during a specified time period (2).

Emission rates, on the other hand, describe the rate of release of a material from a process (3). Three advantages of emission rates have been determined: 1) they remove the effect of the surrounding space from the description of the source and therefore can be applied in different settings, 2) they provide a more systematic (mass) basis for the design of control systems for similar processes, and 3) when there is a control device they allow for the determination of a control efficiency (3,4). Additionally, emission rates are a way to extend limited concentration measurements and check on their consistency. However, emission rates are difficult to specify accurately because, unlike concentrations, they usually cannot be measured directly (2). Due to this problem, an alternative method has been developed to determine emission rates (1,5,6). This procedure involves interpreting area concentration patterns and ventilation rates with respect to one or more appropriate mass balance models.

The relationship between the emission rate and one or more measures of source activity provides the emission factor (8). Emission factors express emission rates as a ratio of mass released to some measure of source activity (3). Development of an emission factor places area concentration data in a format suitable for estimating emissions from the same type of source at other sites and provides a quantitative basis for the development of engineering controls (9). The advantage of using emission factors for indoor sources is that the effects of the surrounding space are removed from the description of the source (3,5). Source activities also have two advantages: 1) they are easily measured by observing the sources and 2) they provide a measure of the highly variable nature of the indoor contaminant source emissions (1).

Emission factors can be a useful tool in estimating worker exposures. By knowing or observing the source activity of the process, emission rates can be determined using the emission factors. These emission rates can then be used to estimate the average contaminant concentration, which may be used to express actual worker exposure.

B. Study Design

This thesis characterizes emission factors for copper plating, degreasing, and wave soldering processes. Two industrial hygiene surveys were conducted in December of 1990 on the degreasing and wave soldering processes at a manufacturing plant in Schaumburg, Illinois. A third industrial hygiene survey was conducted in March of 1991 on the copper plating process at the same manufacturing plant. The pollutants of interest were copper and sulfur for the copper plating process, 1,1,1-trichloroethane (TCA) for the degreasing process, and lead for the wave soldering process. Air concentration measurements (copper, sulfur, and other elements along the copper plating line, TCA at the degreasers, lead, tin, and other elements along the wave soldering lines) were taken at known distances from the contaminant sources, yielding one-hour average concentrations. Air supply and exhaust rates were also measured whenever possible. The average concentrations were used along with the ventilation measurements in mass balance models to estimate emission rates for each of the processes during twelve one-hour sampling intervals. In addition, measures of source activity and process parameters were recorded for each sampling interval and emission factors were calculated.

C. Objectives

The objectives of this thesis were to:

1. Collect data at the plant consisting of: 1) 1,1,1-trichloroethane, lead, copper, sulfur, and other elemental concentrations at known distances from the sources, 2) air supply and exhaust rates, and 3) measures of source activity, including process parameters, which may affect the emission rates.

2. Estimate emission rates using the concentration and ventilation measurements and appropriate mathematical models.
3. Determine the association between the estimated emission rates from the different models for each process area.
4. Derive emission factors by comparing the estimated emission rates with measures of source activity using multiple regression analyses.
5. Evaluate the validity of the models for 1,1,1-trichloroethane by comparing the estimated emission rate with the emission rate determined from a mass balance of material usage for the degreasing process.

D. Background

1. Copper Plating

a. Copper

The plating area studied was a copper plating line utilizing sulfate plating baths. Copper is widely distributed and is an essential element. However, acute copper poisoning can be fatal. In addition, chronic copper exposure can cause acceleration of atherosclerosis, whereas acute copper exposure can cause hypotension (10).

b. Copper Plating

The working area of the copper plating line is shown in Figure 1 and consisted of ten tanks, numbered two to eleven. The volume of the space was 700 m^3. This was a

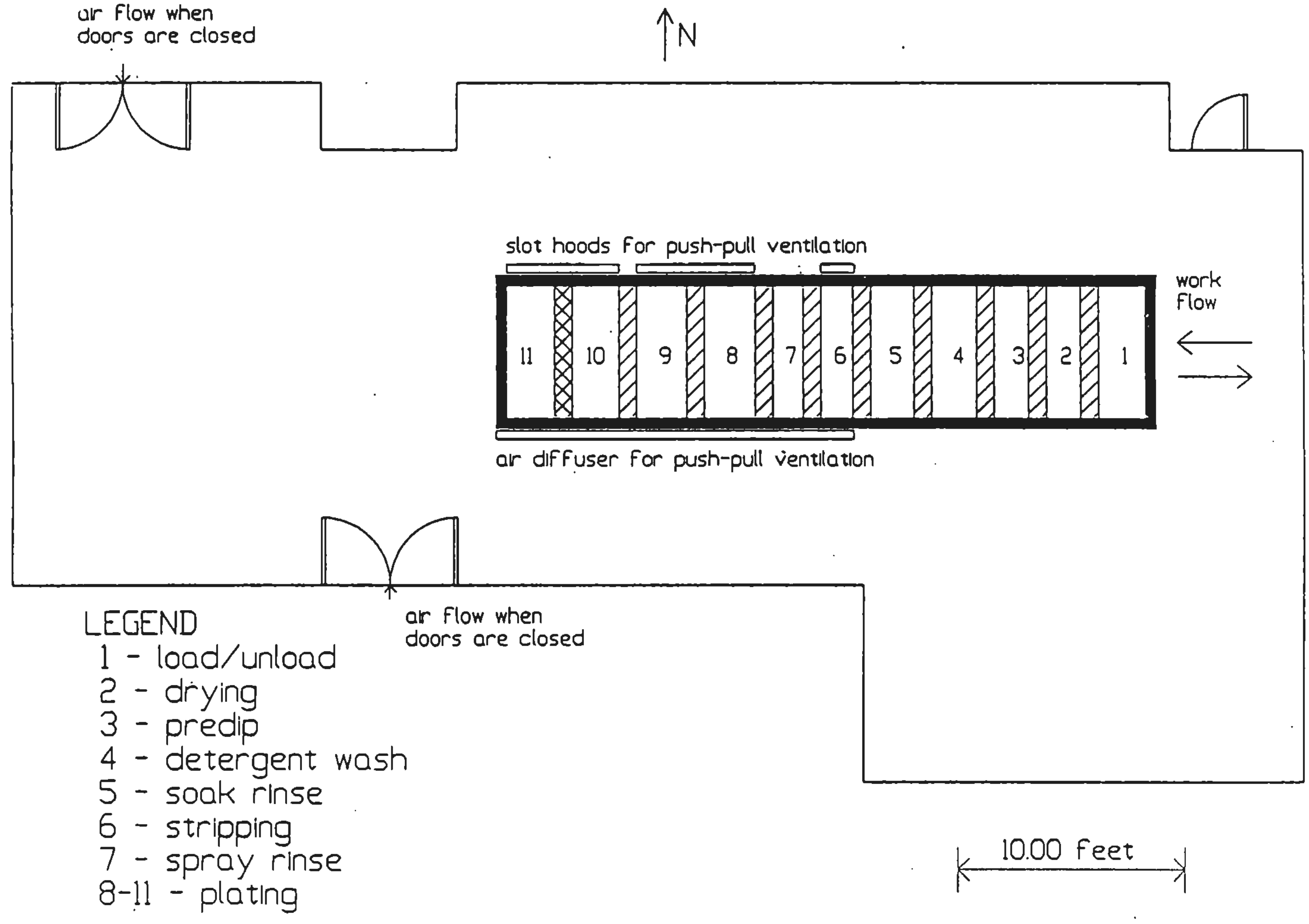

Figure 1. Copper plating line floor plan.

relatively small, well-enclosed space dominated by a local exhaust ventilation system. Tank 2 was for drying, tank 3 was the predip, tank 4 was the detergent wash, tank 5 was the soak rinse, tank 6 was for stripping, tank 7 was the spray rinse, and tanks 8-11 were the plating tanks. Tank 3 and tank 6 were not used during the survey. The plating cycle started and ended in "tank" 1 with loading and unloading. The cycle then went from the plating tanks (8-11) to the spray rinse (tank 7), to the detergent wash (tank 4), to the soak rinse (tank 5), back to the spray rinse (tank 7), and on to the dryer (tank 2) before being unloaded. The entire cycle took an average of 42 minutes and 20 seconds. Local exhaust ventilation was located along the plating line by means of three slot hoods. The slot hoods were along tanks 10-11 (plating), tanks 8-9 (plating), and tank 6 (stripping). A push-pull ventilation system was used. The plating tanks were continuously agitated with sparged air at a rate of 29 cubic feet per minute.

The principal source of air contamination in electroplating operations is the release of the bath electrolyte to the air by the gassing of the bath (11). In copper plating the efficiency of the sulfate plating bath is expected to be nearly 100% and therefore essentially all of the energy is likely to go into the plating operation and little goes into the dissociation of water resulting in gassing (12). Although the contaminant generation rate of the bath is expected to be governed principally by the efficiency of the bath, it also may vary with the metallic ion concentration, the current density (amperes per unit area of workpiece surface), the nature of bath additives, and bath temperature (11).

2. Degreasing

a. Trichloroethane

The degreasing process removes surface oils, grime, and grease from small metal parts by dissolving the oils with a proper solvent. The solvent used in this case was 1,1,1-trichloroethane (TCA). TCA is also commonly referred to as methyl chloroform. TCA is presently not considered to be carcinogenic, but it does produce fatty liver and causes hepatic necrosis (10). Additionally, exposure to massive amounts of TCA may result in saturation of the detoxication pathways (metabolic saturation) resulting in a spillover into the bioactivation pathways (10).

b. Open-Top Vapor Degreasers

The working area for the degreasing process contained three parallel production lines for microcircuits (Figure 2). The volume of the space was 2800 m^3. This was a large space, not totally enclosed, with general area forced air ventilation but no local exhaust systems on the degreasers, and at least three different source release points. Each line consisted of a reflow oven followed by a TCA open-top vapor degreaser (OTVD). Three workbench rows, utilized for assembly and repair of the microcircuits, extended from the reflow ovens to the east. Against the north and west walls were worktables

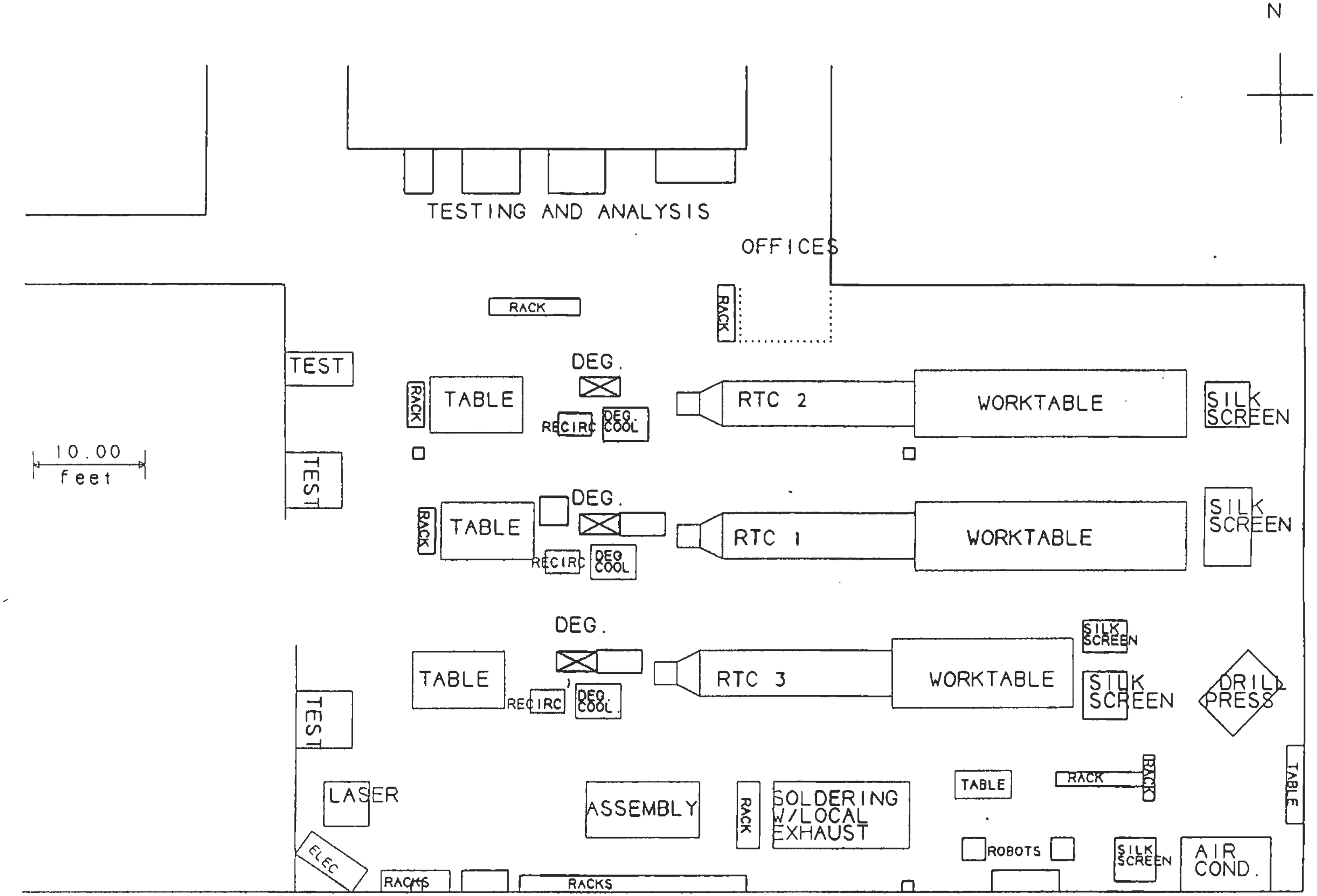

Figure 2. Degreasing process area floor plan.

for product tests and a solvent still (not for TCA) was located in an open bay at the west end of the room.

The reflow ovens were each equipped with a local exhaust system for energy release. A soldering bath operation with local exhaust hoods was located near the south wall. There was no local exhaust ventilation for the degreasers. Three rows of air supply diffusers were suspended above the working areas. Consequently general area ventilation was the primary control method for TCA.

The OTVDs contained three separate regions: cold liquid TCA, hot liquid TCA, and TCA vapor above the hot liquid. The cold liquid TCA could be used with or without ultrasonics. The automatic cycle made use of all three regions of the degreasers.

The operator filled metal baskets with the microcircuit parts to be degreased. Once the baskets were loaded, the degreasing cycle was computer controlled to specific steps and intervals for each step. The cycle was the same for lines one and three. For this cycle the baskets were initially immersed in the hot liquid TCA and then immersed in the cold liquid TCA with ultrasonics, while being raised and lowered about ten times. The baskets then hung in the vapor TCA before dripping excess solvent and returning to start. The cycle for line two began with the baskets hanging in the TCA vapor before being immersed in the hot liquid TCA. Next the baskets were immersed in the cold liquid TCA prior to dripping excess solvent and returning to start. Manual degreasing also occurred on all three lines. Parts were loaded into the baskets and dipped into the TCA. However, no common procedure for manual degreasing was evident. Immersion time varied from less than one minute to five minutes.

Emissions from OTVDs result from diffusion and convection during idling and operating periods, solvent carryout with cleaned parts, leaks and spills from storage containers and compartments, and waste solvent disposal. These factors can all be influenced by worker activity (2). However, one study (3), found that degreaser operating emissions were primarily a function of solvent carryout, which was best described by the total surface area of the parts cleaned, the surface area of the cupped parts, and the observation of solvent dripping from the loaded baskets. In addition, ultrasonic degreasers commonly employ refrigerated or water-chilled coils for control of solvent vapors and therefore the manufacturers claim that local exhaust ventilation is not needed to control emissions (11).

3. Wave Soldering

a. Lead and Tin

In wave soldering, a standing wave of molten solder (primarily lead and tin) is used to solder circuit boards. Lead, the most widespread toxic metal, is toxic in most living things at high exposures and has no demonstrated biological need. The concerns for excess occupational exposure are peripheral neuropathy and/or chronic nephropathy. In addition, lead has multiple hematologic effects and has long been known to cause sterility, abortion, and neonatal mortality and morbidity (10).

Chronic inhalation of tin in the form of dust or fumes leads to benign pneumoconiosis (10). Orally, tin requires relatively large doses (500 mg/kg for 14 months) to produce toxicity (10).

b. Wave Soldering

The working area for the wave soldering process contained three parallel wave soldering lines and was situated in a large open space of approximately 200 feet by 50 feet by 18.4 feet (Figure 3). The volume of the space affected by emissions could not be accurately determined, nor could an air balance be determined. The wave soldering lines included workbenches extending to the east and west along a conveyorized system which were utilized for assembly. Local exhaust ventilation was provided for each wave soldering unit by means of enclosures on each line connected to forced air ventilation duct out of the space. Three rows of elevated diffusers supplied air to the working area and there was also an air recirculation system exhaust and filter against the north wall. Measurements were made in the work area of the direction and velocity of cross drafts (Figure 4). The direction of advective flow in the space was generally in the same direction as that of the work pieces.

Circuit boards were fed into the wave soldering units along a conveyor. The height of the standing wave was adjusted according to the type of board being soldered. The covers enclosing the soldering machines under typical operation remained closed, but were often opened for dedrossing or adjustment purposes. Dross is the waste product formed on the surface of

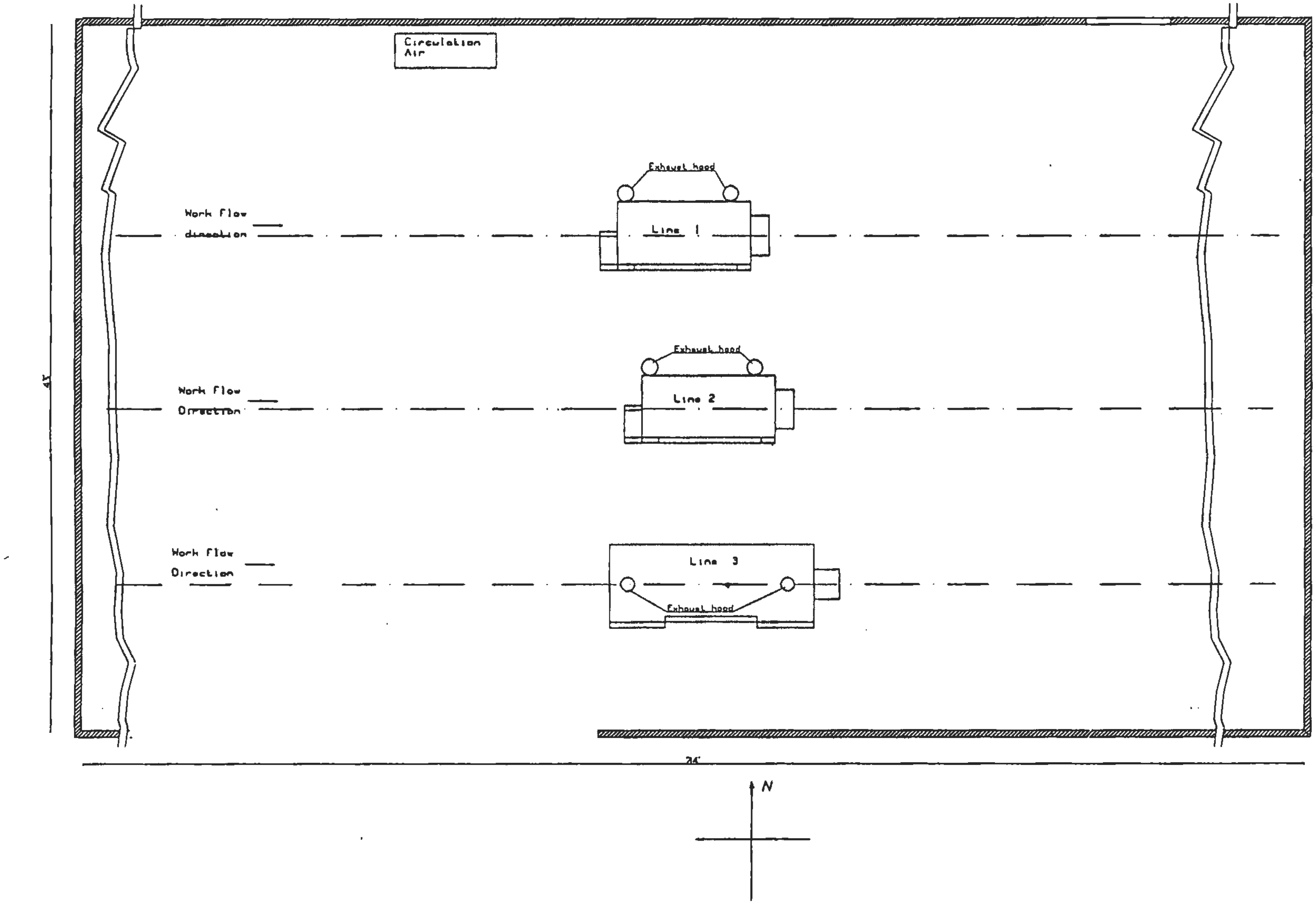

Figure 3. Wave soldering area floor plan.

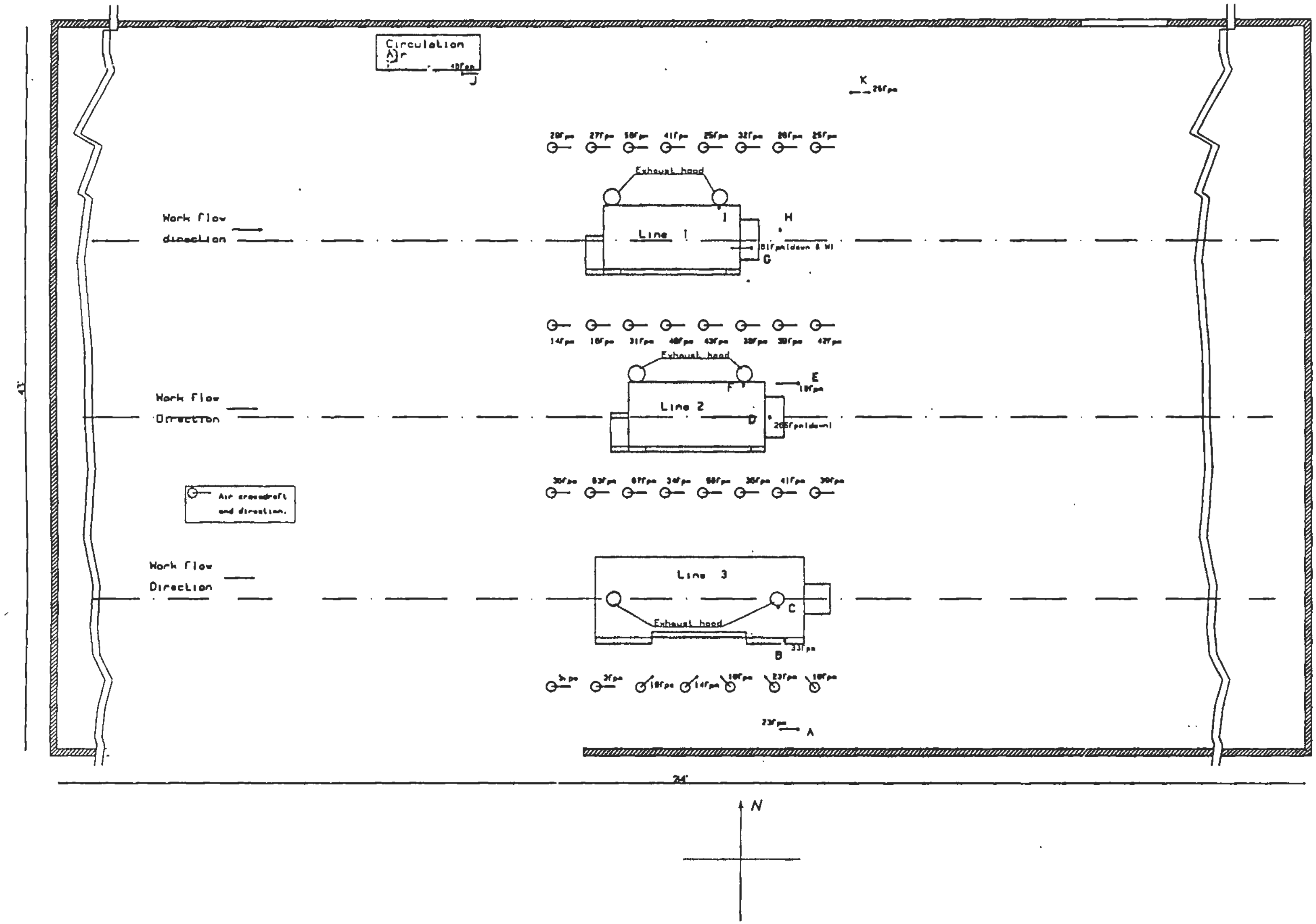

Figure 4. Wave soldering area advective flow pattern.

molten metal. The dross accumulated quickly because the solder was exposed to air and because of fluxes used to enhance the soldering process. In addition to dedrossing, cleaning and refilling also occurred while the covers were open. The operation of the local exhaust systems were likely to be less effective when the covers were open.

II. METHODOLOGY

A. Air Pollution Modeling

The mass balance on a pollutant released to a space could be couched in a variety of ways. The choice of model depends on the type of data collected and which assumptions are appropriate (2). The following five models were used to calculate emission rates for the three process areas.

1. Experimental Mass Balance

Experimental mass balance is based on measurements (or estimates) of concentration and flow rate at each entry and exit point of the space. This relationship can be expressed as:

$$S_{mb} + Q_i C_o = Q_o C_i \qquad (1)$$

where S_{mb} (in mass/time) is the mass balance emission rate, Q_i and Q_o (in volume/time) are the ventilation rates into (Q_i) and out of (Q_o) the workspace, and C_i and C_o (in mass/volume) are the concentrations measured inside (C_i) and outside (C_o) the workspace. This model was used to calculate emission rates for the copper plating and degreasing processes. The identification of entry and exit points with appropriate ventilation rates and inside and outside concentrations was unsure for the wave soldering process and therefore this model was not used.

2. Completely Mixed Space Model

In cases where many sources make significant contributions to area concentrations, it is often more convenient to consider the workplace as a single space which approaches the conditions of a completely mixed container (8). In other words, the contaminant is assumed to have instantaneously mixed with the room air. In this case, the time-dependent mass balance for pollutant flow into and out of an interior space is expressed by (6):

$$V\frac{dC_i}{dt} = kq_0C_o(1 - F_0) + kq_1C_i(1 - F_1) + kq_2C_o - k(q_0 + q_1 + q_2)C_i + S_{cms} - R \qquad (2)$$

where C (in mass/volume) is the concentration indoors (C_i) and outdoors (C_o), t is the sampling time, q (in volume/time) is the volumetric flow rate for make-up air (q_0), recirculation (q_1), and infiltration (q_2), F is the air cleaner efficiency for make-up air (F_0) and recirculation (F_1), V is the room volume, S_{cms} (in mass/time) is the indoor emission rate, R (in mass/time) is the indoor sink removal rate, and k, a factor which accounts for the inefficiency of mixing, is the fraction of incoming air that completely mixes with the room ($0 \leq k \leq 1$). This model was used to calculate emission rates for the copper plating and degreasing processes. The model was not used for the wave soldering area since the space was not easily characterized by an enclosed space.

3. Two-Point Diffusion Model

The two-point diffusion model has been used to determine emission rates when one pollution source is the major contributor to concentrations in the surrounding space (5). As a general observation, the workplace concentration of a contaminant discharged from an isolated source decreases with increasing distance from the source. The rate of contaminant diffusion is based on Fick's Law of Diffusion, which states, for a point source emitting at steady state into an infinite space, that the speed which the emitted contaminants move through the space is proportional to the product of the change in concentration with distance from the source and the molecular diffusivity (5). However, for indoor spaces, the eddy diffusivity, which is usually many orders of magnitude larger than the molecular diffusivity (13,14), is more appropriate than the molecular diffusivity (14,15).

The solution for the diffusion of a pollutant emitted at a constant rate from a point source without deposition in a hemispherical space is given by Carslaw and Jaeger (13) as:

$$C = \frac{S_{tp}}{2\pi Dr} erfc\left[\frac{r}{(4Dt)^{0.5}}\right] \tag{3}$$

where C (in mass/volume) is the instantaneous concentration at any location, r is the radius of the hemisphere, t is the sampling time, D (in area/time) is the eddy diffusivity, and S_{tp} (in mass/time) is the steady-state emission rate. The term erfc stands for the error function complement, or (1 - error function). It is defined as:

$$erfc(y) = 1 - \frac{2}{\pi^{0.5}}\int_0^y \exp(-x^2)\,dx \tag{4}$$

and is readily available in reference tables (16).

The integral of Equation (3) is the appropriate form to characterize average area concentrations, C_{av}, collected over a sampling time, t_{av}. If two concentration samples are collected simultaneously over the same sampling time at two different distances from the source, r_1 and r_2, then the integral form of Equation (3) gives two independent equations:

$$C_{av,r_1} = \frac{\int_0^{t_{av}} \frac{S_{tp}}{2\pi D r_1} erfc[\frac{r_1}{(4Dt)^{0.5}}]\,dt}{t_{av}} \qquad (5)$$

$$C_{av,r_2} = \frac{\int_0^{t_{av}} \frac{S_{tp}}{2\pi D r_2} erfc[\frac{r_2}{(4Dt)^{0.5}}]\,dt}{t_{av}} \qquad (6)$$

Equations (5) and (6) can then be solved simultaneously for D and S_{tp} using a trial and error approach. However, not all solutions are valid because a negative result for D is not physically possible and therefore a meaningful emission rate cannot be calculated. This model was used to calculate emission rates for the copper plating line only. The model was not used in the degreasing and wave soldering areas because it appeared that the concentration gradients between points r_1 and r_2 away from each line were affected by the other lines and the model did not give meaningful results.

4. <u>Box Model</u>

The box model describes the emission rate of a material within a box as a function of the upwind and in-box concentrations, the box size, and the advective velocity. In other words, the concentration of a pollutant in the box is equal to the upwind concentration of the pollutant plus the contribution due to internal sources (i.e., emissions) (3). This relationship can be described mathematically as (3):

$$S_{box} = (C_b - C_u)\,uwh \qquad (7)$$

where S_{box} (in mass/time) is the emission rate of the pollutant, C_b (in mass/volume) is the concentration of the pollutant in the box, C_u (in mass/volume) is the upwind concentration of the pollutant, u (in length/time) is the air velocity through the box, w is the box width, and h is the box height. The box model assumes that complete mixing occurs instantaneously throughout the box (as with Equation 1), that the system is at steady state, and that the air velocity and pollutant emission rate are constant. This model was used to calculate emission rates for lead in the wave soldering area where there was a definite advective air flow. No consistent advective air flow direction was measured in the degreasing and copper plating areas and therefore this model was not used.

5. Receptor Modeling

Receptor models use the chemical and physical characteristics of gases and particles measured at source and receptor to quantitatively allocate the source contributions of each of a number of sources to receptor concentrations (17). No prior assumptions about source location and strength, air mixing, or flow direction are required (18). The result of the allocation is the determination of the fraction of pollutant which comes from each source, but not the total mass released. The general mathematical equation of the receptor modeling is (19):

$$Y_i = A_{ij}\beta_j + E_i \qquad (8)$$

where Y is the concentration at the receptor point, A is the source composition fraction matrix, B is the source contribution, and E is an error term. This approach was used only in the wave soldering area where the local exhaust duct concentrations from each of the three wavelines were used to determine the source composition matrices.

B. Copper Plating

1. Description and Sampling Methods

Sampling took place on March 19 and 20, 1991. Personal sampling pumps were positioned with duct tape, at various heights and distances, along the copper plating line (Figure 5). Particulate samples were collected on 37 millimeter polycarbonate filters. The sampling pumps drew air through the filters at a rate of approximately 2 liters per minute. The actual flow rates varied slightly from sample to sample. All pumps were calibrated with a rotameter, which itself had been calibrated prior to the survey with a soap bubble meter. All filters were removed after approximately one hour and replaced with new filters. Six one-hour periods were monitored on each of the two days during regular production activity, resulting in twelve one-hour concentrations at all five sampling locations. The filters were

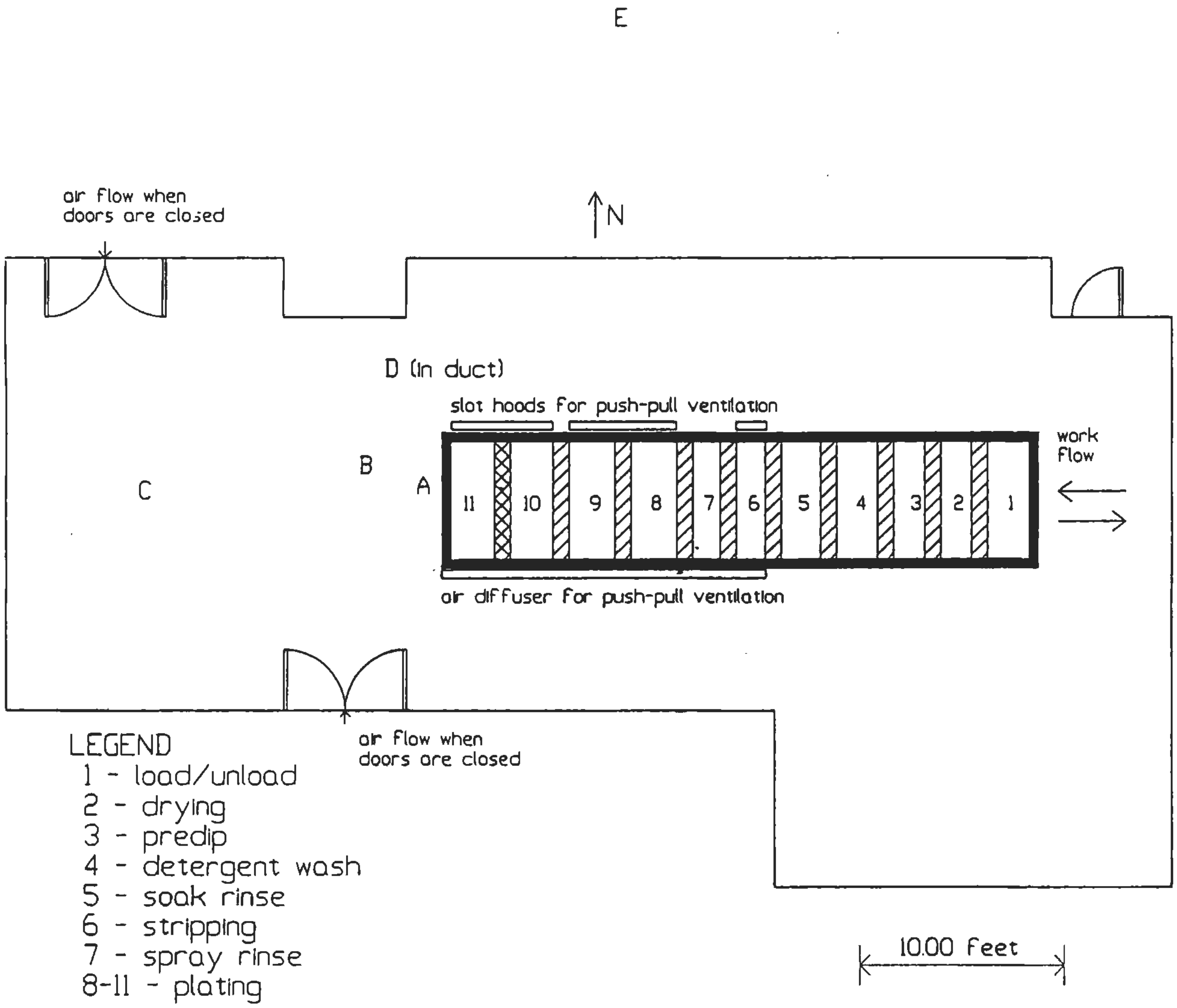

Figure 5. Copper plating line sampling locations (A, B, C, D, E).

analyzed using Proton Induced X-Ray Emissions (PIXE). PIXE determines the mass of all elements deposited on this filter with an atomic weight of at least 23 grams per gram-mole (sodium).

2. Activity Observations

The time and sequence of activities conducted along the copper plating line were recorded by an observer at two-minute intervals. The data collected included board type, number of boards, plating current, temperature of the plating bath, and time the boards spent in each tank. These observations were recorded during the twelve hours when sampling was conducted. The hourly activity data can be found in Appendix A, Table XXXIX.

3. Emission Rates

a. Total Emissions

1) Experimental Mass Balance

At steady state, along the copper plating line there were two exit points and one entry point. The two exit points were the slot hoods alongside the four plating tanks and the laboratory hood in the corner. The entry point was under the two doors which were usually closed. The resulting equation was:

$$S_{mb} = Q_{duct}C_{duct} + Q_{hood}C_{hood} - Q_{into}C_{hall} \qquad (9)$$

All of the concentrations were measured, with the room concentration equal to the average of the three measurements taken inside the room (sampling locations A-C), but not in the duct (sampling location D). The air flow at the two exit points was also measured. However, the air flow into the room could not be measured and was assumed to equal the sum of the air flow leaving the room. The total air flow was 103.6 m^3/min, 53.9 m^3/min exhausting through the slot hoods and 49.7 m^3/min exhausting through the laboratory hood.

2) Completely Mixed Space Model

For the copper plating line there was no measure of the instantaneous concentration at the start of each sampling period therefore the C_s term was assumed to equal zero. However, since a local exhaust ventilation system was in use and the concentration in the duct was measured, a C_{duct} term was added to estimate total emissions. Equation (2) was thus reduced to:

$$V\frac{dC_i}{dt} = C_o q_{into} K + S_{cms} - C_{duct} q_{duct} - C_i q_{hood} \qquad (10)$$

and therefore the integral solution over the averaging time, t_{av}, was:

$$S_{cms} = \frac{C_{av} q_{hood} t_{av}}{t_{av} + \frac{V}{q_{hood}} e^{\frac{-q_{hood} t_{av}}{V}} - \frac{V}{q_{hood}}} - \frac{C_o\left(k q_{into} t_{av} + \frac{V q_{into} k}{q_{hood}} e^{\frac{-q_{hood} t_{av}}{V}} - \frac{V q_{into} k}{q_{hood}}\right)}{t_{av} + \frac{V}{q_{hood}} e^{\frac{-q_{hood} t_{av}}{V}} - \frac{V}{q_{hood}}} + \frac{C_{duct}\left(q_{duct} t_{av} + \frac{V q_{duct}}{q_{hood}} e^{\frac{-q_{hood} t_{av}}{V}} - \frac{V q_{duct}}{q_{hood}}\right)}{t_{av} + \frac{V}{q_{hood}} e^{\frac{-q_{hood} t_{av}}{V}} - \frac{V}{q_{hood}}} \qquad (11)$$

To estimate copper and sulfur emissions along the copper plating line the sampling time (t_{av}) was 60 minutes, the room volume (V) was measured at 696 m^3, the air flow into the room (q_{into}) was 103.6 m^3/min, the air flow measured through the laboratory hood (q_{hood}) was 49.7 m^3/min, the air flow measured through the local exhaust ducts (q_{duct}) was 53.9 m^3/min, and the mixing factor (k) was assumed to be equal to a typical value of 0.3 (6). However, changing the mixing factor (other estimates were 0.1 and 1.0) had little effect on the emission rates probably because k only affected the hall concentration which represented a negligible contribution compared to the contributions due to the other measured concentrations. The room concentration (C_{av}) was the average of sampling locations A-C, the background concentration (C_o) was the hall concentration (sampling location E), and the duct concentration (C_{duct}) was sampling location D (Figure 5).

b. Room Emissions

1) Two-Point Diffusion Model

Unlike the completely mixed space model and experimental mass balance which estimate total emissions, the two-point diffusion model estimates room emissions only. This model has been used to determine emission rates when one pollution source is the major contributor to concentrations in the surrounding space. This description is appropriate for the copper plating line. However, the concentration gradient necessary for the model to produce meaningful results did not consistently occur for either copper or sulfur. The sampling points (locations A-C) may not have been far enough from the source to properly measure the gradient. Additionally, for sulfur, the background concentration (sampling location E) was comparable to the concentrations found in the plating room. Therefore, this model was not used to estimate room emissions for sulfur.

Equations (5) and (6) discussed earlier in this chapter were solved simultaneously for the emission rates using MathCad (20). The distance between the source and the sampling locations (r_1 and r_2) was measured from the center of the four plating tanks and was equal to 2.29 m for r_1 and 3.18 m for r_2. Sampling location A was r_1 and sampling location B was r_2. The concentration gradient between the near (sampling location A) and far points (sampling location C) was not as consistent and therefore fewer meaningful results were obtained.

2) Other Room Emissions

The completely mixed space model and experimental mass balance both estimated total emissions. However, room emission could be estimated by subtracting the duct contribution from the total emission estimates for both experimental mass balance and the completely mixed space model. These copper emissions through the local exhaust were calculated by multiplying the measured concentration in the duct by the measured air flow in the duct for each sampling hour.

4. Emission Factors

Emission factors were calculated using multiple regression techniques. The dependent variable in these regressions was the estimated emission rates and the independent variables were a combination of the source activities. The emission factors are the resulting regression coefficients.

The final regression equations were selected using the SYSTAT MGLH program (21) by examining all possible combinations making physical sense in which the independent variables were not intercorrelated. The selection of the independent variables was dependent primarily upon whether their inclusion made sense physically; and secondarily upon their statistical significance (p) and their coefficient of determination (r^2). The statistical significance of the variables was usually less than 0.1 and the coefficient of determination was maximized as much as possible. In addition, the coefficients (i.e., emission factors) could not be negative because the results then did not make physical sense. The maximum number of independent variables, consistent with the number of observations, that satisfied these requirements were included in the final equations.

Table I lists the activity variables and their description for this process area. In addition, an estimate of the effective energy necessary for plating was calculated for the start of each plating cycle by multiplying the current in the plating bath by the length of time the boards spent in the plating bath. The length of time for each rack of boards in the plating bath was constant (24 minutes). Nine different board types were plated during the study. Table II lists the area of each of these board types. The hourly activity data for this process area can be found in Appendix A, Table XXXIX.

TABLE I

ACTIVITY VARIABLES FOR THE COPPER PLATING LINE

Variable	Description
racksize	average hourly racksize
noboards	total number of boards plated each hour
current	average plating current each hour for all four plating tanks
temp	average temperature of all four plating tanks each hour
plattank	fraction of time boards were being plated each hour in all four plating tanks
in2enter	total square inches of boards entering the four plating tanks each hour
in2plate	total square inches of boards being plated in the four plating tanks each hour
ampmin	calculated estimate of total effective energy each hour

Two sets of regressions were run for this process area. Initially, the independent variables were those collected during the study. The second set of regression equations included the effective energy term as the only independent variable. The effective energy term could not be included with the other independent variables because it was not independent of them.

TABLE II

BOARD SPECIFIC PLATING AREAS FOR THE COPPER PLATING LINE

Key	Board Number	Area (in^2)
1	8483102T01	2.00
2	84833840R01	2.50
3	8484035R01	2.25
4	8483482R01	2.00
5	8484649R01	3.82
6	8484598R01	1.58
7	8482010T01	0.58
8	8480145C01	3.70
9	8484343T01	10.50

C. Degreasing

1. Description and Sampling Methods

Sampling took place on December 4 and 5, 1990. Personal sampling pumps equipped with charcoal adsorption tubes were positioned with duct tape and plastic straps, at various heights and distances, around the three degreasers (Figure 6). The sampling pumps drew air through the charcoal tubes at a rate of approximately 0.2 liters per minute. The actual flow rates varied slightly from sample to sample. All pumps were calibrated with a rotameter, which itself had been calibrated prior to the survey with a soap bubble meter. All charcoal tubes were removed

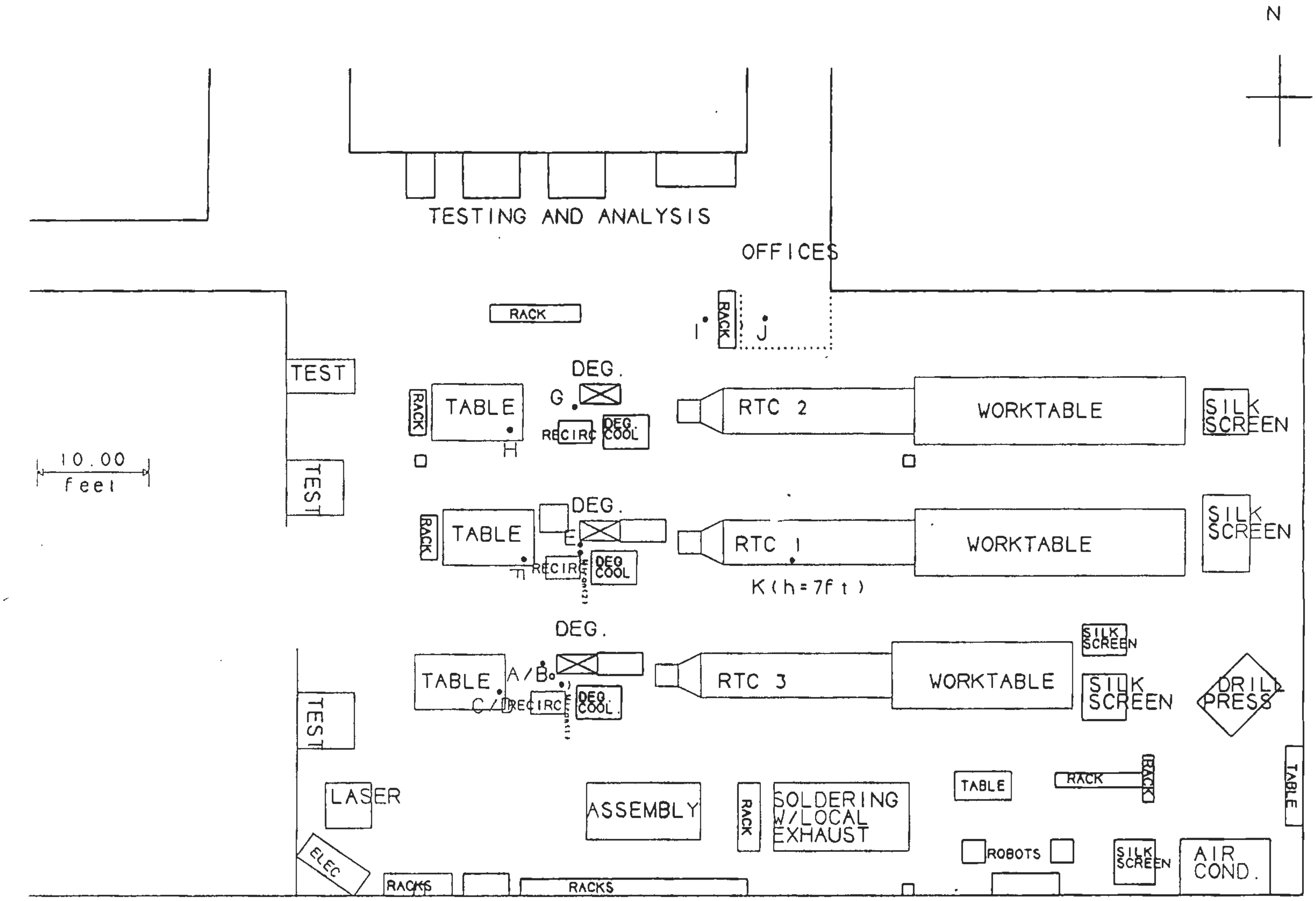

Figure 6. Degreasing process area sampling locations (A, B, C, D, E, F, G, H, I, J, K, Miran (1), Miran (2)).

after approximately one hour and replaced with new tubes. The flow rate of each pump was checked at the beginning, middle, and end of each one-hour sampling period. Six one-hour periods were monitored on each of the two days during regular production activity, resulting in twelve one-hour concentrations at each of the ten sampling locations. All charcoal tubes were analyzed with a gas chromatograph for 1,1,1-trichloroethane (TCA) using the National Institute for Occupational Safety and Health approved method (22). In addition, continuous air monitoring for TCA was conducted at two of the sampling locations with Foxboro/Wilks Miran 1A General Purpose Gas Analyzers. The Mirans were calibrated for TCA prior to use with a closed loop calibration system at a wavelength of 9.3 micrometers.

The two sampling locations for the Mirans were along line 1 (near sampling location E) and along line 3 (near sampling location A/B). Because the Mirans sampled at the same locations as the near charcoal tubes on lines 1 and 3, regression analysis was conducted to determine if any relationship existed between the measured concentrations. This relationship between the one-hour charcoal tube concentrations and the Miran measurements averaged over each hour for line 3 is shown in Figure 7. The regression indicated that the Miran concentrations were higher than the concentrations measured by the charcoal tubes, but that the correlation was strong, with a coefficient of determination, $r^2 = 0.804$. Consequently, an equivalent charcoal tube

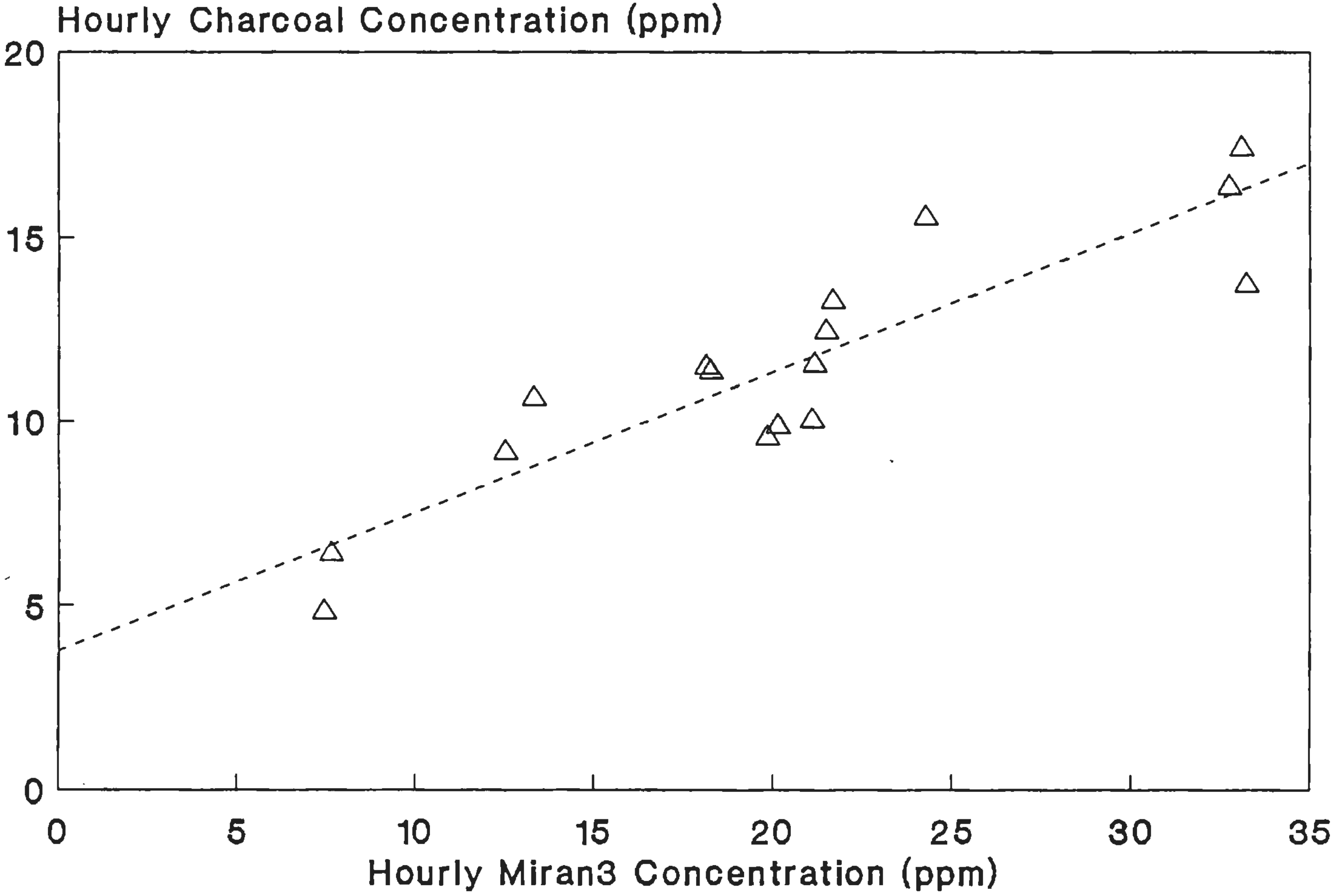

Figure 7. Charcoal tube concentration versus Miran3 concentration for the degreasing process area.

concentration was established for the Miran reading by using the equation from the regression line:

$$\text{Charcoal tube equivalent concentration (ppm)} = (0.379)(\text{Miran concentration, ppm}) + 3.757 \qquad (12)$$

This adjustment allowed for a common basis in other data analysis such as ten-minute measurements. The comparison for line 3 was used for the adjustment because there was less variability in the association between the Miran and the charcoal tube concentration for this line than for line 1 ($r^2 = 0.477$), possibly because of the placement of the charcoal tubes.

2. Activity Observations

The time and sequence of activities conducted on each basket of parts were recorded by an observer at each degreaser and then transposed to two-minute intervals. Observations included the travel number, number of parts per basket, start and end time of each cycle, wash number, and total set time. Non-routine operations were also noted. These observations were recorded during the twelve hours when sampling was conducted. The hourly activity data can be found in Appendix B, Table XLI.

3. Emission Rates

a. Experimental Mass Balance

At steady state in the degreasing process area there were two entry locations and two exit locations. The two entry locations were the air diffusers (sampling location I) and the air entering over the west partitions (leakage) since not all of the walls extended floor to ceiling. The two sources of mass out were the air leaving the room through the air return (sampling location J) and the air leaving through the local exhaust in other parts of the room. The resulting equation was:

$$S_{mb} = Q_{return}C_{return} + Q_{exhaust}C_{exhaust} - Q_{diffuser}C_{diffuser} - Q_{leakage}C_{leakage} \qquad (13)$$

The return air concentration and the air diffuser concentration were measured with charcoal tubes. The exhaust air concentration was estimated to be equal to the average room concentration (average of sampling locations A-H). There was no measurement of the leakage concentration. However, three estimates of the leakage concentration were made. The leakage concentration was set equal to the diffuser concentration (sampling location I), set to zero, and set equal to the lowest measured concentration in the room each hour. All of the air flow rates were measured and the direction of flow determined with smoke tubes, and the resulting air balances are shown in Table III. Since the leakage flow rate was the most difficult to determine, and the least reliable, the total air flow rate out used in subsequent calculations was 279.9 m^3/min.

b. Completely Mixed Space Model

Equation (2) can be simplified for the degreasing area with the following assumptions (6):

1. There is no recirculation or infiltration ($q_1 = q_2 = 0$).
2. The overall volumetric flow rate, q, is due solely to make-up air flow rates ($q = q_0$).

TABLE III

AIR BALANCE IN THE DEGREASING PROCESS AREA

Flow Direction	Air Source	Flow Rate (m^3/min)
in	air diffusers	78.0
in	leakage	373.5
Total In		451.5
out	air return duct	132.6
out	LEV of reflow oven	116.0
out	elephant trunk	11.3
out	hood in still area	9.1
out	LEV still area, 3 sites	10.9
Total Out		279.9

3. The indoor sink removal rate (R) is often unknown and is frequently incorporated with the emission rate (S_{cms}) to result in a net source term.

Therefore, the integral solution over the averaging time, t_{av}, reduces to:

$$S_{cms} = \frac{C_{av}kqt_{av} - C_sV\left(1 - e^{\frac{-kqt_{av}}{V}}\right) - C_o\left(kqt_{av} + Ve^{\frac{-kqt_{av}}{V}} - V\right)}{t_{av} + \frac{V}{kq}e^{\frac{-kqt_{av}}{V}} - \frac{V}{kq}} \qquad (14)$$

where C_{av} is the average room concentration over each sampling period, C_s is the instantaneous TCA concentration at the start of each sampling period, and C_o is the TCA concentration in the air supply. The sampling time (t_{av}) was 60 minutes, the air flow rate (q) was measured at 279.9 m^3/min leaving the room, the room volume (V) was measured at 2798.2 m^3, and the experimentally determined mixing factor (k) was 0.32.

The mixing factor was calculated from the Miran data when all three tanks were covered and the emissions (S) were assumed to equal zero. The equation for removal of a pollutant by ventilation when there is no source term is as follows:

$$C_i - C_o = (C_s - C_o)\, e^{\frac{-kqt}{V}} \qquad (15)$$

where C_i is the Miran concentration averaged over each minute, C_o is the supply air concentration, and C_s is the instantaneous concentration at the beginning of the time interval. The mixing factor was calculated by regressing the natural logarithm of $(C_i - C_o)/(C_s - C_o)$ against time (t). The resulting slope is equal to -kq/V from which it is possible to solve for k. The concentration decay curve is shown in Figure 8.

c. Ten-Minute Emission Rates

Since a continuous measure of the TCA concentration was available from the Miran data, shorter term emission rates could also be calculated and compared with source activities. The short-term time interval was selected at ten minutes. In order to determine whether the Miran readings could properly characterize the concentration changes for the complete room, the charcoal-tube equivalent Miran concentrations were compared with the average room concentrations used in the

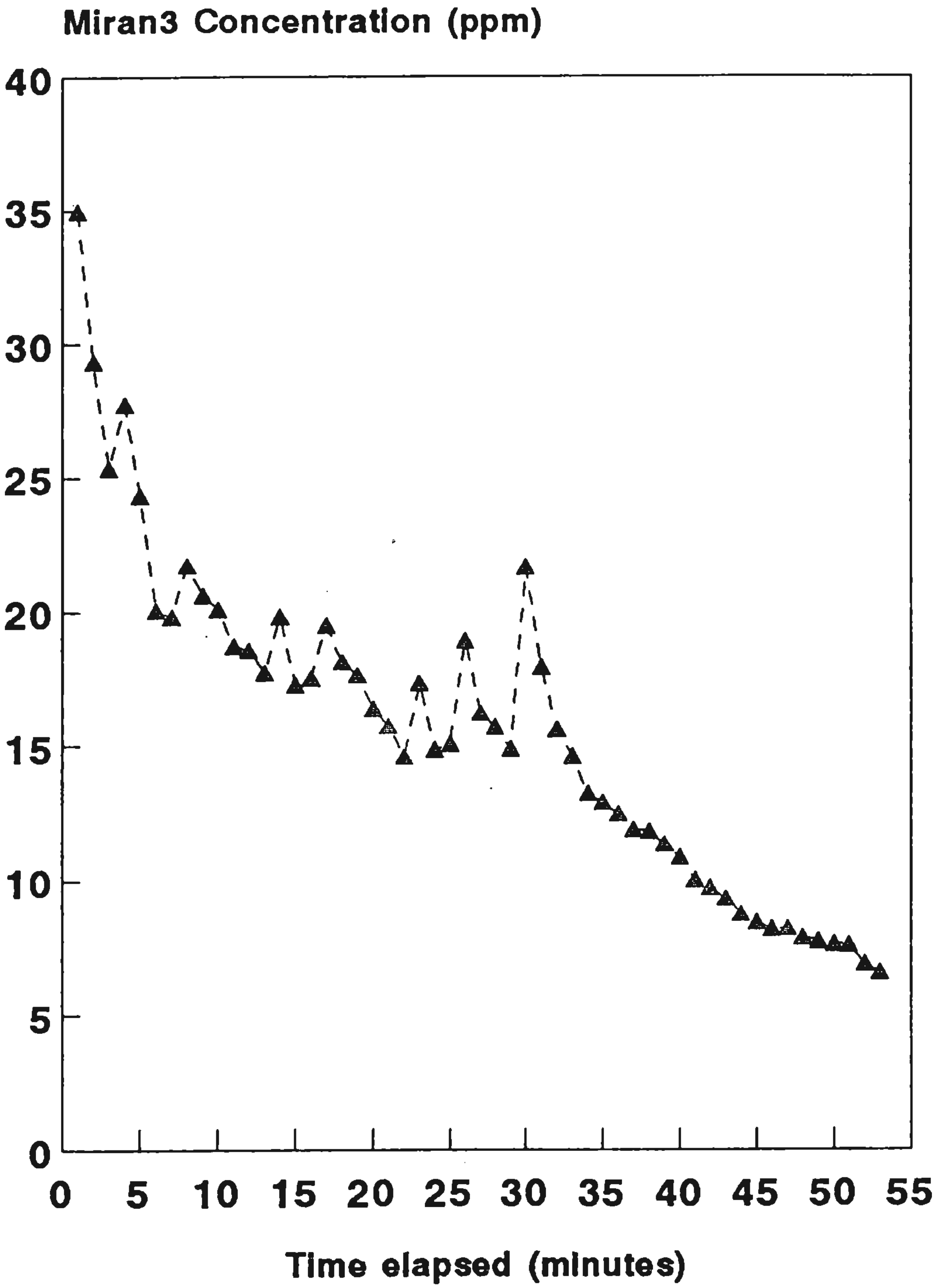

Figure 8. Miran concentration decay curve for the determination of k in the degreasing process area.

completely mixed space model. The r^2 was 0.579 for the Miran average and the r^2 was 0.737 for the Miran on line 1 as shown in Figures 9 and 10. The relationship for line 3 alone was not as good ($r^2 = 0.371$) and therefore was not used to adjust the charcoal-tube equivalent Miran concentrations. When the average Miran concentration was used, the room adjustment was:

Average room concentration (mg/m^3) = (1.231) (Charcoal equivalent Miran average concentration, mg/m^3) + 26.050 (16)

When only Miran1 was used to estimate the room concentration the following adjustment was used:

Average room concentration (mg/m^3) = (1.869) (Charcoal equivalent Miran1 concentration, mg/m^3) + 7.594 (17)

Emission rates were then calculated using these charcoal-tube equivalent Miran concentrations to estimate the room concentrations.

4. Emission Factors

Emission factors were calculated using multiple regression techniques. The dependent variable in these regressions was the estimated emission rates and the independent variables were a combination of the source activities. The emission factors are the resulting regression coefficients.

The final regression equations were selected using the SYSTAT MGLH program (21) by examining all possible combinations making physical sense in which the independent variables were not

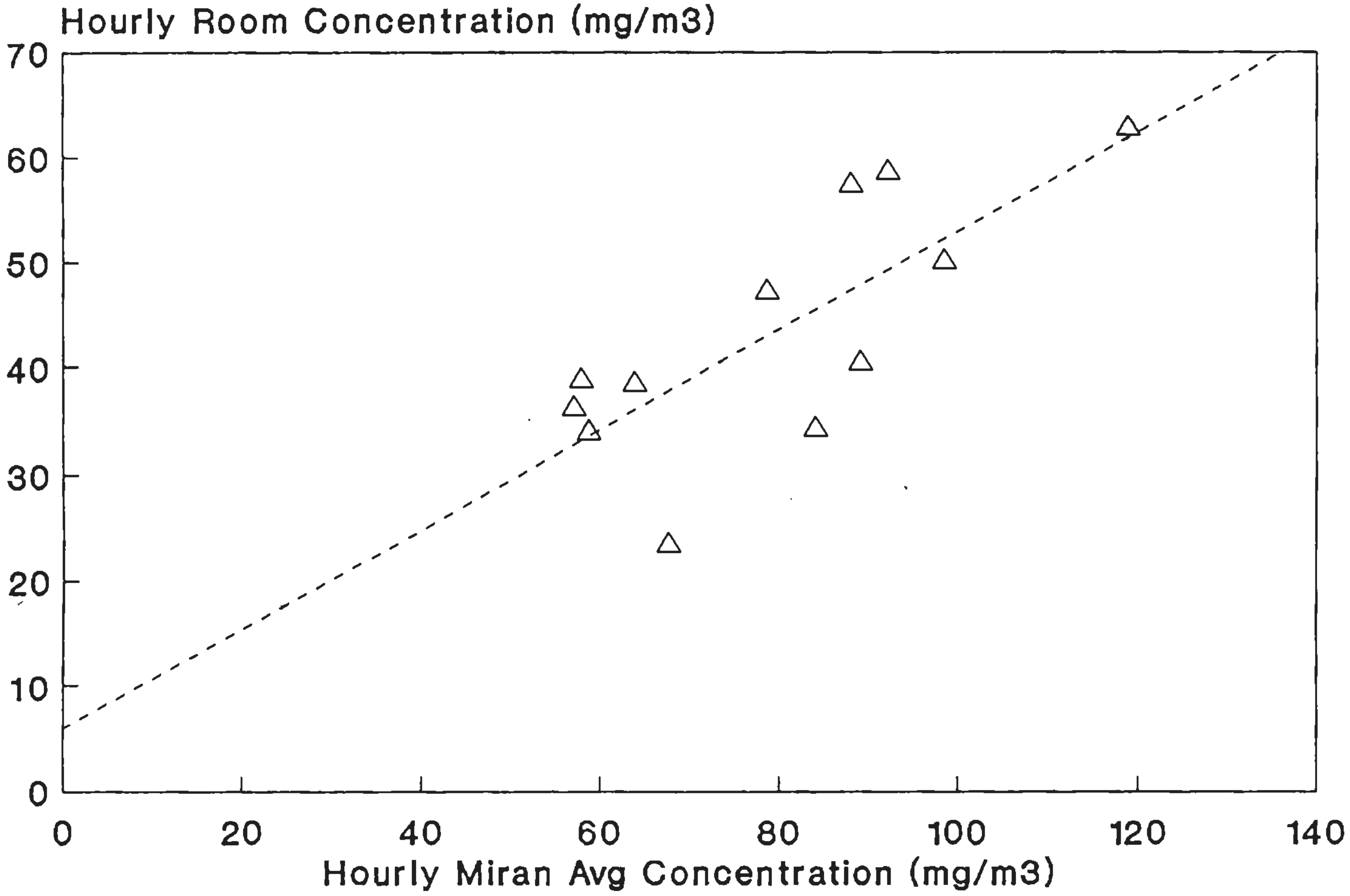

Figure 9. Charcoal-adjusted Miran average concentration versus room concentration (average of sampling locations A-H) for the degreasing process area.

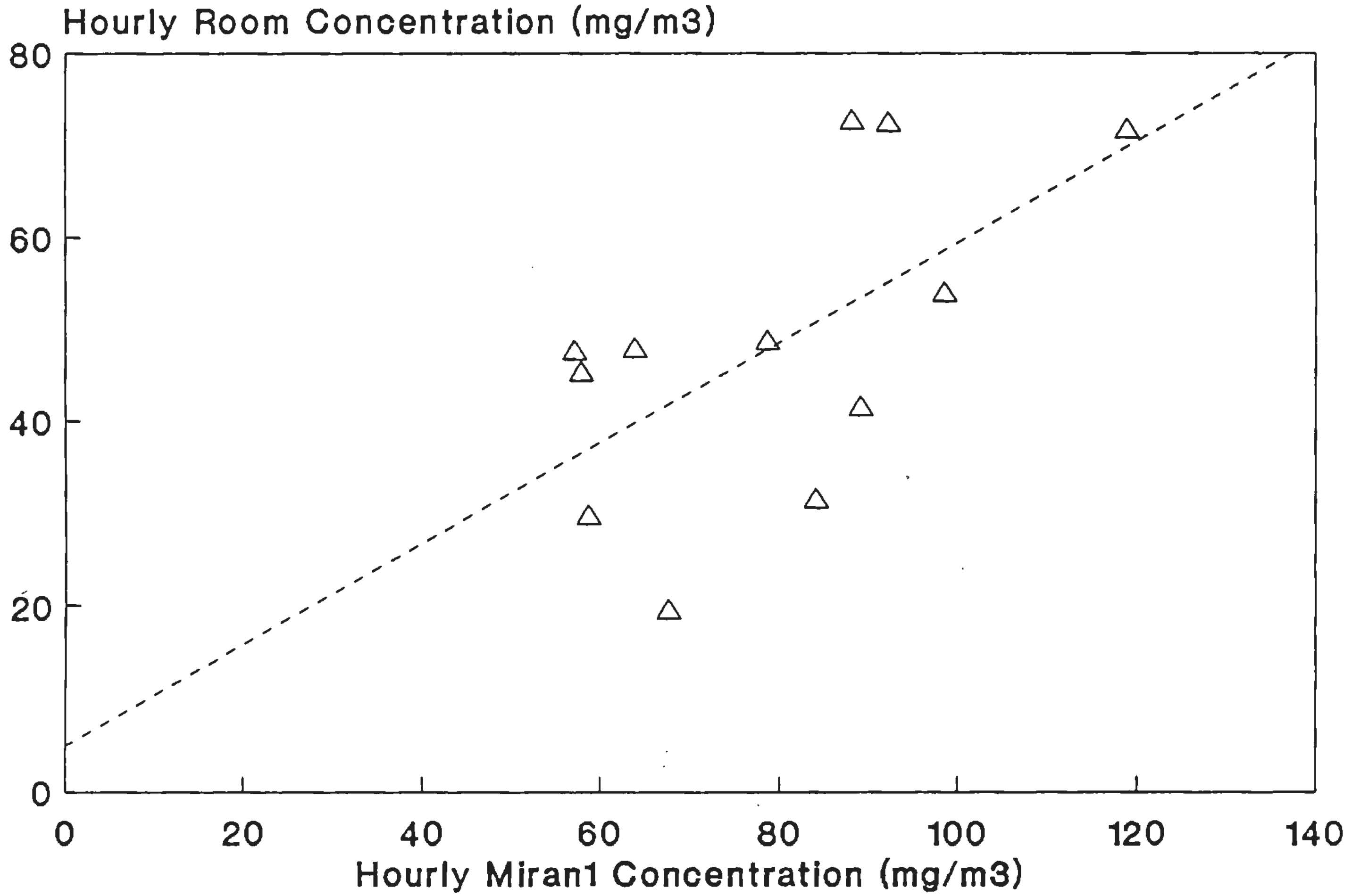

Figure 10. Charcoal-adjusted Miran1 concentration versus room concentration (average of sampling locations A-H) for the degreasing process area.

intercorrelated. The selection of the independent variables was primarily dependent upon whether the coefficient made physical sense; and secondarily upon their statistical significance (p) and their coefficient of determination (r^2). The statistical significance of the variables was usually less than 0.1 and the coefficient of determination was maximized as much as possible. In addition, the coefficients (i.e., emission factors) could not be negative because the results then did not make physical sense. The maximum number of independent variables that satisfied these requirements were included in the final equations.

For the degreasing process area emission factors were determined in two ways. Initially, the activity variables were separated by line and emission factors determined that described the emissions by line. Using this method the percent contribution of each of the three lines was calculated based on the emission factor equations. A requirement for this method was that only one variable from each line would describe that line because only 12 points were available as the dependent variable in the regressions. Table IV lists the 27 original activity variables collected for this process area. However, since only 12 hourly emission rates were calculated, only those activity variables which best described emissions could be included in the regressions.

Given the general agreement between the charcoal tube concentrations and the hourly Miran3 concentrations (as shown in Figure 7) it was decided to use the instantaneous Miran

TABLE IV

ACTIVITY VARIABLES FOR THE DEGREASING PROCESS AREA

Line 1	Line 2	Line 3	Description
travel1	travel2	travel3	average part identification number, categorized from least solvent carryout (1) to most solvent carryout (6)
part1	part2	part3	total number of parts degreased
auto1	auto2	auto3	fraction of time cycle automated
manual1	manual2	manual3	fraction of time cycle manual
basket1	basket2	basket3	fraction of time a previously degreased basket of parts remained near the sampling locations
wash11	wash21	wash31	fraction of time each basket of parts degreased once
wash12	wash22	wash32	fraction of time each basket of parts degreased twice
wash13	wash23	wash33	fraction of time each basket of parts degreased three times
tank1	tank2	tank3	fraction of time degreasing tank covered

concentrations to help select appropriate activity variables. To reduce the 27 original activity variables to a usable number, regressions were run using the TCA concentrations from the two Mirans averaged over one minute to estimate emissions. For these regressions 420 one-minute average concentrations (7 hours) were available for each day. The activity data were also available on a per minute basis. The selected activity variables from these regressions are shown in Table V. These seven activity variables

TABLE V

SELECTED ACTIVITY VARIABLES FOR EMISSION FACTOR DETERMINATION IN THE DEGREASING PROCESS AREA

Variable	Description
basket1	fraction of time a previously degreased basket of parts remained near the sampling locations for line 1
tank1	fraction of time degreasing tank covered for line 1
travel2	average categorized part identification number for line 2
tank2	fraction of time degreasing tank covered for line 2
part3	total number of parts degreased for line 3
auto3	fraction of time cycle automated for line 3
tank3	fraction of time degreasing tank covered for line 3

were then the only ones used to determine the emission factors on a per line basis. Hourly averages for basket1 (fraction of time a previously degreased basket of parts remained near line 1), tank1 (fraction of time line 1 tank covered), travel2 (average categorized part identification number for line 1), tank2 (fraction of time line 2 tank covered), auto3 (fraction of time line 3 cycle automated), tank3 (fraction of time line 3 tank covered), and tank23 (fraction of time lines 2 and 3 tanks were covered) were calculated to use in these regressions. Part3 was the total number of parts degreased during the hour.

The other method of determining emission factors was to group all three lines together and calculate the emission factors on a per variable basis to determine the effect of activity on overall emissions from the space. The average travel number was replaced with the total cross-sectional area of the parts because the area was thought to be a better measure than the travel number and because it became available in time for this part of the analysis. The wash number was not included since it was closely correlated with whether the cycle was automated. Table VI lists the activity variables used for this part of the analysis. Table XLII, Appendix B, shows the cross-sectional areas of the microcircuits degreased during the survey.

TABLE VI

GROUPED ACTIVITY VARIABLES FOR EMISSION FACTOR DETERMINATION IN THE DEGREASING PROCESS AREA

Variable	Description
tank	average fraction of time the three degreasing tanks are uncovered
part	total number of parts degreased in all three tanks
basket	average fraction of time a previously degreased basket of parts remains near the sampling locations
auto	average fraction of time the degreasing cycle is automated
manual	average fraction of time the degreasing cycle is manual
squarein	total square inches of parts being degreased

D. Wave Soldering

1. Description and Sampling Methods

Sampling took place on December 6 and 7, 1990. Personal and area sampling pumps were positioned with duct tape and plastic straps, at various heights and distances, along the three wave soldering lines (Figure 11). Particulate samples were collected on 37 millimeter polycarbonate filters. The sampling pumps drew air through the filters at a rate of 3-5 liters per minute. The actual flow rates varied from sample to sample. All pumps were calibrated with a rotameter, which itself had been calibrated prior to the survey with a soap bubble meter. All filters were removed after approximately one hour and replaced with new filters. The flow rate of each pump was checked at the beginning, middle, and end of each sampling period. Six one-hour periods were monitored on each of two days during regular production activity, resulting in twelve one-hour concentrations at all ten sampling locations. The filters were analyzed using PIXE.

2. Activity Observations

The time and sequence of activities conducted along each of the three lines were recorded at two-minute intervals. Data collected by the observers included board type, number of boards, and the time at which soldering pot scraping and dedrossing took place. These observations were recorded during the twelve hours when sampling was conducted. The hourly activity data can be found in Appendix C, Table XLIII.

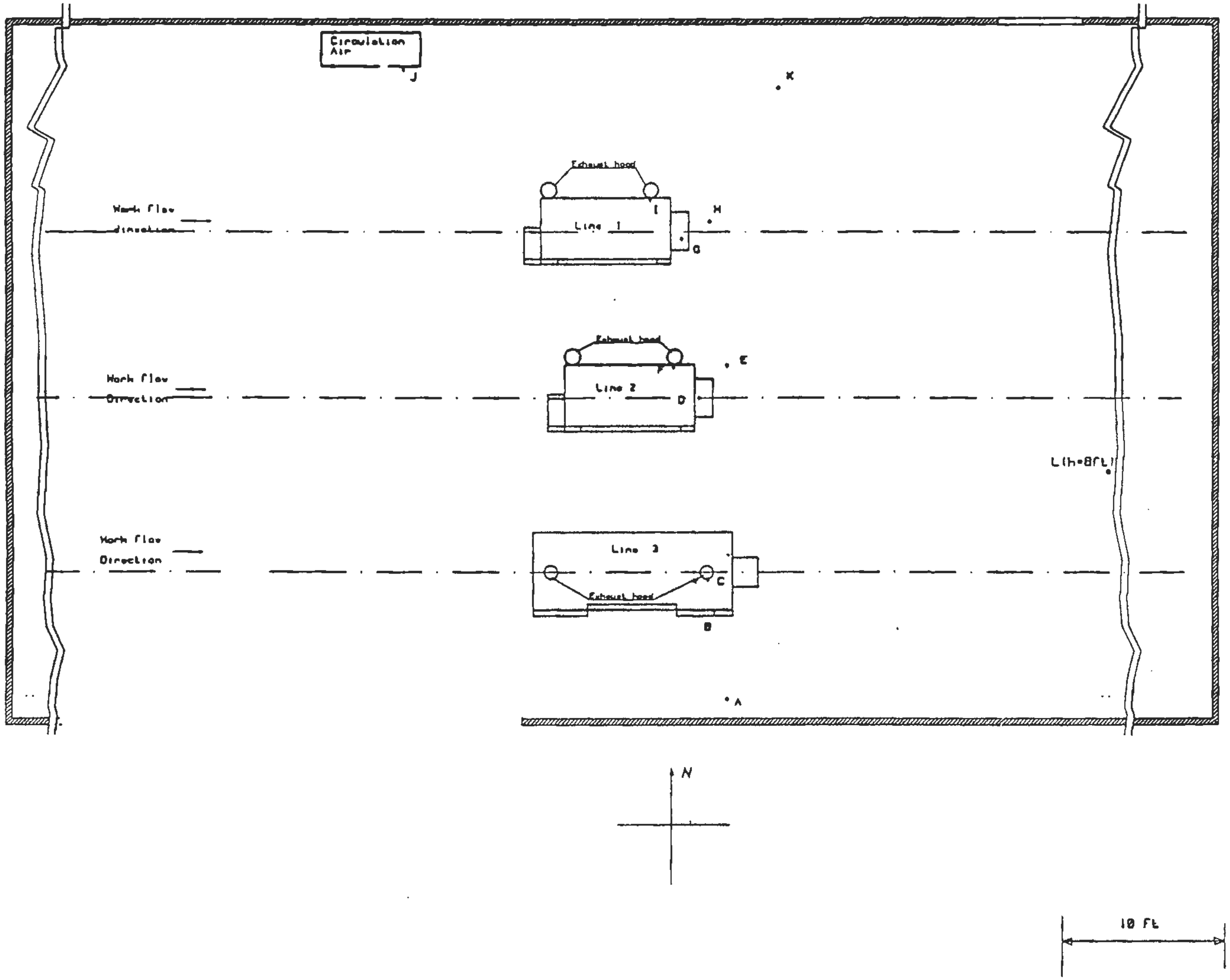

Figure 11. Wave soldering area sampling locations (A, B, C, D, E, F, G, H, I, J, K, L).

3. Emission Rates

a. Box Model

The box model was described earlier in this chapter and shown in Equation (7). It was chosen because, as shown in Figure 4, the direction of advective flow was the same as that of the work flow. For the wave soldering area, the box width (w) was 13.11 m, the width of the bay containing the three wavelines. The box height (h) was the measured height to the air diffusers and not to the ceiling, which could not be measured, and was 3.05 m, and the average advective velocity (u) was 10.15 m/min. The advective velocity was the average of all easterly flowing measurements along the three lines, as shown in Figure 11. The u*w*h product was then equal to 405.85 m^3/min for the calculation of the hourly box model emission rates. The upwind concentration, C_u, was the concentration measured at the recirculation air (sampling location J). The box concentration, C_b, was the average of the near and far sampling points from all three lines (sampling locations A, B, D, E, G, H).

b. Receptor Modeling

Multiple regression analysis (Equation 8) was used for the receptor modeling in the wave soldering area. The dependent variables were the ambient compositions measured at each of eight sampling locations (A, B, D, E, G, H, J, K as shown in Figure 11) while the independent variables were the mass fractions of the elements in the duct concentrations (sampling locations C, F, and I) being used as the source points.

The receptor allocation procedure used 16 fitting elements: silicon, sulfur, chlorine, titanium, vanadium, manganese, iron, nickel, copper, rubidium, strontium, yttrium, zirconium, molybdenum, tin, and lead. Between eight and twelve of these fitting elements were used for each of the regressions. To be included as a fitting element, the element needed to be greater than the background levels for at least nine of the twelve sampling hours at each receptor point. The receptor point determined which fitting elements were included because one-tenth of the receptor point's concentration was used as a weighting factor and therefore needed to be greater than zero. Eight of the fitting elements were used for at least seven of the regressions, including sulfur, chlorine, manganese, iron, nickel, copper, tin, and lead. The other eight fitting elements were used for four or fewer of the regressions.

The fitting procedure allocates the particulate matter measured at a particular location to the three sources included in the model. Since there was no measure of total particulates, the sum of all detected elements was used as a surrogate.

Multiple regression analysis using the SYSTAT MGLH program (21) and a no-intercept model was done for all eight of the receptor points for each of the twelve sampling hours. Nine regression equations were run for each hour. Table VII shows all of these regression equations. The FI term comes from combining the contributions of wavelines 1 and 2 because both lines utilized the same machine model. Two final regression equations

TABLE VII

RECEPTOR MODELING REGRESSION EQUATIONS FOR THE WAVE SOLDERING AREA

Dependent Variable[a]	Independent Variables[b]
Y	C + F + I
Y	C + F
Y	C + I
Y	C + FI
Y	F + I
Y	C
Y	F
Y	I
Y	FI

[a] eight receptor points (sampling locations A, B, D, E, G, H, J, K) as shown in Figure 11 were the dependent variables

[b] sampling locations shown in Figure 11 with C from line 3, F from line 2, I from line 1

for each receptor point were then selected that best described the contribution from the source points. The resulting equations were: $Y = C + FI$ and $Y = C + F + I$ in which Y is the receptor point. Since the chemical pattern of the duct concentrations of the three lines were often co-linear, it was usually not possible to fit coefficients for all three with one equation. If the selected equations did not contain all positive coefficients when running the original regressions, then the coefficients were calculated with a model containing fewer source terms. The final solution was arrived at by averaging the terms of the regression equations which contained all positive coefficients and as many as possible of the source points. Often the final solution was the average of the coefficients from the regression equations containing only single source points. An example for receptor point d, hour 6, only single source point coefficients were used to calculate the final solution. The three single source point equations were $D = 0.726C$, $D = 1.733F$, and $D = 1.178I$. The final solution was then each coefficient divided by three because the final solution was the average from three equations. The resulting equation was then $D = 0.242C + 0.578F + 0.393I$.

4. Emission Factors

Emission factors were calculated using multiple regression techniques. The dependent variable in these regressions was the estimated emission rates and the independent variables were a combination of the source activities. The emission factors are the resulting regression coefficients.

The final regression equations were selected using the SYSTAT MGLH program (21) by examining all possible combinations making physical sense in which the independent variables were not intercorrelated. The selection of the independent variables was primarily dependent upon whether the coefficient made physical sense; and secondarily upon their statistical significance (p) and their coefficient of determination (r^2). The statistical significance of the variables was usually less than 0.1 and the coefficient of determination was maximized as much as possible. In addition, the coefficients (i.e., emission factors) could not be negative because the results then did not make physical sense. The maximum number of independent variables that satisfied these requirements were included in the final equations.

Initially emission factors were determined using the box model emission rates as the dependent variable. Table VIII lists the activity variables and their description for this process area. Each of these activity variables were summed or averaged over the 12 sampling hours. The hourly activity data for this process area can be found in Appendix C, Table XLIII.

Using the results from the emission factor equations based on the box model, two activity variables were selected to determine the relationship between the selected activity variables and the lead contribution from each waveline based on the receptor modeling equations. The two activity variables which had the most effect on the box model emissions were the total board count each hour and the total scrapings and

TABLE VIII

ACTIVITY VARIABLES FOR THE WAVE SOLDERING AREA

Variable	Description
boards	total number of boards soldered
hood	total number of hood cover openings
open	fraction of time hood cover opened
scr/ded	total number of scrapings and dedrossings

dedrossings each hour. In addition, the total hood openings each hour was included because it appeared to be related to the calculated lead contribution. Finally, the three activity variables were separated into their contributions from each of the three wavelines.

Of the most interest was the lead and tin contributions. From a comparison of the duct concentrations with the area concentrations (Appendix C, Table XLIV) it became apparent that only lead, tin, and possibly chlorine were associated with the sources. All the other components were from the room air. Consequently the evaluation of the effect of source activities focused on lead.

The lead contribution from each source was calculated by multiplying the coefficient from the receptor model regression equation at each receptor point by the ratio of lead to the sum of all detected elements for the source. The lead contribution for each source was then regressed against each of the selected activity variables to determine if any relationship existed.

III. RESULTS

A. Copper Plating

1. Copper and Sulfur Concentrations

One-hour average copper concentrations from the five sampling locations (Figure 5) are shown in Table IX. One-hour average sulfur concentrations from the five sampling locations are shown in Table X. Hours 1 through 6 were collected on March 19, 1991 and hours 7 through 12 were collected on March 20, 1991. The duct concentrations for these two elements were always the largest and the concentration measured in the hall (background) was always the smallest for copper. For sulfur the room concentration (average of sampling locations A-C) was very similar to the hall concentration. A consistent concentration gradient between the concentrations measured at the near, mid, and far points was not evident. However, the near point was higher than the mid location in 10 of the 12 hours. The concentrations of other elements such as silicon, chlorine, titanium, chromium, iron, nickel, zinc, bromine, lead, potassium, manganese, zirconium, molybdenum, vanadium, and calcium did not show the lower hall concentration and were more constant in concentration between sampling locations (Table XL, Appendix A). Therefore only copper and sulfur were chosen for evaluation. All measured concentrations were below the OSHA permissible exposure limit for either copper dusts and mists (1000 $\mu g/m^3$) or sulfuric acid (1000 $\mu g/m^3$). The copper and sulfur concentration patterns

TABLE IX

HOURLY COPPER CONCENTRATIONS ALONG THE COPPER PLATING LINE ($\mu g/m^3$)

Sample Date	Sample Time[a]	A[b] Near	B[b] Mid	C[b] Far	D[b] Duct	E[b] Hall
3-19-91	8:00- 8:59	0.13	0.07	0.02	6.19	0.017
3-19-91	9:00- 9:59	0.31	0.04	0.38	4.64	0.015
3-19-91	10:00-10:59	0.46	0.35	0.37	4.28	0.003
3-19-91	11:00-11:59	0.03	0.26	0.35	3.69	0.009
3-19-91	12:00-12:59	0.11	0.28	0.05	8.49	0.013
3-19-91	13:00-13:59	0.22	0.26	0.33	8.44	0.025
3-20-91	8:00- 8:59	0.59	0.09	0.12	5.01	0.004
3-20-91	9:00- 9:59	0.41	0.15	0.13	13.1	0.008
3-20-91	10:00-10:59	0.78	0.10	0.17	8.73	0.009
3-20-91	11:00-11:59	0.39	0.14	0.17	14.2	0.006
3-20-91	12:00-12:59	0.64	0.16	0.17	14.7	0.009
3-20-91	13:00-13:59	0.30	0.14	0.24	14.5	0.005
	MEAN	0.36	0.17	0.21	8.85	0.010

[a] approximate times

[b] sampling locations are shown in Figure 5

TABLE X

HOURLY SULFUR CONCENTRATIONS ALONG THE COPPER PLATING LINE ($\mu g/m^3$)

Sample Date	Sample Time[a]	A[b] Near	B[b] Mid	C[b] Far	D[b] Duct	E[b] Hall
3-19-91	8:00- 8:59	0.40	0.48	-	12.8	3.10
3-19-91	9:00- 9:59	1.50	-	1.56	8.0	1.65
3-19-91	10:00-10:59	1.78	1.65	1.79	7.8	0.57
3-19-91	11:00-11:59	-	1.59	1.81	6.4	-
3-19-91	12:00-12:59	2.60	8.44	1.16	26.2	0.94
3-19-91	13:00-13:59	0.94	2.04	1.74	17.7	0.82
3-20-91	8:00- 8:59	3.15	1.64	2.01	10.2	1.61
3-20-91	9:00- 9:59	3.28	3.31	3.05	30.1	3.21
3-20-91	10:00-10:59	3.70	1.77	2.32	19.7	2.27
3-20-91	11:00-11:59	2.53	2.29	2.15	31.4	2.26
3-20-91	12:00-12:59	4.85	2.88	3.64	34.4	2.82
3-20-91	13:00-13:59	3.23	3.55	3.51	34.5	4.77
	Mean	2.33	2.47	2.06	19.9	2.00

[a] approximate times

[b] sampling locations are shown in Figure 5

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made physical sense because copper and sulfur (from sulfuric acid) were both present in the plating baths.

2. Emission Rates

For the copper plating line, hourly emission rates for both copper and sulfur were estimated using three mathematical models: experimental mass balance, the completely mixed space model, and the two-point diffusion model. The emission rates calculated from experimental mass balance and from the completely mixed space model estimated total emissions, including those into the local exhaust ventilation duct. The two-point diffusion model estimated emissions into the room only. However, room emissions were also estimated by subtraction of the duct emissions from both the experimental mass balance and from the completely mixed space model.

a. Experimental Mass Balance

Twelve one-hour emission rates were estimated using Equation (9) for both copper (Table XI) and for sulfur (Table XII). The average one-hour emission rate for copper was 29 mg/hr and that for sulfur was 59 mg/hr.

b. Completely Mixed Space Model

Twelve one-hour emission rates were estimated using Equation (11) for both copper (Table XI) and for sulfur (Table XII). The average hourly emission rate for copper was 29 mg/hr and for sulfur was 73 mg/hr.

TABLE XI

HOURLY TOTAL COPPER EMISSIONS ALONG THE COPPER PLATING LINE FROM EXPERIMENTAL MASS BALANCE AND THE COMPLETELY MIXED SPACE MODEL (mg/hr)

Sample Date	Sample Time[a]	Smb	Scms
3-19-91	8:00- 8:59	20.1	20.2
3-19-91	9:00- 9:59	15.6	15.6
3-19-91	10:00-10:59	14.9	14.8
3-19-91	11:00-11:59	12.5	12.4
3-19-91	12:00-12:59	27.8	27.8
3-19-91	13:00-13:59	27.9	28.0
3-20-91	8:00- 8:59	16.9	16.8
3-20-91	9:00- 9:59	43.2	43.1
3-20-91	10:00-10:59	29.2	29.1
3-20-91	11:00-11:59	46.7	46.6
3-20-91	12:00-12:59	48.5	48.4
3-20-91	13:00-13:59	47.8	47.7
	MEAN	29.2	29.2

[a] approximate times

TABLE XII

HOURLY TOTAL SULFUR EMISSIONS ALONG THE COPPER PLATING LINE FROM EXPERIMENTAL MASS BALANCE AND THE COMPLETELY MIXED SPACE MODEL (mg/hr)

Sample Date	Sample Time[a]	Smb	Scms
3-19-91	8:00- 8:59	23.3	48.2
3-19-91	9:00- 9:59	18.8	31.6
3-19-91	10:00-10:59	27.1	30.7
3-19-91	11:00-11:59	24.3	23.6
3-19-91	12:00-12:59	91.0	96.4
3-19-91	13:00-13:59	57.0	62.8
3-20-91	8:00- 8:59	30.0	41.8
3-20-91	9:00- 9:59	87.1	111.2
3-20-91	10:00-10:59	57.4	74.3
3-20-91	11:00-11:59	94.3	111.4
3-20-91	12:00-12:59	105.0	125.6
3-20-91	13:00-13:59	92.4	129.0
	MEAN	59.0	73.9

[a] approximate times

c. Correlation

The hourly emission rates for both copper and sulfur from each of the two models were very similar. To determine how similar, a Pearson correlation matrix was constructed. The matrix provides the correlation coefficients, r, which measure the strength of the linear relationship between the sample observations of two variables. The two variables were either the copper emission rates from experimental mass balance and the completely mixed space model or the sulfur emission rates from the same two models. For the copper emissions $r = 1.000$ and for the sulfur emission $r = 0.970$. The coefficients of determination, r^2, for the copper emissions were $r^2 = 1.000$ and for the sulfur emissions $r^2 = 0.941$.

d. Two-Point Diffusion Model

For copper, the concentration gradient with distance was steep enough in eight of the twelve hours to give positive values of the diffusivity (Table XIII). Concentrations for the other four hours did not produce a result because Equations (5) and (6) did not give a positive value of D. The average hourly room emission rate for copper was 0.14 mg/hr.

e. Other Room Emissions

The results of the room emission estimates based on experimental mass balance and the completely mixed space model are shown in Table XIII. The average hourly room emissions for copper based on experimental mass balance was 0.67 mg/hr and based on the completely mixed space model was 0.61 mg/hr. Table

TABLE XIII

HOURLY ROOM COPPER EMISSIONS ALONG THE COPPER PLATING LINE FROM THE TWO-POINT DIFFUSION MODEL, EXPERIMENTAL MASS BALANCE, AND THE COMPLETELY MIXED SPACE MODEL (mg/hr)

Sample Date	Sample Time[a]	Stp	D (m^2/min)	Smb[b]	Scms[b]
3-19-91	8:00- 8:59	0.06	0.27	0.11	0.19
3-19-91	9:00- 9:59	0.12	0.02	0.63	0.60
3-19-91	10:00-10:59	-	-	1.15	0.95
3-19-91	11:00-11:59	-	-	0.58	0.52
3-19-91	12:00-12:59	-	-	0.36	0.37
3-19-91	13:00-13:59	-	-	0.65	0.67
3-20-91	8:00- 8:59	0.20	0.02	0.77	0.65
3-20-91	9:00- 9:59	0.10	0.07	0.64	0.56
3-20-91	10:00-10:59	0.31	0.02	0.99	0.85
3-20-91	11:00-11:59	0.10	0.07	0.66	0.57
3-20-91	12:00-12:59	0.17	0.03	0.91	0.79
3-20-91	13:00-13:59	0.10	0.14	0.64	0.55
	MEAN	0.14		0.67	0.61

[a] approximate times

[b] These emission rates are for room emissions only. The duct contribution has been removed and therefore these values are different than the emission rates in Table XI.

- no meaningful result obtained

XIV shows the Pearson correlation matrix for the room emissions using the three models. These estimates of room emissions were well correlated since $r \geq 0.797$ ($r^2 > 0.61$) with the least agreement between the two-point diffusion model and the experimental mass balance (Figure 12). The relationship between the emissions for the eight common sampling hours indicated that the mass balance emission rate was about 2.5 times the two-point rate. The difference suggests that while a controlled system may have been appropriate in the east-west direction, there may be a significant advection term in the direction of the control hood (north side). However, both approaches appear to reflect the same emission pattern since the r^2 was high.

TABLE XIV

PEARSON CORRELATION MATRIX FOR ROOM EMISSIONS ALONG THE COPPER PLATING LINE FOR THE TWO-POINT DIFFUSION MODEL, EXPERIMENTAL MASS BALANCE, AND THE COMPLETELY MIXED SPACE MODEL

r	Stp	Smb	Scms
Stp	1.000		
Smb	0.797	1.000	
Scms	0.806	0.995	1.000

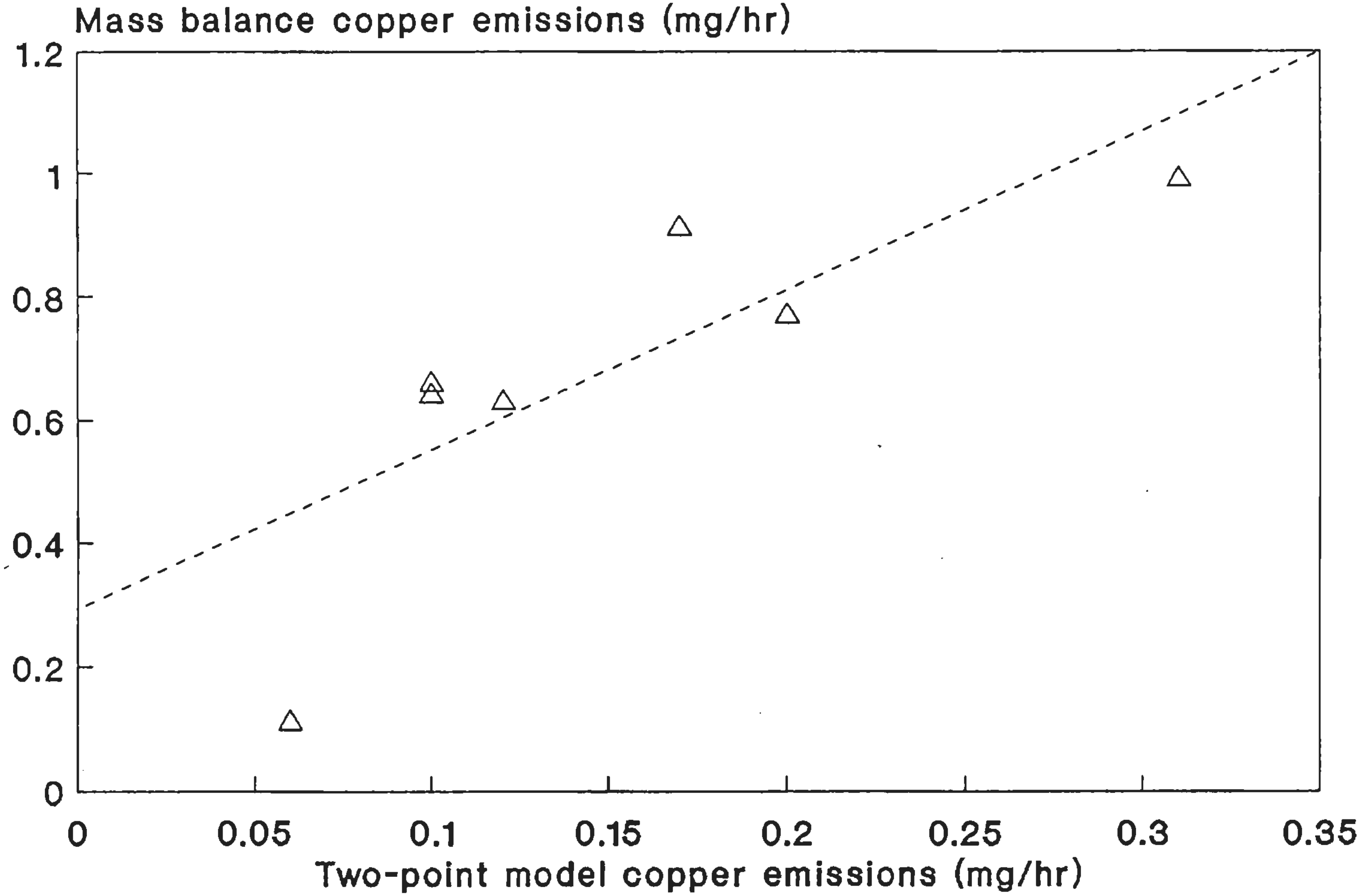

Figure 12. Mass balance copper emissions into the room versus two-point diffusion model copper emissions into the room for the copper plating line.

f. Duct Efficiency

An advantage of calculating the room emissions based on experimental mass balance and the completely mixed space model was that the efficiency of the local exhaust duct could also be calculated. Table XV shows the duct efficiency based on both experimental mass balance and the completely mixed space model. For both models the average duct efficiency was greater than 0.97.

TABLE XV

DUCT EFFICIENCY FOR COPPER EMISSIONS ALONG THE COPPER PLATING LINE BASED ON EXPERIMENTAL MASS BALANCE AND THE COMPLETELY MIXED SPACE MODEL

Sample Date	Sample Time[a]	ηmb	ηcms
3-19-91	8:00- 8:59	0.994	0.991
3-19-91	9:00- 9:59	0.960	0.962
3-19-91	10:00-10:59	0.923	0.936
3-19-91	11:00-11:59	0.954	0.958
3-19-91	12:00-12:59	0.987	0.987
3-19-91	13:00-13:59	0.977	0.976
3-20-91	8:00- 8:59	0.954	0.961
3-20-91	9:00- 9:59	0.985	0.987
3-20-91	10:00-10:59	0.966	0.971
3-20-91	11:00-11:59	0.986	0.988
3-20-91	12:00-12:59	0.981	0.984
3-20-91	13:00-13:59	0.987	0.988
	MEAN	0.971	0.974

[a] approximate times

3. Emission Factors

Emission factors were initially determined using all of the collected activity variables averaged or summed over the sampling periods. The resulting equations based on the total emissions included only the variable in2enter, as shown in Figures 13 - 16. These equations included a constant to account for unexplained emissions. Additionally, sampling hour 10 was not included in the regressions because the high emission rate and zero value for the activity variables controlled the results. In other words, when hour 10 was included the slope of the least squares fit curve was negative. Table XVI shows the emission factors based on total emissions for the other 11 hours. The in2plate activity variable also showed a relationship with the model emission rates, although not as strong as the in2enter activity variable. These relationships are shown in Appendix A, Figures 46 - 49.

Similarly, emission factors were determined based on the estimates of room emissions. These equations also contained a constant, but hour 10 was included in these regressions. The emission factor equations for room emissions included only the activity variable in2plate, as shown in Figures 17 - 19, or the activity variable in2enter, as shown in Appendix A, Figures 50 - 52. Table XVII shows these emission factors.

Emission factors were also determined for an estimate of the effective energy required for the plating process, the ampmin variable. This was done for both total emissions and for room

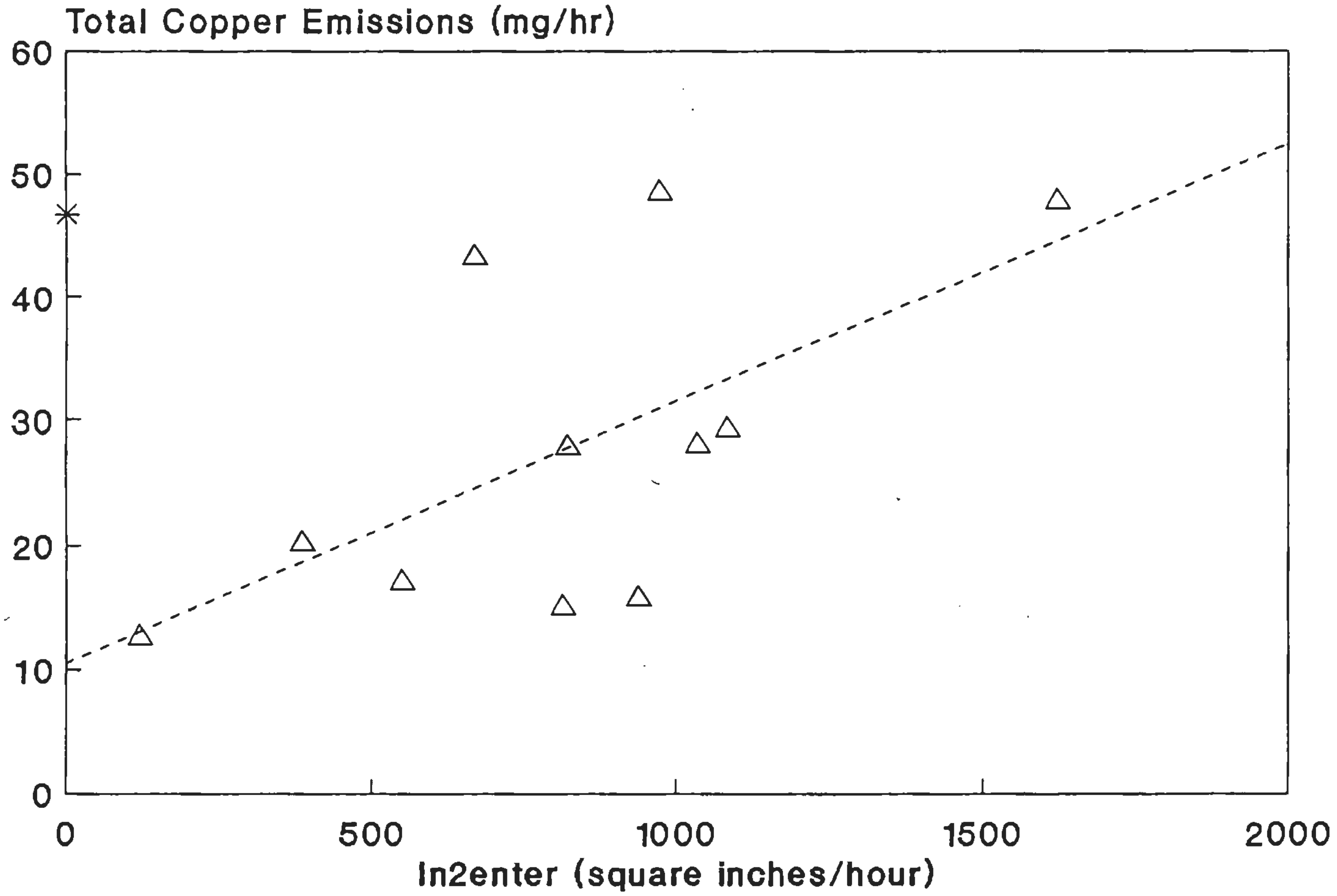

Figure 13. Mass balance total copper emissions versus the in2enter activity variable for the copper plating line.

Emission factor = 0.0210 mg/in^2, n = 11

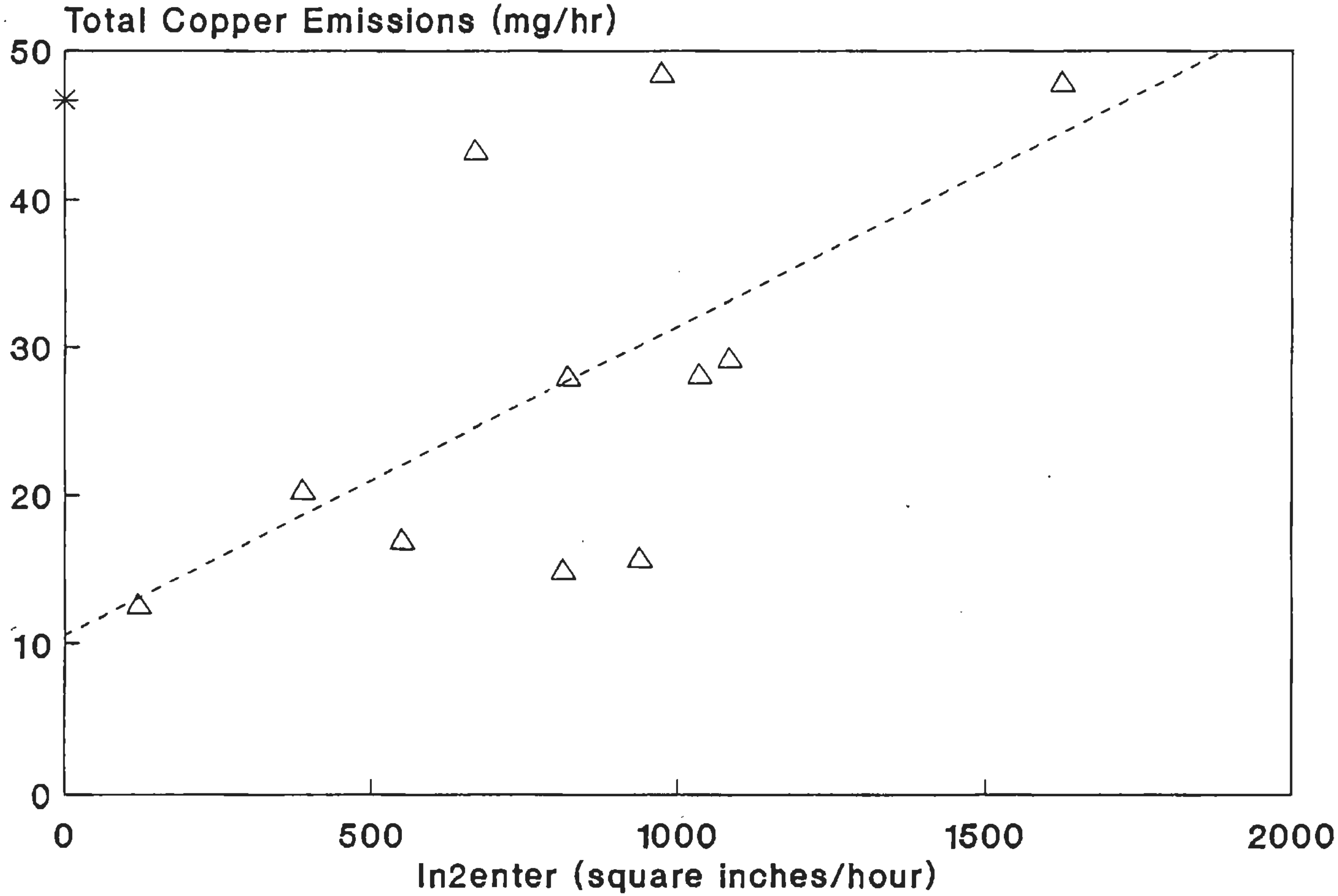

Figure 14. Completely mixed space model total copper emissions versus the in2enter activity variable for the copper plating line.

Emission factor = 0.0209 mg/in^2, n = 11

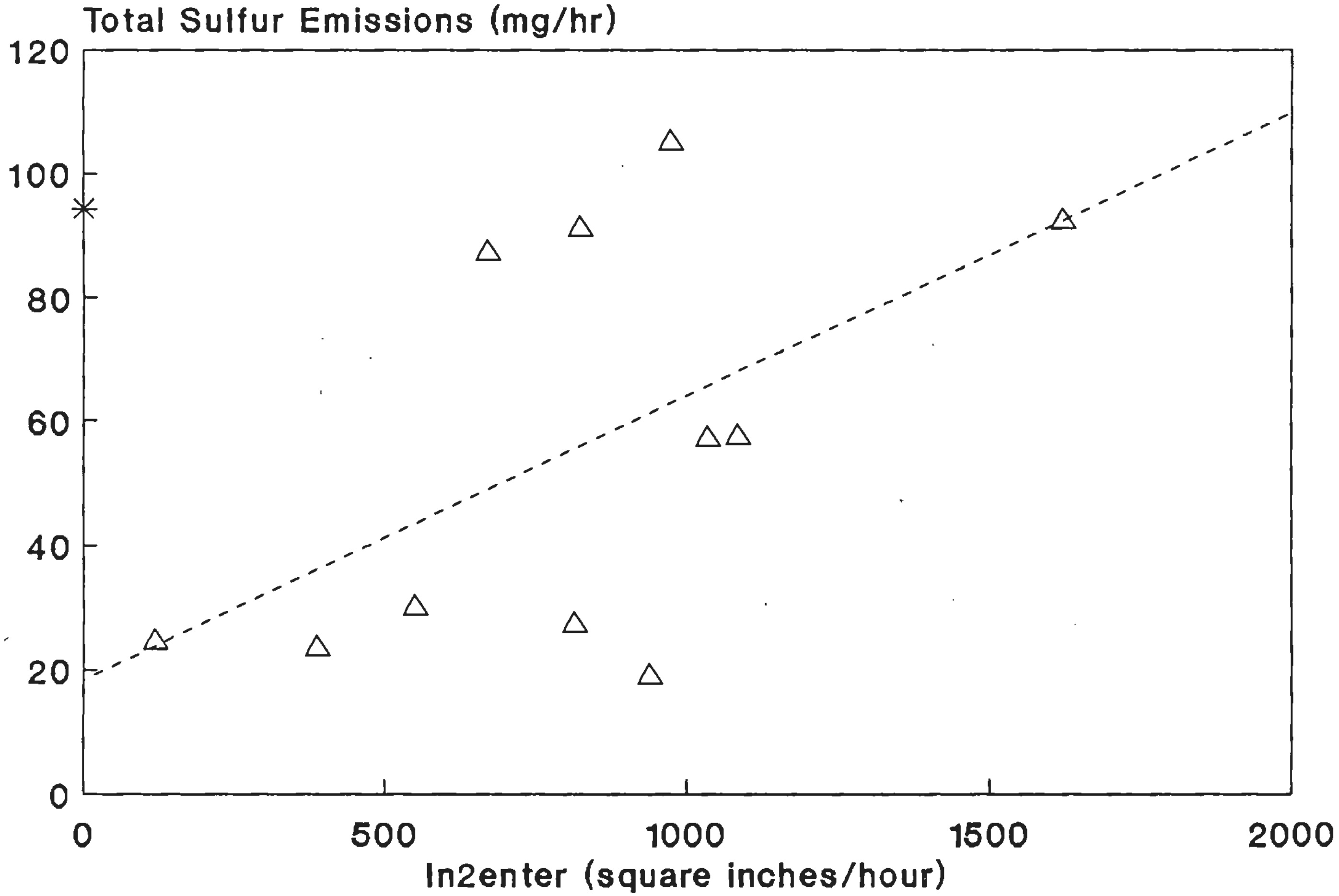

Figure 15. Mass balance total sulfur emissions versus the in2enter activity variable for the copper plating line.

Emission factor = 0.0458 mg/in^2, n = 11

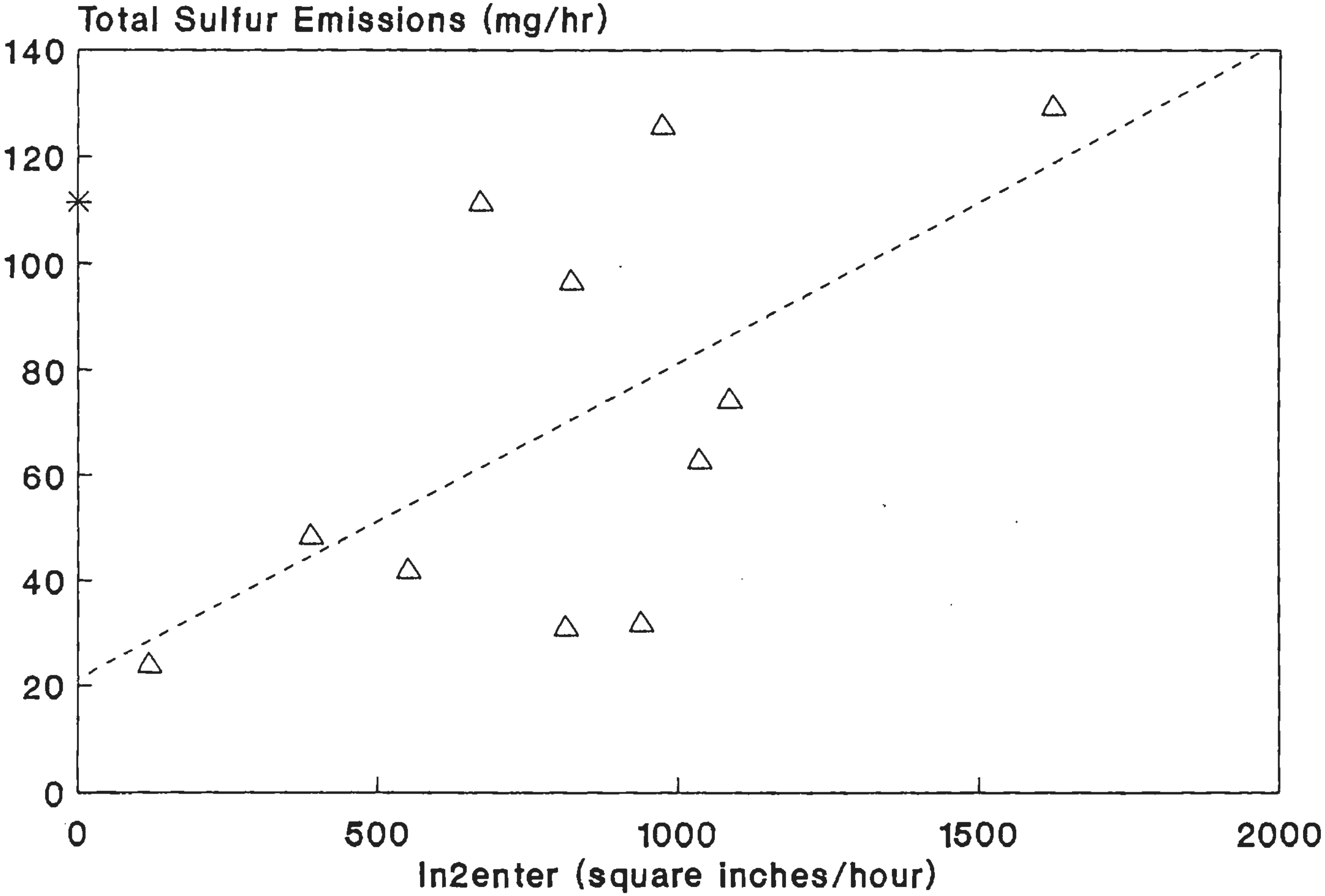

Figure 16. Completely mixed space model total sulfur emissions versus the in2enter activity variable for the copper plating line.

Emission factor = 0.0603 mg/in^2, n = 11

TABLE XVI

EMISSION FACTORS BASED ON TOTAL EMISSIONS ALONG THE COPPER PLATING LINE

Model	Constant (mg/hr)	In2enter (mg/in^2)	r^{2a}	n
COPPER				
Smb	10.5	0.0210	0.385	11
Scms	10.5	0.0209	0.384	11
SULFUR				
Smb	18.2	0.0458	0.302	11
Scms	21.1	0.0603	0.368	11

[a] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the observed emission rates.

TABLE XVII

EMISSION FACTORS BASED ON COPPER EMISSIONS INTO THE ROOM ALONG THE COPPER PLATING LINE

Model	Constant (mg/hr)	In2enter (mg/in^2)	In2plate (mg/in^2)	r^{2a}	n
Stp	0.111	$4.3*10^{-5}$		0.072	8
Stp	0.105		$3.8*10^{-5}$	0.113	8
Smb	0.544	$1.73*10^{-4}$		0.080	12
Smb	0.484		$1.86*10^{-4}$	0.166	12
Scms	0.495	$1.47*10^{-4}$		0.103	12
Scms	0.452		$1.50*10^{-4}$	0.193	12

[a] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the observed emission rates.

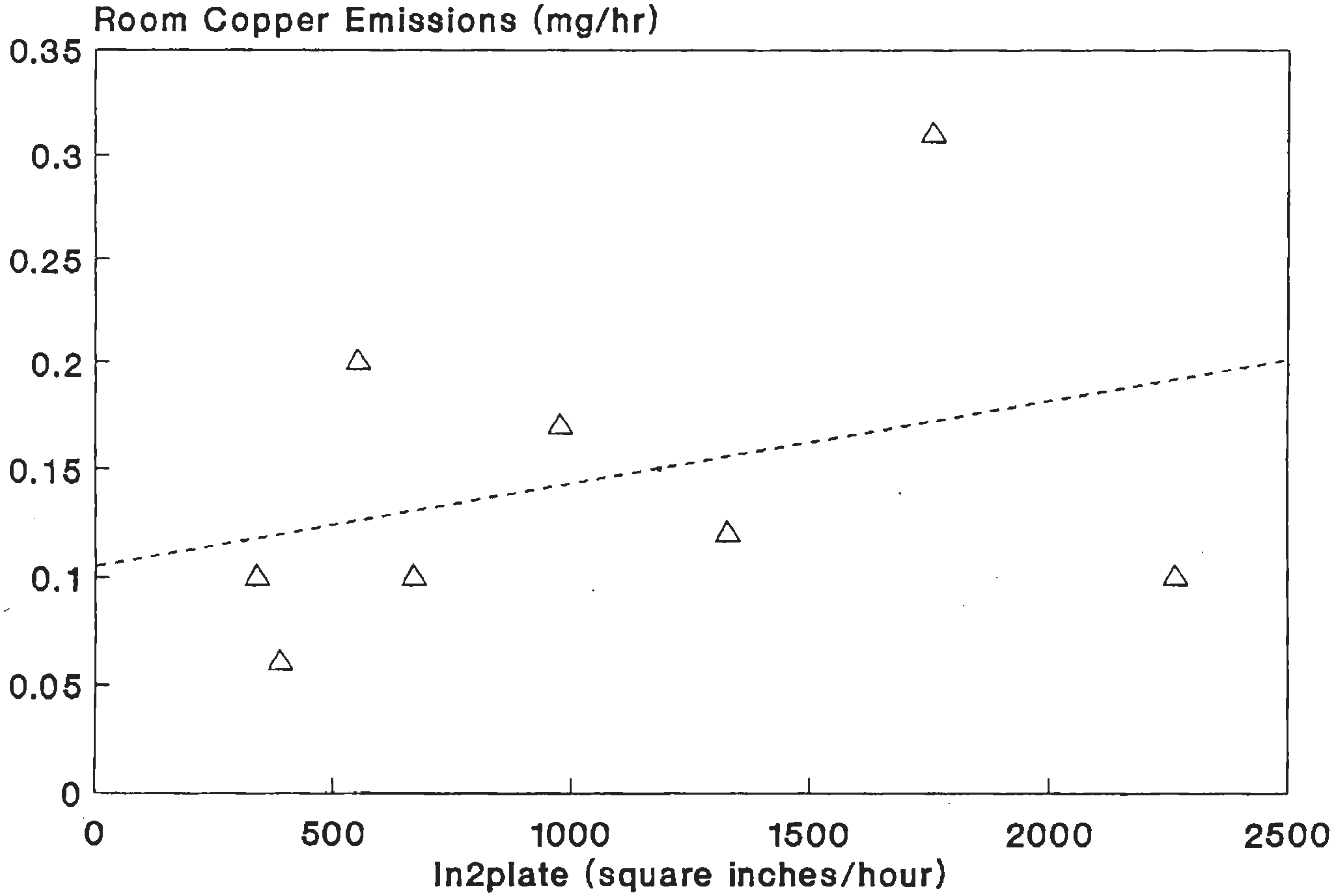

Figure 17. Two-point diffusion model copper emissions into the room versus the in2plate activity variable for the copper plating line.

Emission factor = $3.8*10^{-5}$ mg/in^2, n = 8

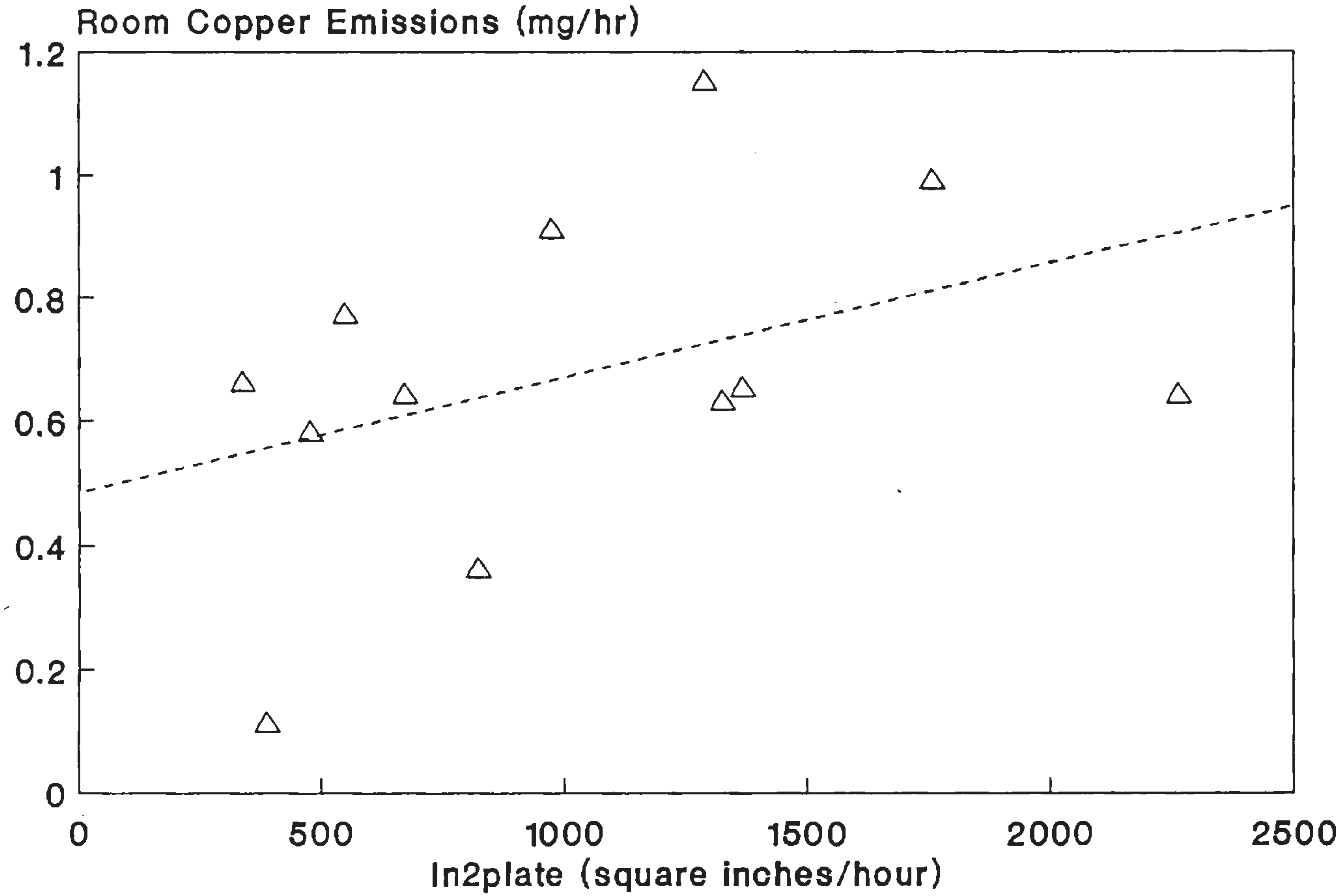

Figure 18. Mass balance copper emissions into the room versus the in2plate activity variable for the copper plating line.

Emission factor = 1.86×10^{-4} mg/in^2, n = 12

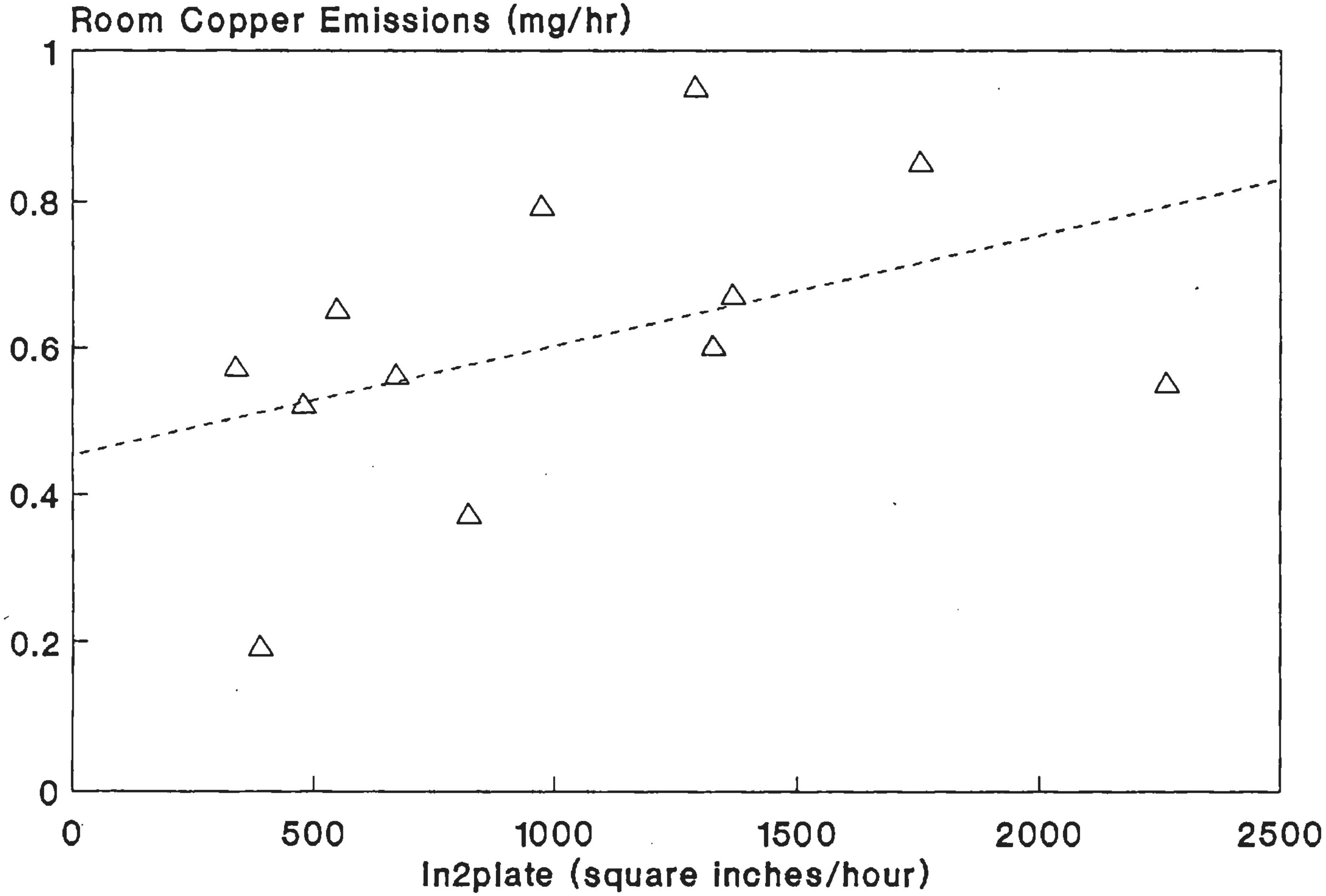

Figure 19. Completely mixed space model copper emissions into the room versus the in2plate activity variable for the copper plating line.

Emission factor = $1.50*10^{-4}$ mg/in^2, n = 12

emissions, as shown in Figures 20-26. The results of these regressions are shown in Table XVIII. These equations also included a constant and sampling hour 10 was again excluded for the total emissions. It appears that in terms of the effective energy, the ampmin variable explains total emissions and duct emissions much better that it explains room emissions.

TABLE XVIII

EMISSION FACTORS FOR THE EFFECTIVE ENERGY VARIABLE ALONG THE COPPER PLATING LINE

Model	Constant (mg/hr)	Ampmin (mg/amp*min)	r^{2a}	n
TOTAL				
Copper				
Smb	11.01	$4.15*10^{-3}$	0.375	11
Scms	11.00	$4.14*10^{-3}$	0.374	11
Sulfur				
Smb	19.36	$9.06*10^{-3}$	0.294	11
Scms	22.04	$1.20*10^{-2}$	0.366	11
ROOM				
Stp	0.120	$0.6*10^{-5}$	0.041	8
Smb	0.564	$2.9*10^{-5}$	0.058	12
Scms	0.513	$2.5*10^{-5}$	0.074	12

[a] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the observed emission rates.

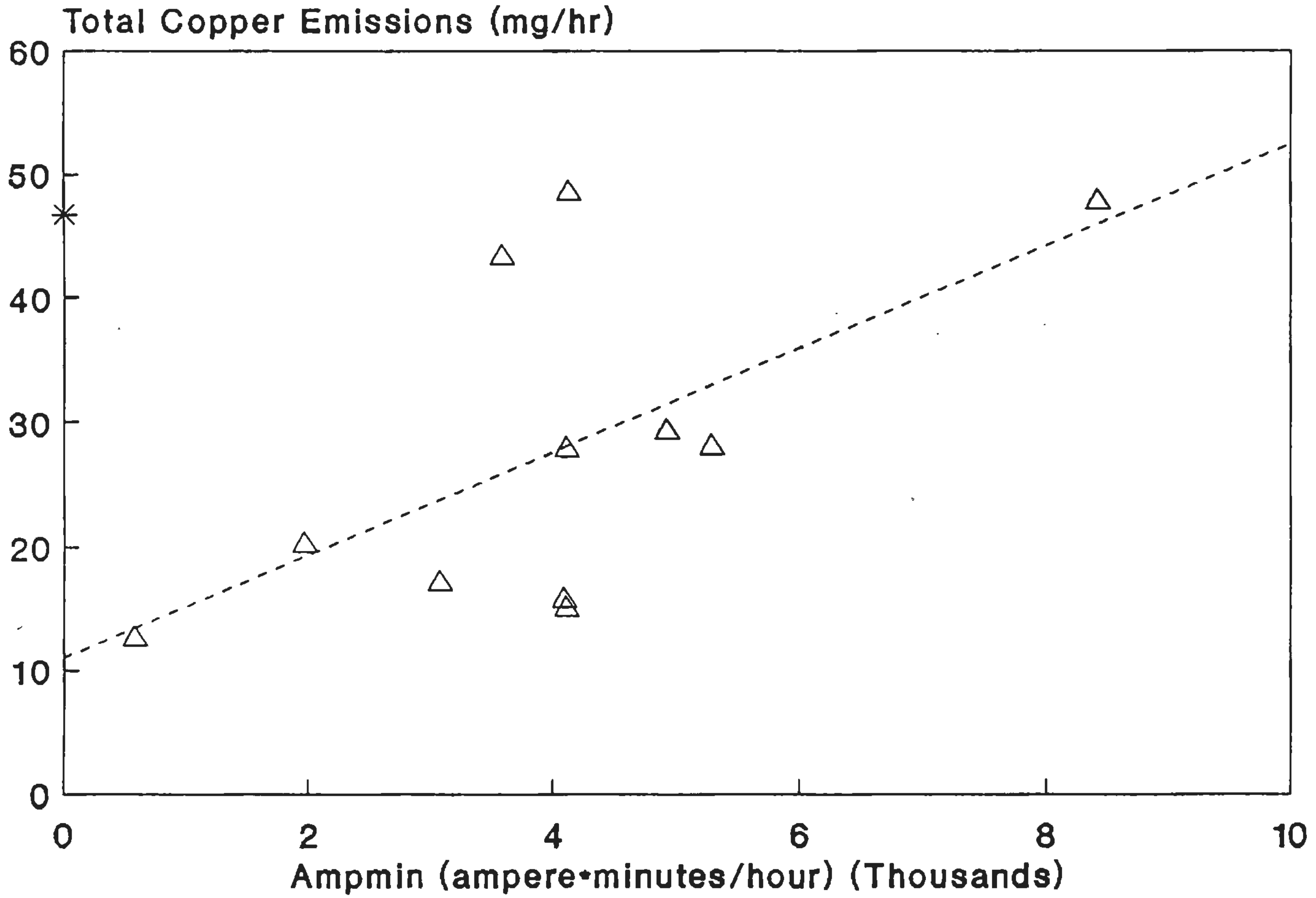

Figure 20. Mass balance total copper emissions versus the ampmin activity variable for the copper plating line.

Emission factor = 0.00415 mg/amp*min, n = 11

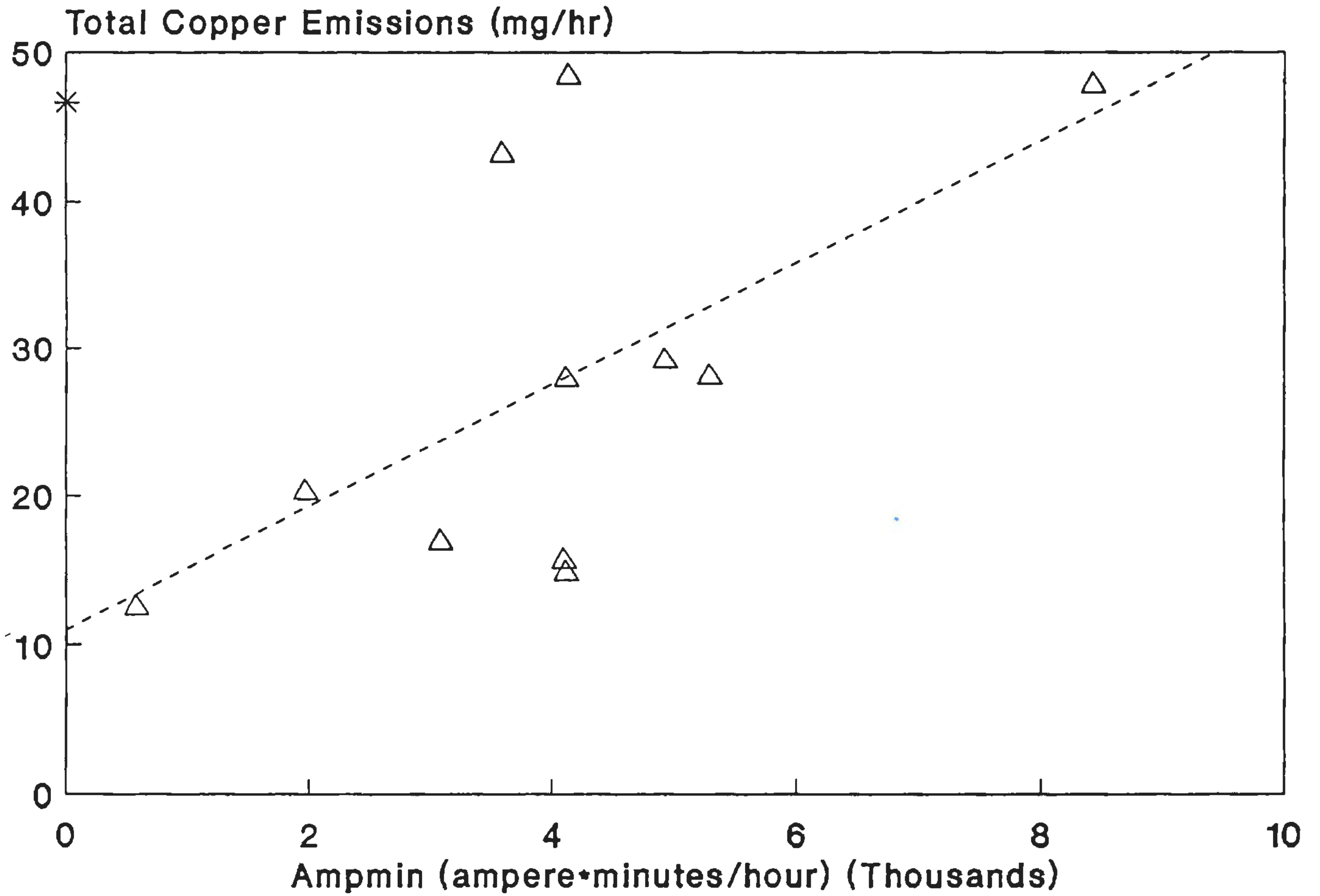

Figure 21. Completely mixed space model total copper emissions versus the ampmin activity variable for the copper plating line.

Emission factor = 0.00414 mg/amp*min, n = 11

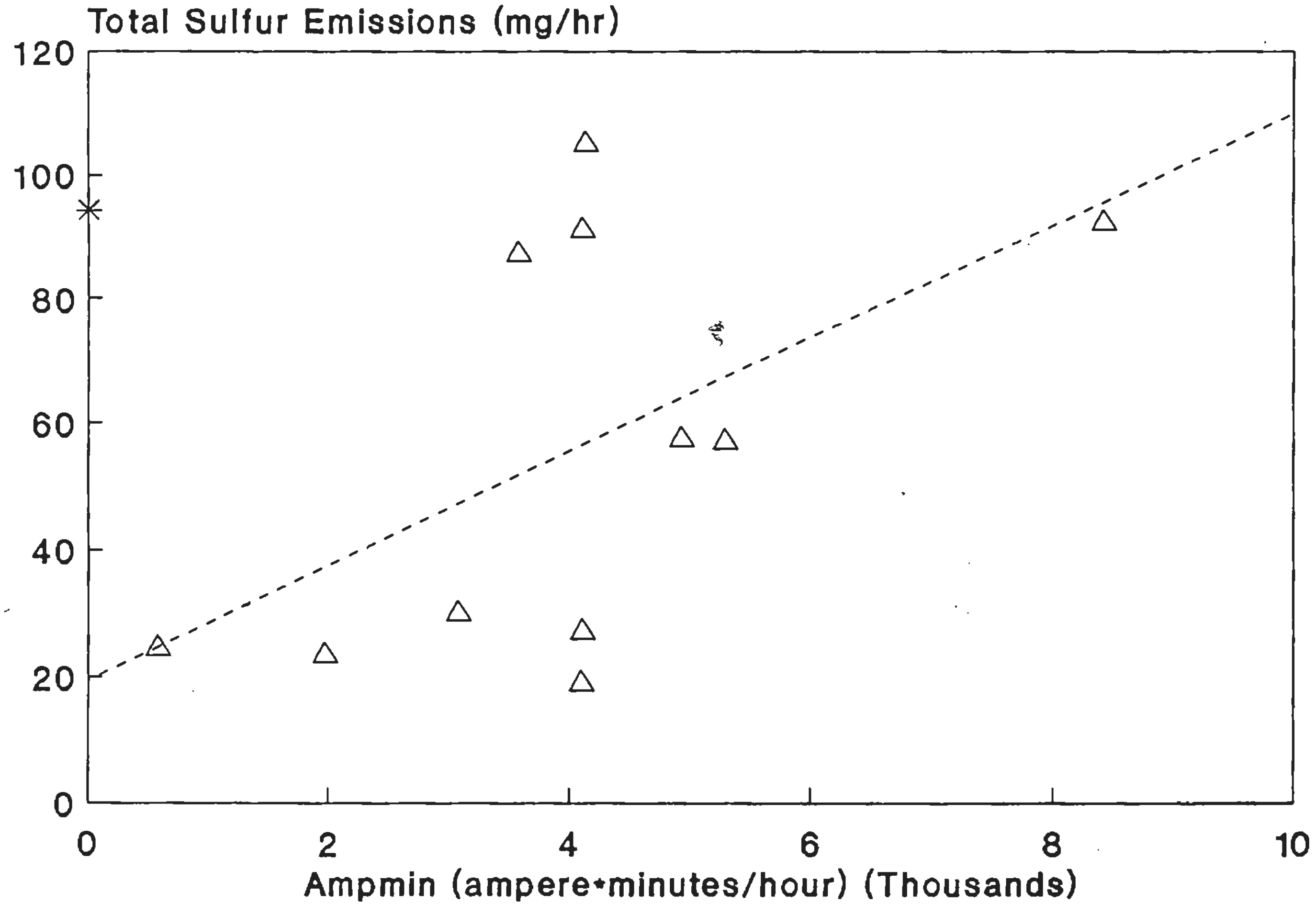

Figure 22. Mass balance total sulfur emissions versus the ampmin activity variable for the copper plating line.

Emission factor = 0.00906 mg/amp*min, n = 11

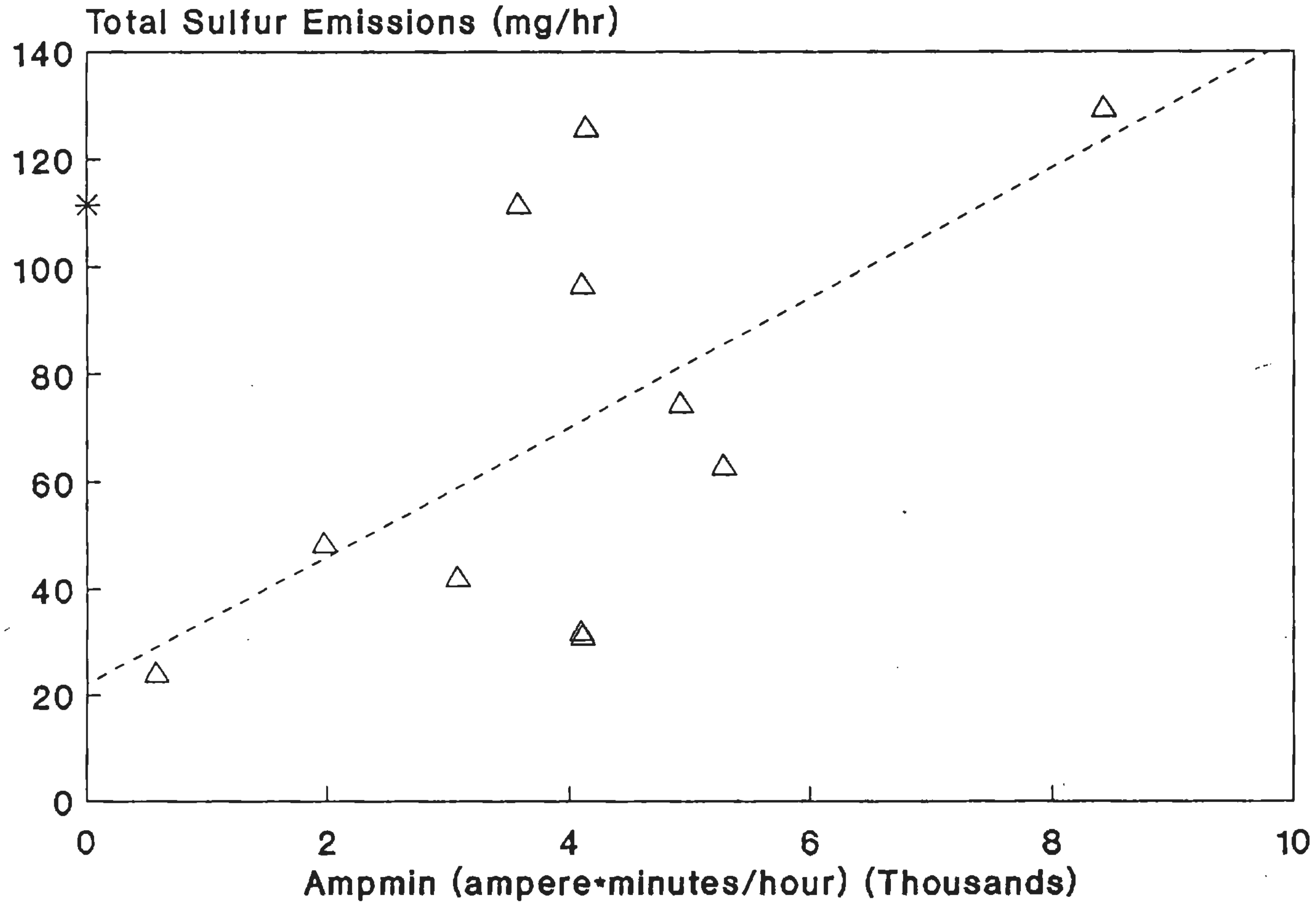

Figure 23. Completely mixed space model total sulfur emissions versus the ampmin activity variable for the copper plating line.

Emission factor = 0.0120 mg/amp*min, n = 11

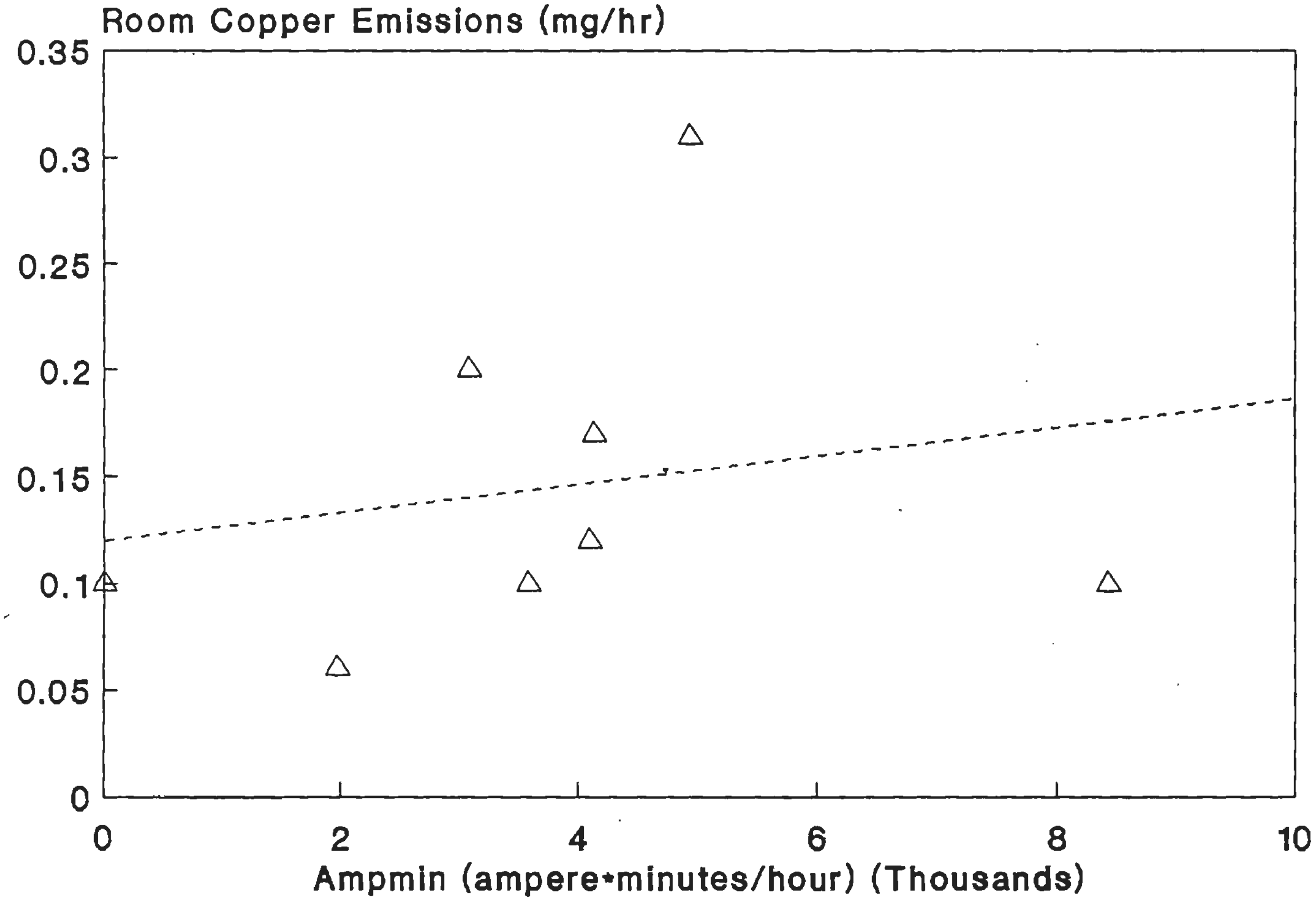

Figure 24. Two-point diffusion model copper emissions into the room versus the ampmin activity variable for the copper plating line.

Emission factor = $0.6*10^{-5}$ mg/amp*min, n = 8

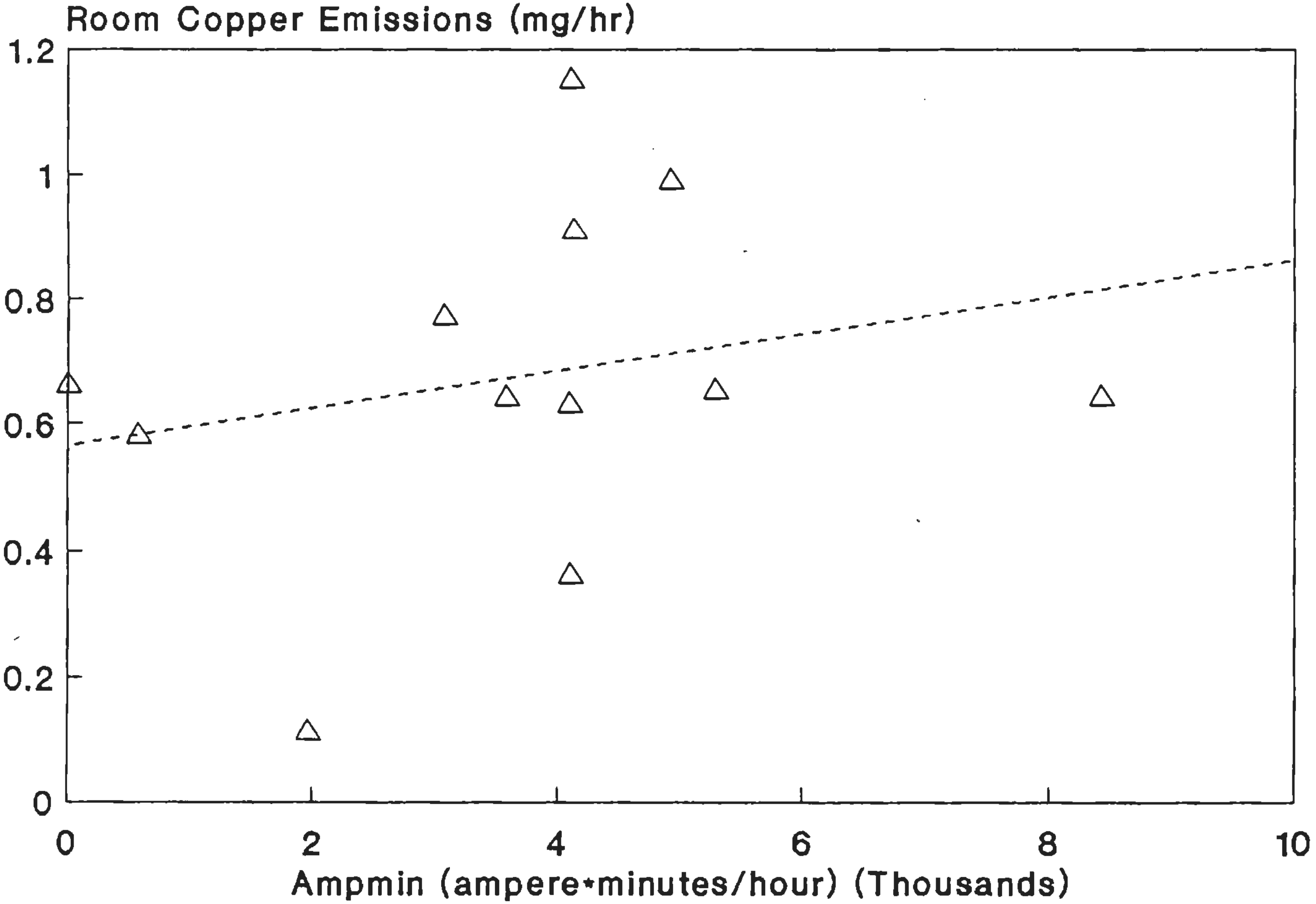

Figure 25. Mass balance copper emissions into the room versus the ampmin activity variable for the copper plating line.

Emission factor = $2.9*10^{-5}$ mg/amp*min, n = 12

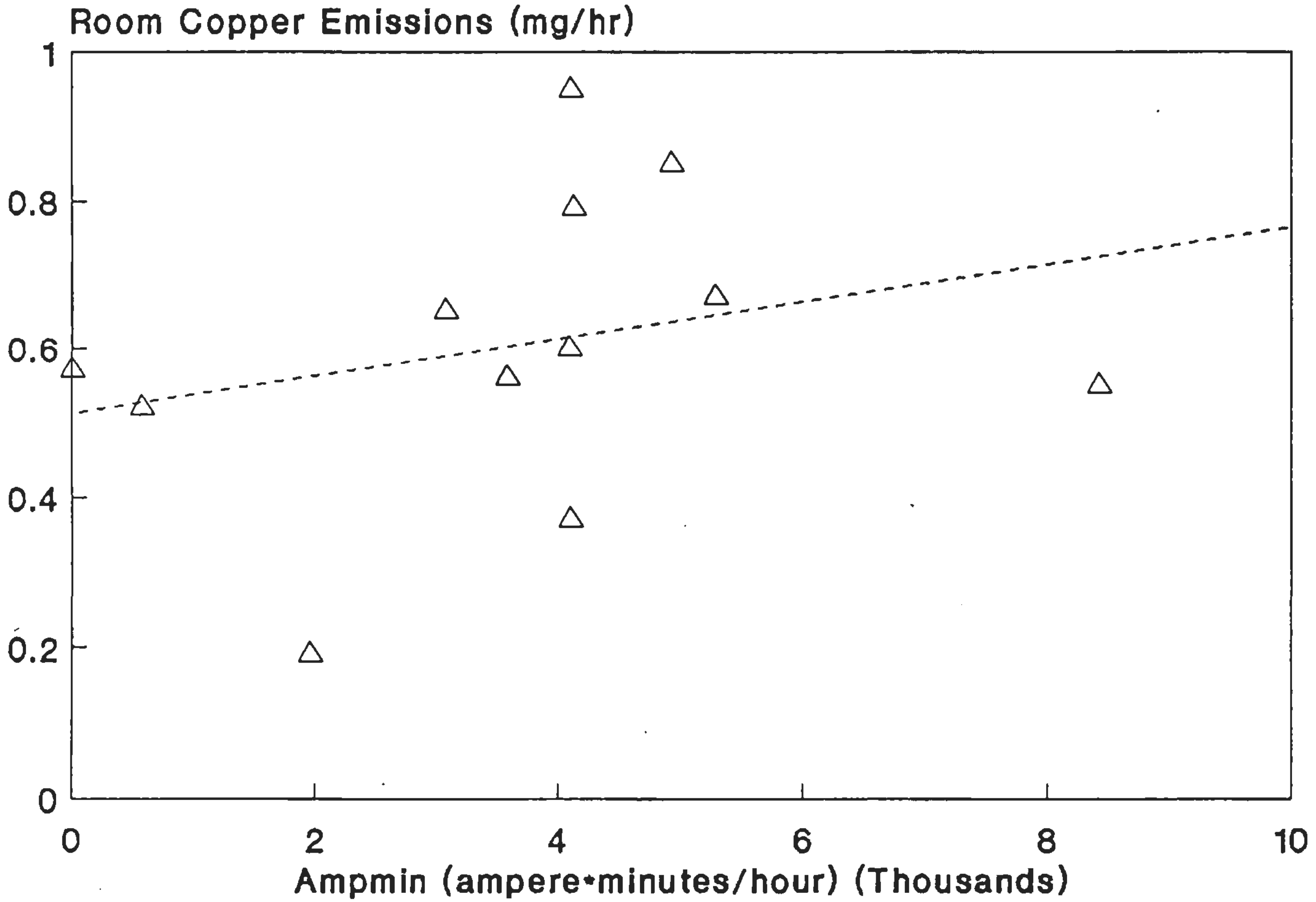

Figure 26. Completely mixed space model copper emissions into the room versus the ampmin activity variable for the copper plating line.

Emission factor = $2.5*10^{-5}$ mg/amp*min, n = 12

B. Degreasing

1. 1,1,1-Trichloroethane Concentrations

One-hour average 1,1,1-trichloroethane concentrations (TCA), in mg/m^3, from the ten sampling locations (Figure 6) are shown in Table XIX. Hours 1 through 6 were collected on December 4 and hours 7 through 12 were collected on December 5, 1990. A decreasing concentration gradient with distance away from the lines was observed for all but one hour between the sampling locations pairs A/B and C/D , the E and F pair, and the G and H pair. All of the measured concentrations were below the OSHA permissible exposure limit for TCA of 1900 mg/m^3.

The hourly average results of the Mirans are shown in Table XX. Table XXI shows the charcoal tube adjusted Miran concentrations, in mg/m^3. Additionally, although the Miran was calibrated for TCA, it does not react only to TCA. There can be interference, so the fact that the measurements are not numerically the same as the concentrations measured at sampling locations A, B, and E is to be expected.

2. Emission Rates

For the degreasing process area, hourly emission rates were estimated using experimental mass balance and the completely mixed space model. The results from these calculations are presented below.

a. Experimental Mass Balance

As described in the previous chapter, emission rate estimates were calculated based on three assumed leakage

TABLE XIX

HOURLY 1,1,1-TRICHLOROETHANE CONCENTRATIONS FROM THE DEGREASING PROCESS AREA BY SAMPLING LOCATION (mg/m^3)

Hour	A[a]	B[a]	C[a]	D[a]	E[a]	F[a]	G[a]	H[a]	I[a]	J[a]
1	72.7	53.2	46.6	36.9	104	65.5	50.8	26.6	13.7	-
2	73.7	76.1	53.4	33.1	277	80.6	79.5	31.4	13.1	28.9
3	92.4	86.1	70.0	55.0	431	74.3	100	40.1	23.9	55.8
4	73.1	96.5	66.4	51.8	297	74.7	90.0	36.5	27.8	44.7
5	53.9	52.2	44.4	26.9	121	58.2	82.5	23.0	8.3	49.4
6	97.5	92.5	83.3	65.5	148	75.4	138	35.7	24.0	53.6
7	81.9	62.9	66.9	82.2	192	57.4	58.8	26.1	29.3	51.4
8	56.7	43.2	50.7	43.1	146	46.6	59.5	23.4	16.5	38.4
9	63.1	52.6	53.1	38.3	319	58.8	62.6	24.6	33.8	45.1
10	68.0	54.8	54.4	41.5	173	51.3	45.9	21.5	41.5	38.5
11	35.0	26.3	32.8	-	313	47.6	51.3	16.9	5.3	42.1
12	62.6	61.9	47.5	32.3	363	53.7	66.9	23.9	25.1	51.8
Mean	69.2	63.2	55.8	46.1	240	62.0	74.0	27.5	21.9	45.4

[a] sampling locations are shown in Figure 6

\- pump failure

TABLE XX

HOURLY RESPONSE OF MIRANS CALIBRATED FOR 1,1,1-TRICHLOROETHANE CONCENTRATIONS IN THE DEGREASING PROCESS AREA (mg/m^3)

Date	Sampling Time[a]	Miran1[b]	Miran3[b]
12-4-90	8:00- 8:59	55.6	115
12-4-90	9:00- 9:59	102	181
12-4-90	10:00-10:59	132	171
12-4-90	11:00-11:59	112	132
12-4-90	12:00-12:59	75	109
12-4-90	13:00-13:59	109	180
12-5-90	8:00- 8:59	110	118
12-5-90	9:00- 9:59	91.1	68.3
12-5-90	10:00-10:59	88.0	72.6
12-5-90	11:00-11:59	66.8	116
12-5-90	12:00-12:59	62.4	41.1
12-5-90	13:00-13:59	93.7	99.3
	MEAN	91.6	117

[a] approximate times

[b] sampling locations are shown in Figure 6

TABLE XXI

HOURLY CHARCOAL-TUBE ADJUSTED 1,1,1-TRICHLOROETHANE CONCENTRATIONS[a] MEASURED BY THE MIRANS IN THE DEGREASING PROCESS AREA (mg/m^3)

Date	Sampling Time[b]	Miran1	Miran3
12-4-90	8:00- 8:59	41.6	64.2
12-4-90	9:00- 9:59	59.2	89.1
12-4-90	10:00-10:59	70.8	88.1
12-4-90	11:00-11:59	62.9	70.6
12-4-90	12:00-12:59	49.0	61.8
12-4-90	13:00-13:59	61.8	88.9
12-5-90	8:00- 8:59	62.5	65.3
12-5-90	9:00- 9:59	55.0	46.4
12-5-90	10:00-10:59	53.8	48.0
12-5-90	11:00-11:59	45.8	64.5
12-5-90	12:00-12:59	44.1	36.1
12-5-90	13:00-13:59	56.0	58.1
	MEAN	55.2	65.1

[a] Charcoal tube equivalent concentration (ppm) = (0.379)(Miran concentration, ppm) + 3.757

[b] approximate times

concentrations since this concentration was not measured during the survey. The results of these calculations are shown in Table XXII. As can be seen in this table, the average one-hour emission rate when the leakage concentration was assumed equal to the diffuser concentration (S_{mb1}) was equal to 703 g/hr; the average one-hour emission rate when the leakage concentration was assumed equal to zero (S_{mb2}) was equal to 977 g/hr; and the average one-hour emission rate when the leakage concentration was assumed equal to the lowest measured concentration in the room (S_{mb3}) was equal to 740 g/hr. Because no diffuser concentration was obtained during the first hour of sampling, no estimate of the emission rate was possible with this model and therefore the averages were based on just 11 estimates.

b. Completely Mixed Space Model

After the mixing factor had been determined, the hourly emission rates were estimated. In the completely mixed space model, the room concentration (C_{av}) was the average from sampling locations A-H, the supply air concentration (C_o) was from sampling location I, and the instantaneous concentration at the start of each sampling hour (C_s) was evaluated from the average concentrations from the two Mirans at that point in time adjusted to the charcoal tube equivalent using Equation (12). These hourly emission rates are shown in Table XXII and the average of the twelve estimates was 393 g/hr.

TABLE XXII

HOURLY EMISSION RATES FROM THE DEGREASING PROCESS AREA FOR THE COMPLETELY MIXED SPACE MODEL AND THREE ESTIMATES OF EXPERIMENTAL MASS BALANCE (g/hr)

Date	Sampling Time[a]	Scms	Smb1	Smb2	Smb3
12-4-90	8:00- 8:59	251	-	-	-
12-4-90	9:00- 9:59	462	789	948	789
12-4-90	10:00-10:59	679	1090	1380	1090
12-4-90	11:00-11:59	514	759	1100	759
12-4-90	12:00-12:59	276	764	865	763
12-4-90	13:00-13:59	438	838	1129	838
12-5-90	8:00- 8:59	328	611	967	650
12-5-90	9:00- 9:59	261	547	747	547
12-5-90	10:00-10:59	412	534	944	645
12-5-90	11:00-11:59	157	173	676	415
12-5-90	12:00-12:59	452	844	908	844
12-5-90	13:00-13:59	481	777	1080	792
	MEAN	393	703	977	740

[a]approximate times

- missing data prohibited calculation of emission rate

c. Correlation

As seen in Table XXII, the absolute value of the hourly emission rates differed between the models. To determine if the estimates were similar a Pearson correlation matrix was performed. This matrix can be found in Table XXIII. The correlation matrix lists the correlation coefficients, r, which measure the strength of the linear relationship between the sample observations of two variables. For the hourly emission rates, the strength of the linear relationship is strong since the smallest r = 0.826. If we were to draw time plots, the hourly pattern of estimates was similar, even though the actual emission rates differed between the models.

TABLE XXIII

PEARSON CORRELATION MATRIX OF THE HOURLY EMISSION RATES FROM THE DEGREASING PROCESS AREA FOR THE COMPLETELY MIXED SPACE MODEL AND THREE ESTIMATES OF EXPERIMENTAL MASS BALANCE

r	Scms	Smb1	Smb2	Smb3
Scms	1.000			
Smb1	0.853	1.000		
Smb2	0.921	0.826	1.000	
Smb3	0.894	0.972	0.880	1.000

d. Solvent Inventory

The emission rate was also determined from the solvent inventory. During the survey no solvent was added to any of the degreasing tanks. On December 6, 1990, the day after the sampling was completed, a total of 6 gallons of TCA was added to the three tanks. Assuming prior addition was just before the sampling began and that the tanks were in operation for 16 hours/day, an emission rate was estimated knowing that the density of the solvent was approximately 11 pounds/gallon. The resulting emission rate based on the solvent inventory was 624 g/hr.

e. Ten-Minute Emission Rates

As described in the previous chapter, ten-minute emission rates were calculated from the completely mixed space model using both the average Miran and the Miran1 concentrations to estimate room emissions. These ten-minute emission rates are shown in Table XXIV. The average ten-minute emission rate based on the average Miran concentration was 1590 g/hr and the average ten-minute emission rate based on the Miran1 concentration was 1480 g/hr. However, the correlation between these two emission rate estimates was not as good as for the hourly estimates (r = 0.640) possibly because of fluctuations in the measured TCA concentrations have a greater effect on the ten-minute emission rates than when averaged over an hour.

A summary of the average emission rates from each of the models can be found in Table XXV.

TABLE XXIV

TEN-MINUTE EMISSION RATES FROM THE DEGREASING PROCESS AREA FOR THE MIRAN AVERAGE AND MIRAN1 USING THE COMPLETELY MIXED SPACE MODEL (g/hr)

Date	Sampling Time[a]	Sav	S1
12-4-90	8:00- 8:09	1200	749
12-4-90	8:10- 8:19	1420	739
12-4-90	8:20- 8:29	2240	1280
12-4-90	8:30- 8:39	1430	818
12-4-90	8:40- 8:49	1690	1040
12-4-90	8:50- 8:59	1320	1070
12-4-90	9:00- 9:09	1410	1650
12-4-90	9:10- 9:19	1840	1980
12-4-90	9:20- 9:29	2370	1810
12-4-90	9:30- 9:39	3230	2520
12-4-90	9:40- 9:49	2740	1700
12-4-90	9:50- 9:59	2140	1730
12-4-90	10:00-10:09	2630	1660
12-4-90	10:10-10:19	1530	2130
12-4-90	10:20-10:29	1840	2660
12-4-90	10:30-10:39	1620	2680
12-4-90	10:40-10:49	2290	2000
12-4-90	10:50-10:59	2570	2710
12-4-90	11:00-11:09	1230	1930
12-4-90	11:10-11:19	2350	1970
12-4-90	11:20-11:29	1830	2720
12-4-90	11:30-11:39	1400	1610
12-4-90	11:40-11:49	1300	1600
12-4-90	11:50-11:59	1220	1350
12-4-90	12:00-12:09	618	1050

[a] approximate times

TABLE XXIV (CONTINUED)

Date	Sampling Time[a]	Sav	S1
12-4-90	12:10-12:19	1140	985
12-4-90	12:20-12:29	1140	872
12-4-90	12:30-12:39	2310	1620
12-4-90	12:40-12:49	-	179
12-4-90	12:50-12:59	1600	1600
12-4-90	13:00-13:09	1700	1700
12-4-90	13:10-13:19	1360	1070
12-4-90	13:20-13:29	2950	2310
12-4-90	13:30-13:39	1280	1410
12-4-90	13:40-13:49	1700	1400
12-4-90	13:50-13:59	767	498
12-5-90	8:00- 8:09	1600	1630
12-5-90	8:10- 8:19	1530	1560
12-5-90	8:20- 8:29	2170	1590
12-5-90	8:30- 8:39	1280	1290
12-5-90	8:40- 8:49	1400	1540
12-5-90	8:50- 8:59	1190	1150
12-5-90	9:00- 9:09	1280	1290
12-5-90	9:10- 9:19	1310	1390
12-5-90	9:20- 9:29	1320	1670
12-5-90	9:30- 9:39	1420	1660
12-5-90	9:40- 9:49	1420	1620
12-5-90	9:50- 9:59	1440	1660
12-5-90	10:00-10:09	1320	1490
12-5-90	10:10-10:19	1210	1190
12-5-90	10:20-10:29	2080	2080
12-5-90	10:30-10:39	1540	1390

[a] approximate times

TABLE XXIV (CONTINUED)

Date	Sampling Time[a]	Sav	S1
12-5-90	10:40-10:49	1110	1230
12-5-90	10:50-10:59	1240	1300
12-5-90	11:00-11:09	2360	1250
12-5-90	11:10-11:19	1820	1480
12-5-90	11:20-11:29	1360	1140
12-5-90	11:30-11:39	1150	790
12-5-90	11:40-11:49	963	604
12-5-90	11:50-11:59	1060	953
12-5-90	12:00-12:09	1090	909
12-5-90	12:10-12:19	1140	995
12-5-90	12:20-12:29	1110	1050
12-5-90	12:30-12:39	1930	2590
12-5-90	12:40-12:49	1020	1220
12-5-90	12:50-12:59	1370	1550
12-5-90	13:00-13:09	1480	1950
12-5-90	13:10-13:19	1290	1390
12-5-90	13:20-13:29	1900	1750
12-5-90	13:30-13:39	1380	1190
12-5-90	13:40-13:49	1350	1070
12-5-90	13:50-13:59	1010	854
	MEAN	1590	1480

[a] approximate times

TABLE XXV

EMISSION RATE SUMMARY FOR THE DEGREASING PROCESS AREA (g/hr)

Model	Average Emission Rate	n
Smb1	703	11
Smb2	977	11
Smb3	740	11
Scms	393	12
Sinv	624	
Sav	1590	71
S1	1480	72

3. Emission Factors

a. By Line

Emission factors were initially determined with the activity variables separated by degreasing line for both the hourly and ten-minute emission rate estimates as discussed in the previous chapter. This was done to identify, if possible, which line needed to be controlled more, if any. The resulting equations included the activity variables basket1, tank2, and part3. Only when the completely mixed space model emission rates were used did the above variables become inappropriate because not all of the selected variables had positive coefficients. The emission factor equation for the completely mixed space model included the activity variables basket1, travel2, and part3. These regression equations did not contain a constant because the object was to determine the fractional contribution of each line to the total emissions. Table XXVI displays the emission factors by line and Table XXVII then shows the fractional contribution of each line to the total emissions by emission rate model. Line 2, according to these models, contributed the majority of the emissions into the room.

TABLE XXVI

EMISSION FACTORS BY LINE FOR THE DEGREASING PROCESS AREA

Model	Basket1 (g)	Tank2 (g)	Part3 (g/part)	n
Smb1	225	669	0.57	11
Smb2	134	1070	1.28	11
Smb3	186	731	1.06	11
Sav	920	828	21.5	35
S1	777	1110	7.78	36

Scms = 322.74basket1 + 219.81travel2 + 1.05part3

TABLE XXVII

FRACTIONAL CONTRIBUTION OF EACH LINE IN THE DEGREASING PROCESS AREA BASED ON THE EMISSION FACTOR EQUATIONS

Model	Line 1	Line 2	Line 3
Smb1	0.195	0.759	0.046
Smb2	0.075	0.855	0.070
Smb3	0.117	0.809	0.074
Scms	0.466	0.350	0.183
Sav	0.332	0.455	0.213
S1	0.297	0.561	0.145
MEAN	0.247	0.631	0.122

b. By Variable

Emission factors were also calculated with the activity variables from the three lines combined to determine the effect of total activity on the estimated emissions. The activity variables for this analysis were selected independently of the variables selected for the emission factor determination by line because the objective for this part of the analysis was different than for calculating emission factors by line. Table VI lists the activity variables used for this part of the analysis.

The resulting equations for the hourly emission rate estimates included the activity variables part, manual, and squarein. However, the emission factor equations based on the ten-minute emission rate estimates included the activity variables part, auto, and manual. Table XXVIII shows the hourly emission factors while

TABLE XXVIII

HOURLY EMISSION FACTORS BY VARIABLE FOR THE DEGREASING PROCESS AREA

Model	Constant (g/hr)	Part (g/part)	Manual (g)	Squarein (g/in^2)	r^{2a}	n
Smb1	270	0.20	9010	0.22	0.469	11
Smb2	565	0.20	5830	0.40	0.742	11
Smb3	400	0.18	6140	0.22	0.601	11
Scms	55	0.15	7020	0.23	0.762	12

[a] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the observed emission rates.

Table XXIX shows the ten-minute emission factors. These regression equations did include a constant and their coefficient of determination (r^2) is included in the table. For the hourly emission factor equations, the explained portion of the emission rate ranged from 0.469 to 0.762, whereas the explained portion of the emission rate from the ten-minute emission factor equations ranged from 0.180 to 0.272.

C. Wave Soldering

1. Lead Concentrations

One-hour average lead concentrations from the eleven sampling locations (Figure 11) are shown in Table XXX. Hours 1 through 6 were collected on December 6, 1990 and hours 7 through 12 were collected on December 7, 1990. All measured concentrations

TABLE XXIX

TEN-MINUTE EMISSION FACTORS BY VARIABLE FOR THE DEGREASING PROCESS AREA

Model	Constant (g/hr)	Part (g/part)	Auto (g)	Manual (g)	r^{2a}	n
Sav	1160	0.04	992	2830	0.180	35
S1	989	0.43	1070	3160	0.272	36

[a] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the observed emission rates.

were below the OSHA permissible exposure limit for lead of 50 $\mu g/m^3$. The hourly concentrations of other elements detected during the sampling including magnesium, aluminum, silicon, sulfur, chlorine, potassium, calcium, titanium, vanadium, chromium, manganese, iron, nickel, copper, zinc, gallium, selenium, bromine, rubidium, strontium, yttrium, zirconium, molybdenum, and tin can be found in Appendix C, Table XLIII.

2. Emission Rates

For the wave soldering area hourly emission rates were estimated using the box model. In addition, receptor modeling was used to determine the contribution of each source to the measured concentrations at the receptor points.

a. Box Model

One-hour lead emission rates were estimated using Equation (7) and are shown in Table XXXI. Only ten of the twelve hours produced positive emission rates and the average hourly lead emission rate was 50 mg/hr. The reason for this was that a

TABLE XXX

HOURLY LEAD CONCENTRATIONS FROM THE WAVE SOLDERING AREA BY SAMPLING LOCATION ($\mu g/m^3$)

Hour	A[a]	B[a]	C[a]	D[a]	E[a]	F[a]	G[a]	H[a]	I[a]	J[a]
1	2.08	0.704	13.0	1.62	0.183	17.9	1.76	0.205	70.4	0.491
2	0.187	0.385	8.14	0.748	0.328	12.0	0.955	0.485	40.9	0.143
3	0.594	1.18	7.43	3.96	30.1	17.1	4.53	4.02	18.5	1.10
4	0.341	0.412	2.62	0.813	1.19	0.249	18.5	12.7	32.1	0.754
5	1.07	0.763	11.8	1.12	0.875	39.2	1.61	0.539	120	0.559
6	0.118	0.054	14.5	0.158	0.098	16.4	0.511	0.127	28.4	0.546
7	0.309	1.23	4.60	4.49	17.5	4.12	0.870	0.327	8.97	0.117
8	0.463	0.936	4.84	1.32	1.59	6.31	2.37	2.79	11.0	1.40
9	0.346	0.273	6.93	0.285	0.317	3.61	0.396	0.228	8.61	0.239
10	0.467	0.426	5.46	2.43	18.3	2.14	0.550	0.488	15.9	0.484
11	1.95	0.799	3.46	1.23	7.38	9.00	17.6	70.5	43.7	16.0
12	0.535	0.427	15.6	0.698	0.485	14.1	0.625	0.520	6.53	0.686

[a] sampling locations are shown in Figure 11

K (12-6-90) = 0.468 $\mu g/m^3$, K (12-7-90) = 0.320 $\mu g/m^3$

TABLE XXXI

HOURLY EMISSION RATES FROM THE WAVE SOLDERING AREA FOR THE BOX MODEL (mg/hr)

Date	Sampling Time[a]	Sbox
12-6-90	8:30- 9:29	14.5
12-6-90	9:30-10:29	8.94
12-6-90	10:30-11:29	153
12-6-90	11:30-12:29	119
12-6-90	12:30-13:29	10.1
12-6-90	13:30-14:29	-
12-7-90	8:00- 8:59	97.3
12-7-90	9:00- 9:59	4.24
12-7-90	10:00-10:59	1.59
12-7-90	11:00-11:59	80.2
12-7-90	12:00-12:59	14.1
12-7-90	13:00-13:59	-
	MEAN	50.1

[a] approximate times

- no meaningful result obtained

mixed air value (location J) was used as the upwind value in Equation (7). This measurement location is probably not totally representative of conditions not influenced by the soldering lines. Additionally, activity decreased during the hours that produced negative emission rates and affected the area downwind concentrations, but there was probably a lag for the upwind value. However, as will be shown, setting the upwind value equal to zero gave emission rates which were much less in agreement with source activities than when the concentration from sampling point J was used. In fact, the regressions produced negative coefficients.

b. Receptor Modeling

Regression equations for each of the eight receptor points describing the contributions from the three source points are summarized in Table XXXII (Y = C + FI and Y = C + F + I) in which Y represents each of the eight receptor points, C is the contribution from line 3, F is the contribution from line 2, and I is the contribution from line 1. These regression equations were then used to determine the lead contribution from each of the three wavelines. The hourly lead contribution and the fraction of the average measured lead concentration from the near and far sampling points on all three lines (sampling locations A, B, D, E, G, H) are shown in Table XXXIII for Y = C + FI and Table XXXIV for Y = C + F + I. The individual hourly lead contributions for these two equations at each of the eight receptor points can be found in Appendix C,

TABLE XXXII

FINAL RECEPTOR MODELING EQUATIONS FOR THE WAVE SOLDERING AREA

Hour	$A = C + FI$	$A = C + F + I$
1	$A = 4.41C + 5.51FI$	$A = 3.28C + 2.63F + 4.39I$
2	$A = 1.38C + 0.74FI$	$A = 0.92C + 0.60F + 0.41I$
3	$A = 0.07C + 3.70FI$	$A = 3.70C + 1.42F + 5.12I$
4	$A = 0.34C + 3.33FI$	$A = 1.25C + 2.34F + 0.47I$
5	$A = 2.55C + 2.53FI$	$A = 1.70C + 1.76F + 1.55I$
6	$A = 0.24C + 0.52FI$	$A = 0.16C + 0.40F + 0.29I$
7	$A = 1.12C + 1.11FI$	$A = 0.75C + 0.74F + 1.38I$
8	$A = 1.97C + 1.52FI$	$A = 1.31C + 1.32F + 0.69I$
9	$A = 3.27C + 1.53FI$	$A = 6.30C + 0.54F + 0.17I$
10	$A = 4.06C + 2.51FI$	$A = 2.70C + 1.96F + 1.41I$
11	$A = 2.36C + 1.27FI$	$A = 1.57C + 0.50F + 1.78I$
12	$A = 1.26C + 4.10FI$	$A = 1.24C + 1.79F + 2.31I$

Hour	$B = C + FI$	$B = C + F + I$
1	$B = 2.48C + 1.99FI$	$B = 1.65C + 1.74F + 1.04I$
2	$B = 2.58C + 1.54FI$	$B = 1.72C + 1.22F + 0.88I$
3	$B = 5.50C + 3.79FI$	$B = 3.20C + 1.43F + 4.04I$
4	$B = 0.38C + 4.29FI$	$B = 1.17C + 3.65F + 0.40I$
5	$B = 3.27C + 1.27FI$	$B = 1.50C + 1.58F + 1.34I$
6	$B = 0.09C + 0.19FI$	$B = 0.06C + 0.15F + 0.10I$
7	$B = 2.22C + 1.80FI$	$B = 1.48C + 1.20F + 1.21I$
8	$B = 3.82C + 2.88FI$	$B = 2.54C + 2.19F + 1.43I$
9	$B = 3.04C + 1.02FI$	$B = 2.03C + 0.92F + 0.52I$
10	$B = 3.32C + 1.95FI$	$B = 2.21C + 1.44F + 1.10I$
11	$B = 1.12C + 0.72FI$	$B = 0.75C + 0.29F + 0.67I$
12	$B = 1.47C + 2.86FI$	$B = 0.96C + 1.40F + 1.48I$

TABLE XXXII (CONTINUED)

Hour	$D = C + FI$	$D = C + F + I$
1	$D = 3.83C + 3.45FI$	$D = 2.55C + 2.95F + 1.84I$
2	$D = 4.27C + 3.06FI$	$D = 2.85C + 2.44F + 1.67I$
3	$D = 31.0C + 4.38FI$	$D = 24.0C + 8.85F + 2.36I$
4	$D = 0.43C + 5.43FI$	$D = 1.68C + 2.70F + 1.48I$
5	$D = 3.83C + 3.55FI$	$D = 3.63C + 3.89F + 0.04I$
6	$D = 0.36C + 0.70FI$	$D = 0.24C + 0.57F + 0.39I$
7	$D = 3.56C + 3.82FI$	$D = 2.37C + 2.63F + 2.42I$
8	$D = 5.69C + 4.59FI$	$D = 3.79C + 2.81F + 2.36I$
9	$D = 2.00C + 0.70FI$	$D = 1.33C + 0.55F + 0.39I$
10	$D = 4.27C + 15.0FI$	$D = 5.60C + 6.69F + 5.73I$
11	$D = 7.88C + 0.03FI$	$D = 3.84C + 1.00F + 3.39I$
12	$D = 0.66C + 4.40FI$	$D = 0.67C + 1.69F + 2.69I$

Hour	$E = C + FI$	$E = C + F + I$
1	$E = 0.73C + 0.49FI$	$E = 0.48C + 0.44F + 0.26I$
2	$E = 2.31C + 1.30FI$	$E = 1.54C + 1.02F + 0.75I$
3	$E = 16.1C + 5.77FI$	$E = 9.06C + 14.5F + 2.90I$
4	$E = 0.05C + 1.81FI$	$E = 0.26C + 0.69F + 1.66I$
5	$E = 3.14C + 2.98FI$	$E = 2.09C + 2.22F + 1.72I$
6	$E = 0.20C + 0.41FI$	$E = 0.13C + 0.34F + 0.23I$
7	$E = 2.14C + 2.36FI$	$E = 1.42C + 1.63F + 1.51I$
8	$E = 7.24C + 5.77FI$	$E = 4.83C + 4.57F + 2.69I$
9	$E = 1.97C + 0.74FI$	$E = 1.31C + 0.57F + 0.42I$
10	$E = 3.86C + 4.82FI$	$E = 0.72C + 0.77F + 23.1I$
11	$E = 5.04C + 3.97FI$	$E = 3.36C + 1.59F + 6.04I$
12	$E = 0.10C + 4.34FI$	$E = 0.72C + 1.44F + 1.55I$

TABLE XXXII (CONTINUED)

Hour	G = C + FI	G = C + F + I
1	G = 4.87C + 4.14FI	G = 3.19C + 3.51F + 2.24I
2	G = 3.21C + 2.28FI	G = 1.96C + 1.83F + 1.46I
3	G = 19.7C + 0.04FI	G = 9.04C + 17.3F + 0.24I
4	G = 7.09C + 2.49FI	G = 3.05C + 0.70F + 30.9I
5	G = 4.78C + 4.73FI	G = 3.19C + 3.44F + 2.87I
6	G = 0.52C + 0.74FI	G = 0.35C + 0.55F + 0.44I
7	G = 2.84C + 2.51FI	G = 1.89C + 1.75F + 1.60I
8	G = 6.88C + 7.14FI	G = 6.22C + 2.42F + 4.69I
9	G = 2.12C + 0.76FI	G = 1.41C + 0.58F + 0.44I
10	G = 2.20C + 1.36FI	G = 1.47C + 0.92F + 0.87I
11	G = 8.27C + 5.19FI	G = 7.89C + 1.30F + 8.28I
12	G = 1.57C + 3.70FI	G = 1.05C + 2.36F + 2.54I

Hour	H = C + FI	H = C + F + I
1	H = 0.84C + 0.57FI	H = 0.56C + 0.51F + 0.30I
2	H = 3.10C + 1.87FI	H = 2.06C + 1.47F + 1.08I
3	H = 7.42C + 10.7FI	H = 5.59C + 11.5F + 3.31I
4	H = 2.39C + 2.25FI	H = 0.83C + 1.35F + 5.79I
5	H = 1.13C + 1.17FI	H = 0.75C + 0.85F + 0.71I
6	H = 0.27C + 0.56FI	H = 0.18C + 0.46F + 0.31I
7	H = 1.01C + 0.91FI	H = 0.67C + 0.62F + 0.59I
8	H = 10.6C + 4.45FI	H = 4.91C + 2.87F + 9.50I
9	H = 4.87C + 0.31FI	H = 4.55C + 0.51F + 0.07I
10	H = 2.30C + 1.37FI	H = 1.53C + 0.94F + 0.84I
11	H = 5.83C + 6.23FI	H = 5.70C + 1.86F + 7.75I
12	H = 1.31C + 2.80FI	H = 0.87C + 1.73F + 2.00I

TABLE XXXII (CONTINUED)

Hour	J = C + FI	J = C + F + I
1	J = 2.36C + 1.62FI	J = 1.57C + 1.49F + 0.81I
2	J = 0.98C + 0.50FI	J = 0.65C + 0.40F + 0.28I
3	J = 6.65C + 6.31FI	J = 5.06C + 2.24F + 4.72I
4	J = 1.74C + 2.36FI	J = 1.56C + 1.72F + 0.79I
5	J = 1.53C + 0.93FI	J = 1.02C + 0.44F + 0.85I
6	J = 1.21C + 2.51FI	J = 0.81C + 2.02F + 1.41I
7	J = 0.39C + 0.39FI	J = 0.26C + 0.30F + 0.23I
8	J = 3.76C + 1.88FI	J = 3.74C + 1.05F + 0.85I
9	J = 4.97C + 0.41FI	J = 4.66C + 0.60F + 0.10I
10	J = 3.34C + 1.97FI	J = 2.23C + 1.44F + 1.12I
11	J = 6.17C + 3.90FI	J = 4.11C + 1.62F + 5.85I
12	J = 1.76C + 4.08FI	J = 1.17C + 2.64F + 2.75I

Hour	K = C + FI	K = C + F + i
1	K = 0.44C + 0.44FI	K = 0.29C + 0.37F + 0.23I
2	K = 0.57C + 0.55FI	K = 0.38C + 0.38F + 0.35I
3	K = 0.56C + 0.71FI	K = 0.23C + 0.43F + 0.64I
4	K = 0.44C + 0.77FI	K = 0.18C + 0.95F + 0.41I
5	K = 0.38C + 0.41FI	K = 0.25C + 0.30F + 0.25I
6	K = 0.12C + 0.81FI	K = 0.17C + 0.40F + 0.34I
7	K = 0.85C + 0.80FI	K = 0.56C + 0.56F + 0.51I
8	K = 0.97C + 0.83FI	K = 0.65C + 0.54F + 0.43I
9	K = 0.42C + 0.80FI	K = 0.17C + 0.23F + 1.23I
10	K = 0.34C + 1.32FI	K = 0.45C + 0.60F + 0.50I
11	K = 0.80C + 0.69FI	K = 0.75C + 0.14F + 0.72I
12	K = 1.20C + 0.54FI	K = 1.20C + 0.21F + 0.32I

TABLE XXXIII

HOURLY LEAD CONTRIBUTION AND FRACTION OF MEASURED LEAD EXPLAINED BY THE RECEPTOR MODELING EQUATION $Y = C + FI$ FOR THE WAVE SOLDERING AREA ($\mu g/m^3$)

Hour	Lines 1 and 2	Line 3	Predicted Concentration[a]	Measured Concentration[a]
1	0.610 (0.56)	0.401 (0.37)	1.011	1.093
2	0.309 (0.60)	0.276 (0.54)	0.585	0.515
3	0.624 (0.08)	0.921 (0.12)	1.545	7.413
4	0.573 (0.10)	0.135 (0.02)	0.708	5.679
5	0.572 (0.57)	0.641 (0.53)	1.213	0.998
6	0.081 (0.46)	0.085 (0.48)	0.166	0.178
7	0.402 (0.10)	0.417 (0.10)	0.819	4.133
8	0.806 (0.51)	0.797 (0.50)	1.603	1.580
9	0.115 (0.38)	0.716 (0.39)	0.831	0.308
10	0.556 (0.15)	0.216 (0.06)	0.772	3.785
11	0.350 (0.02)	0.958 (0.06)	1.308	16.072
12	0.319 (0.58)	0.220 (0.40)	0.539	0.548

[a] Average of sampling locations A, B, D, E, G, H.

TABLE XXXIV

HOURLY LEAD CONTRIBUTION AND FRACTION OF MEASURED LEAD EXPLAINED BY THE RECEPTOR MODELING EQUATION Y = C + F + I FOR THE WAVE SOLDERING AREA ($\mu g/m^3$)

Hour	Line 1	Line 2	Line 3	Predicted Concentration[a]	Measured Concentration[a]
1	0.464 (0.42)	0.346 (0.32)	0.312 (0.29)	1.122	1.093
2	0.205 (0.40)	0.210 (0.41)	0.181 (0.35)	0.596	0.515
3	0.235 (0.03)	1.499 (0.20)	0.630 (0.08)	2.364	7.413
4	1.620 (0.29)	0.214 (0.04)	0.104 (0.02)	1.938	5.679
5	0.326 (0.33)	0.425 (0.42)	0.441 (0.44)	1.192	0.998
6	0.055 (0.31)	0.054 (0.30)	0.056 (0.32)	0.165	0.178
7	0.280 (0.07)	0.253 (0.06)	0.278 (0.07)	0.811	4.133
8	0.618 (0.39)	0.158 (0.10)	0.329 (0.21)	1.105	1.580
9	0.067 (0.22)	0.046 (0.15)	0.117 (0.38)	0.230	0.308
10	0.832 (0.22)	0.204 (0.05)	0.153 (0.04)	1.189	3.785
11	0.870 (0.05)	0.059 (0.004)	0.725 (0.04)	1.654	16.072
12	0.202 (0.37)	0.132 (0.24)	0.190 (0.35)	0.524	0.548

[a] Average of sampling locations A, B, D, E, G, H.

Tables XLIV and XLV. Figures 27 and 28 show the relationship between the average predicted and average measured hourly lead concentrations for the each of the receptor modeling equations. When the nine outlying measured concentrations were removed from the relationship, a better least squares fit was obtained. This pattern also was evident for the tin concentrations, as shown in Figures 29 and 30. The same nine outlying measured concentrations were removed. The measured lead to tin concentration ratio differed between the outlying points and the remaining points in Figure 31.

Using these receptor modeling equations a lead residual was calculated for each sampling hour to determine the fraction of the average measured lead concentration that was explained by the receptor modeling equation. These results are shown for each receptor point in Appendix C, Tables XLVI and XLVII.

3. Emission Factors

a. Box Model

Emission factors were determined using all of the collected activity variables summed over the sampling periods. The resulting equations included the individual variables of number of boards and total scrapings and dedrossings, as shown in Figures 32 and 33. No more than one activity variable could be included because negative coefficients resulted. These equations contained a constant to account for the unexplained emissions and are summarized in Table XXXV.

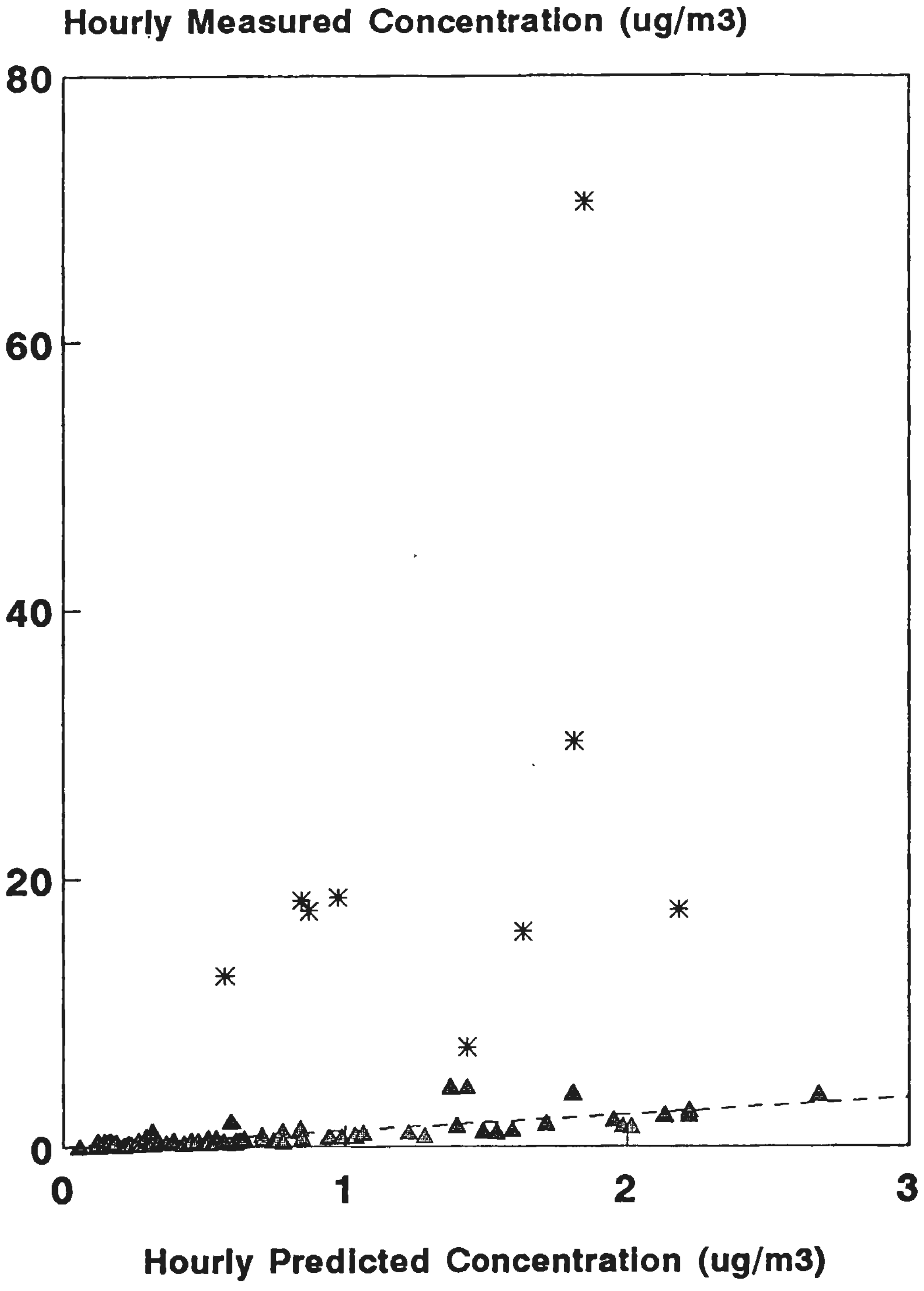

Figure 27. Measured versus predicted lead concentrations from the receptor modeling equation Y = C + FI for the wave soldering area.

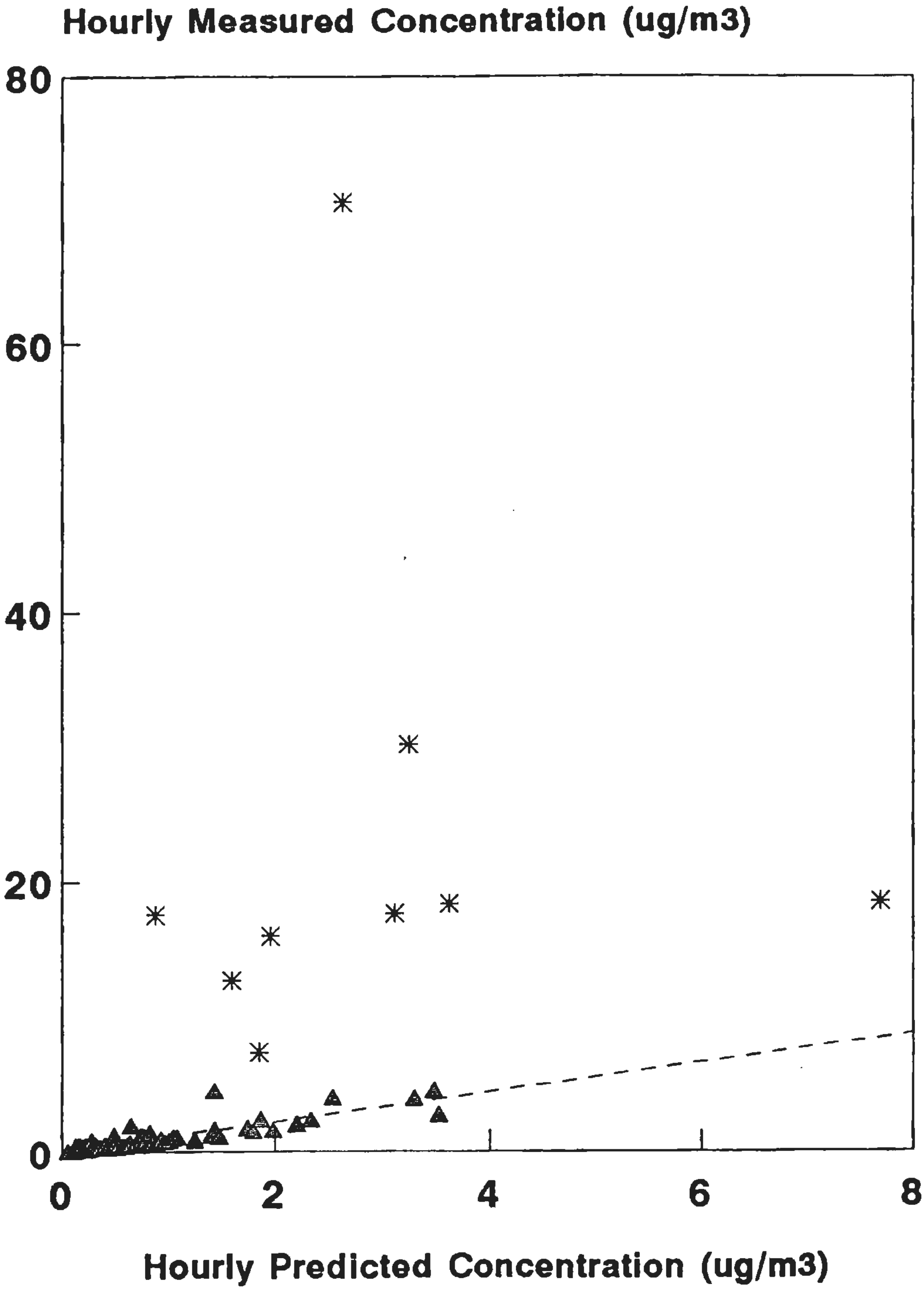

Figure 28. Measured versus predicted lead concentrations from the receptor modeling equation Y = C + F + I for the wave soldering area.

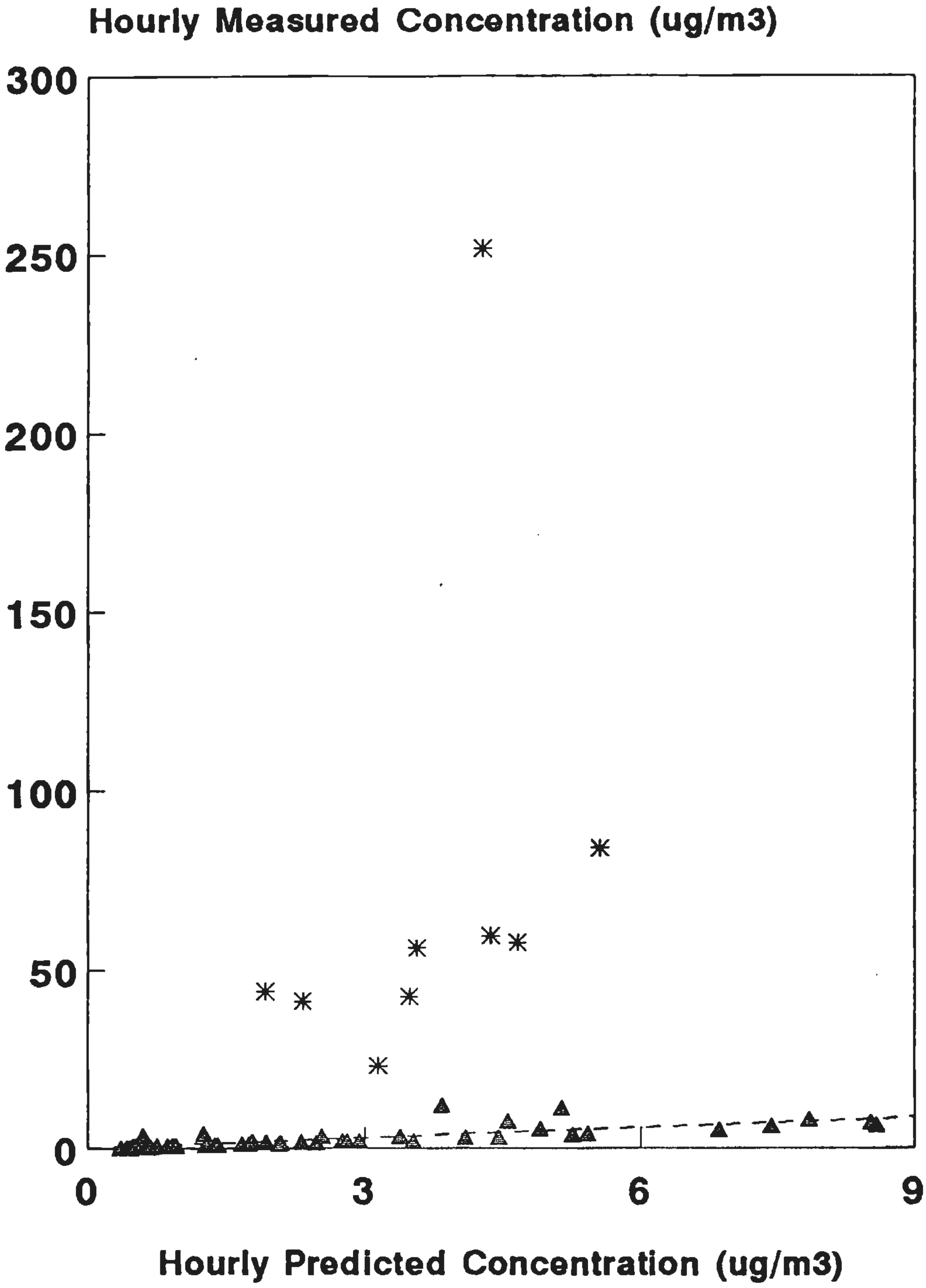

Figure 29. Measured versus predicted tin concentrations from the receptor modeling equation Y = C + FI for the wave soldering area.

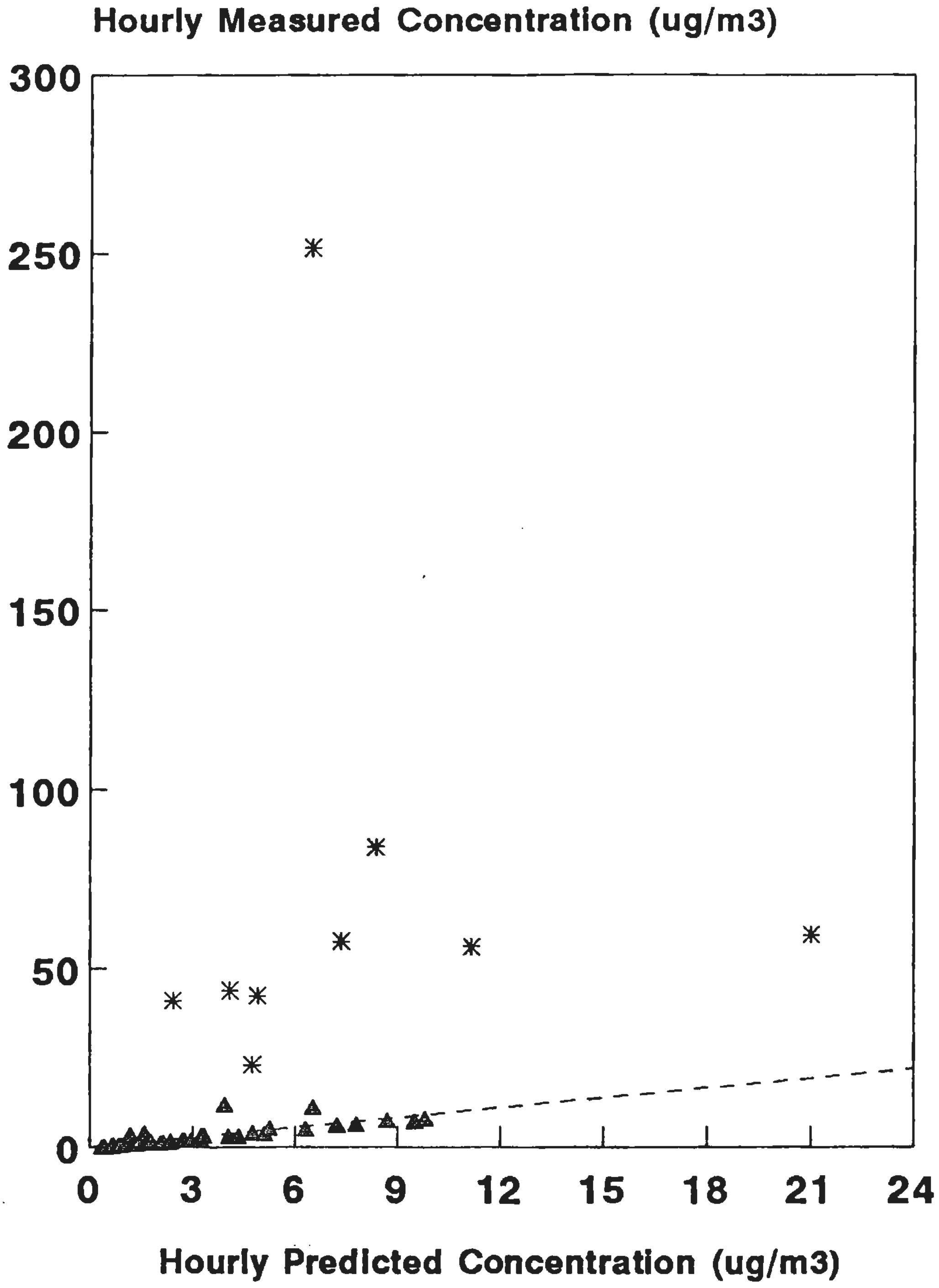

Figure 30. Measured versus predicted tin concentrations from the receptor modeling equation Y = C + F + I for the wave soldering area.

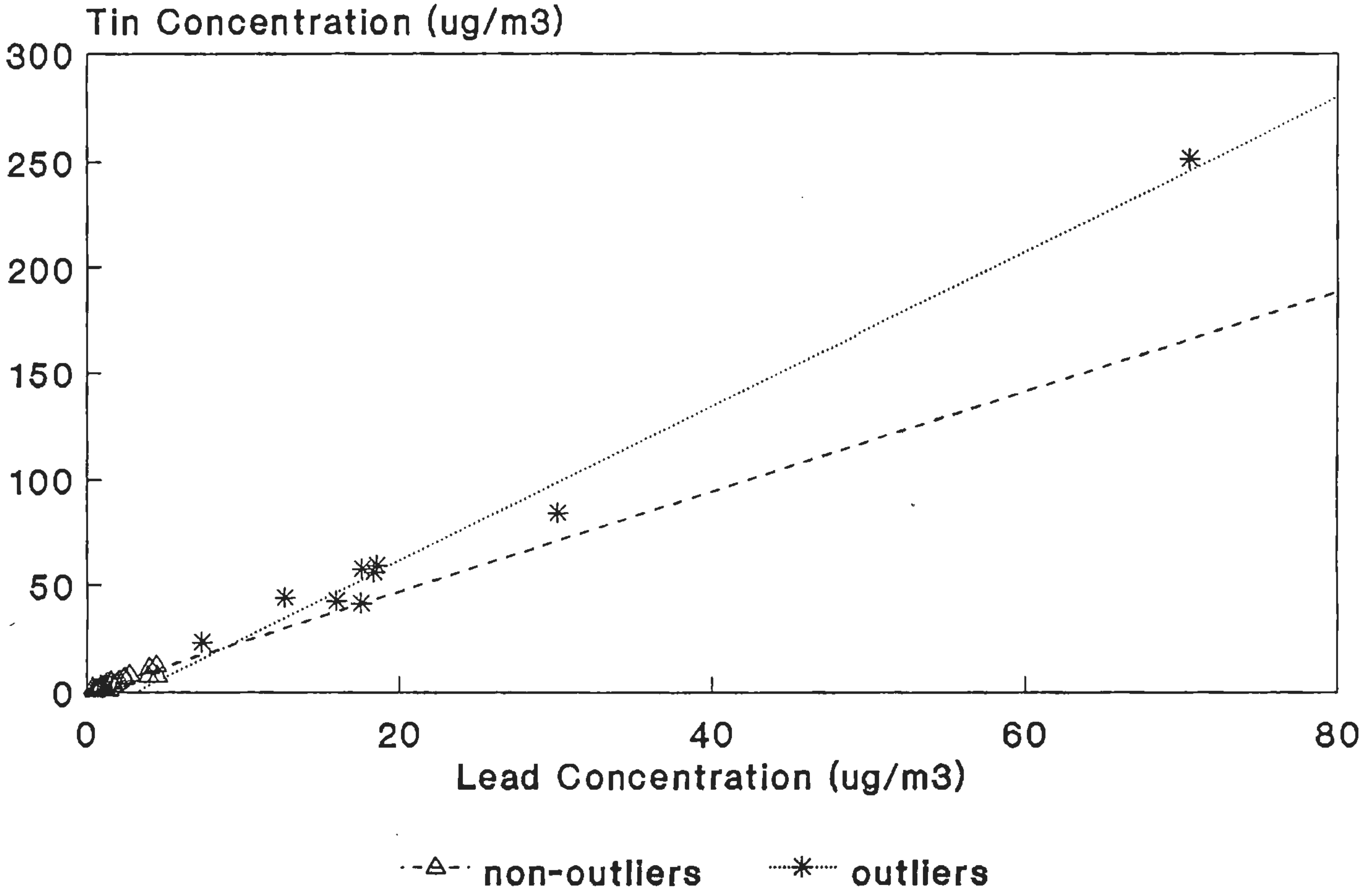

Figure 31. Measured tin versus measured lead concentrations for the wave soldering area.

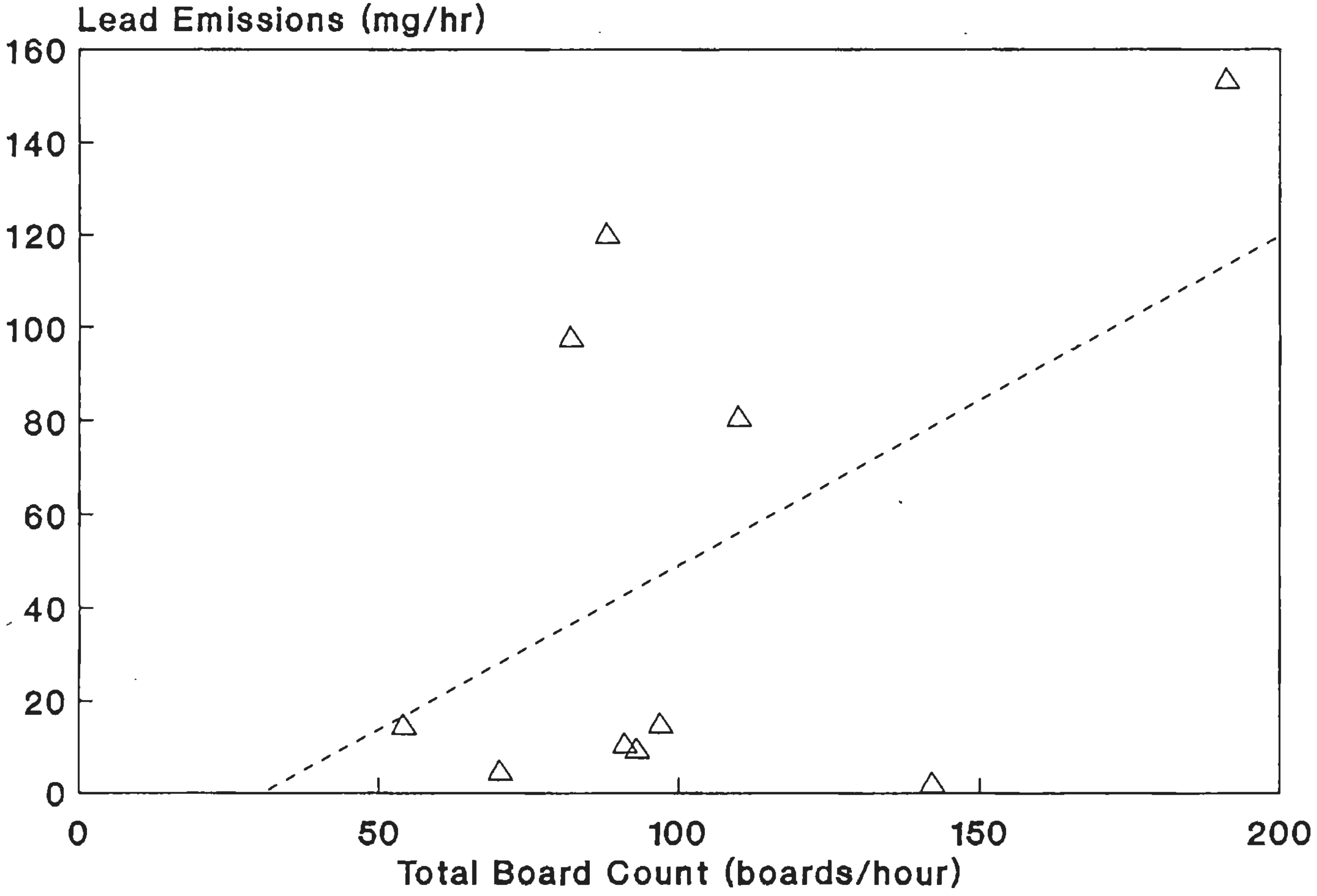

Figure 32. Box model lead emissions versus total board count for the wave soldering area.

Emission factor = 0.708 mg/boards, n = 10

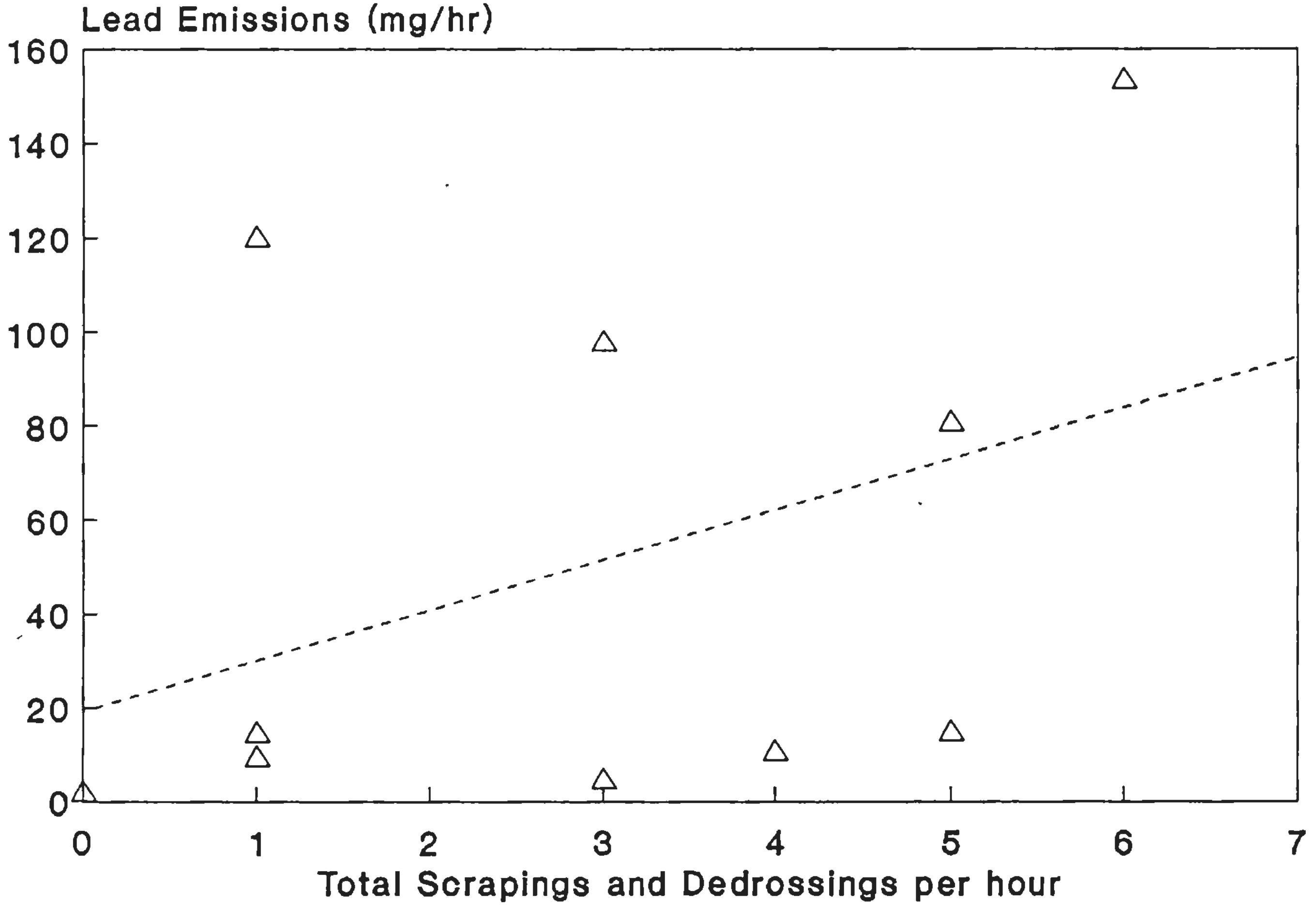

Figure 33. Box model lead emissions versus total scrapings and dedrossings for the wave soldering area.

Emission factor = 10.7 mg/scrapings and dedrossings, n = 10

TABLE XXXV

EMISSION FACTORS FROM THE BOX MODEL FOR THE WAVE SOLDERING AREA

Equation	r^{2a}	n
box = 0.708boards - 21.6	0.238	10
box = 10.7scr/ded + 19.2	0.156	10

[a] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the observed emission rates.

b. Receptor Modeling

As a partial check on whether the receptor model predictions were physically consistent, the lead contribution from each source was regressed against each of three activity variables at each receptor point. Table XXXVI summarizes the best of these relationships and the results are displayed in Figures 34 through 44. Tables XLVIII through LII, Appendix C, summarize the relationships for each line. Additionally, lead emissions by line were estimated using the box model and the hourly lead contribution for each line. These emission rates were then regressed against the scrapings and dedrossings from each line, as shown in Figure 45.

TABLE XXXVI

SUMMARY OF BEST RELATIONSHIPS BETWEEN INDIVIDUAL LINE CONTRIBUTIONS TO RECEPTOR POINT LEAD AND SOURCE ACTIVITIES FOR INDIVIDUAL LINES

Receptor Point[a]	Receptor Equation[b]	Lead Contribution from Line	Source Activity	Regression Coefficient	r^2
Line 1					
G	G = C + F + I	2	scr/ded from line 2	0.599 (μg Pb/ m^3)/scr + ded	0.815
H	H = C + F + I	2	scr/ded from line 2	0.406 (μg Pb/ m^3)/scr + ded	0.861
Line 2					
D	D = C + F + I	2	scr/ded from line 2	0.291 (μg Pb/ m^3)/scr + ded	0.739
E	E = C + F + I	2	scr/ded from line 2	0.519 (μg Pb/ m^3)/scr + ded	0.860
Line 3					
A	A = C + F + I	3	scr/ded from line 3	0.083 (μg Pb/ m^3)/scr + ded	0.319
B	B = C + F + I	3	scr/ded from line 3	0.092 (μg Pb/ m^3)/scr + ded	0.699

[a] sampling locations shown in Figure 11

[b] C = line 3 fingerprint; F = line 2 fingerprint; I = line 1 fingerprint

TABLE XXXVI (CONTINUED)

Receptor Point[a]	Receptor Equation[b]	Lead Contribution from Line	Source Activity	Regression Coefficient	r^2
Line 3					
A	A = C + F + I	3	hood openings from line 3	0.045 (μg Pb/m^3)/hood	0.631
B	B = C + F + I	3	hood openings from line 3	0.027 (μg Pb/m^3)/hood	0.420
Recirculation Air					
J	J = C + F + I	2	scr/ded from line 2	0.048 (μg Pb/m^3)/scr + ded	0.303
Supply Air					
K	K = C + F + I	2	scr/ded from line 2	0.004 (μg Pb/m^3)/scr + ded	0.078
K	K = C + F + I	3	hood openings from line 3	0.092 (μg Pb/m^3)/hood	0.113

[a] sampling locations shown in Figure 11

[b] C = line 3 fingerprint; F = line 2 fingerprint; I = line 1 fingerprint

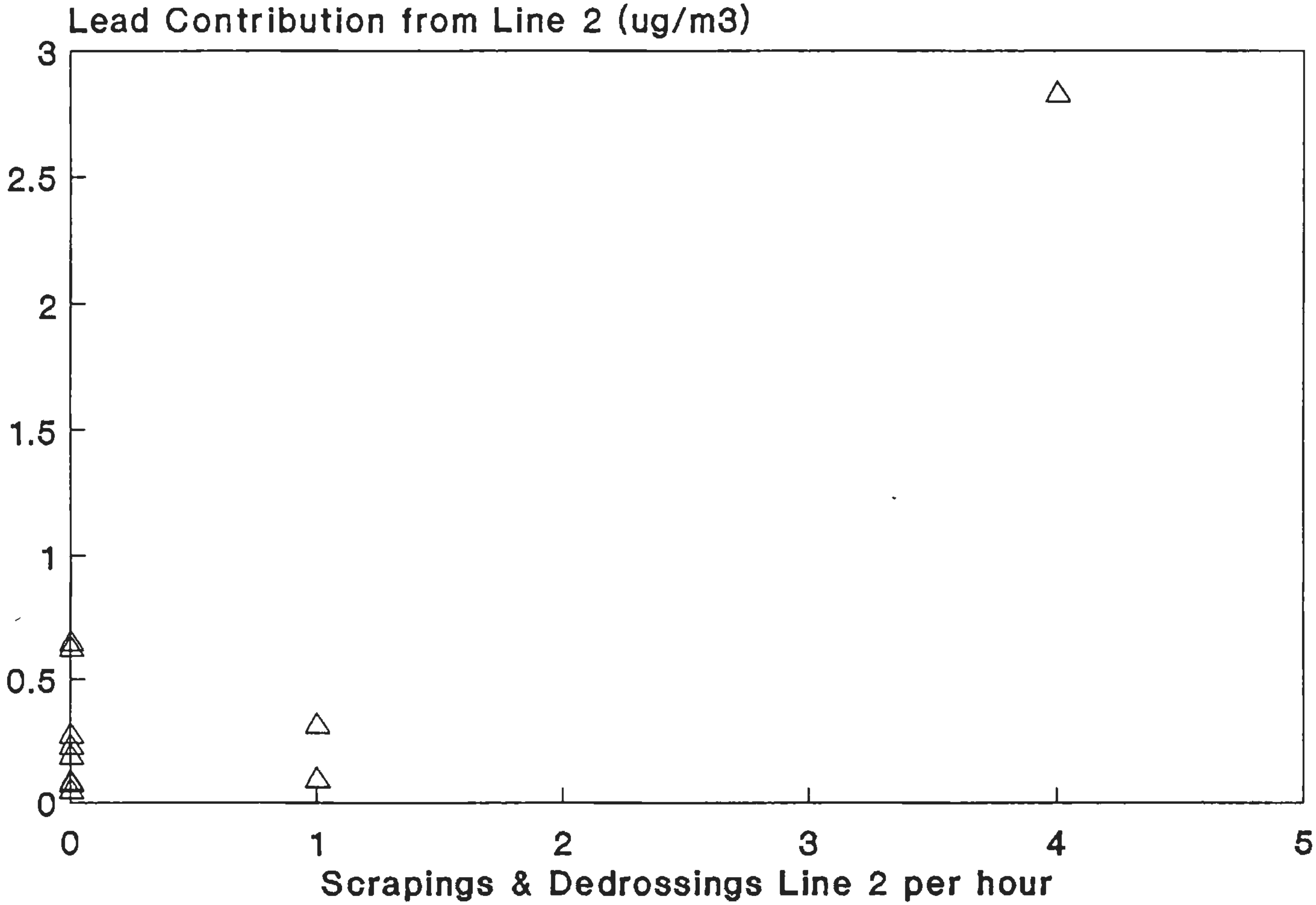

Figure 34. Lead contribution for line 1 (receptor point G) from line 2 (source point F), receptor modeling equation G = C + F + I, versus scrapings and dedrossings from line 2 for the wave soldering area.

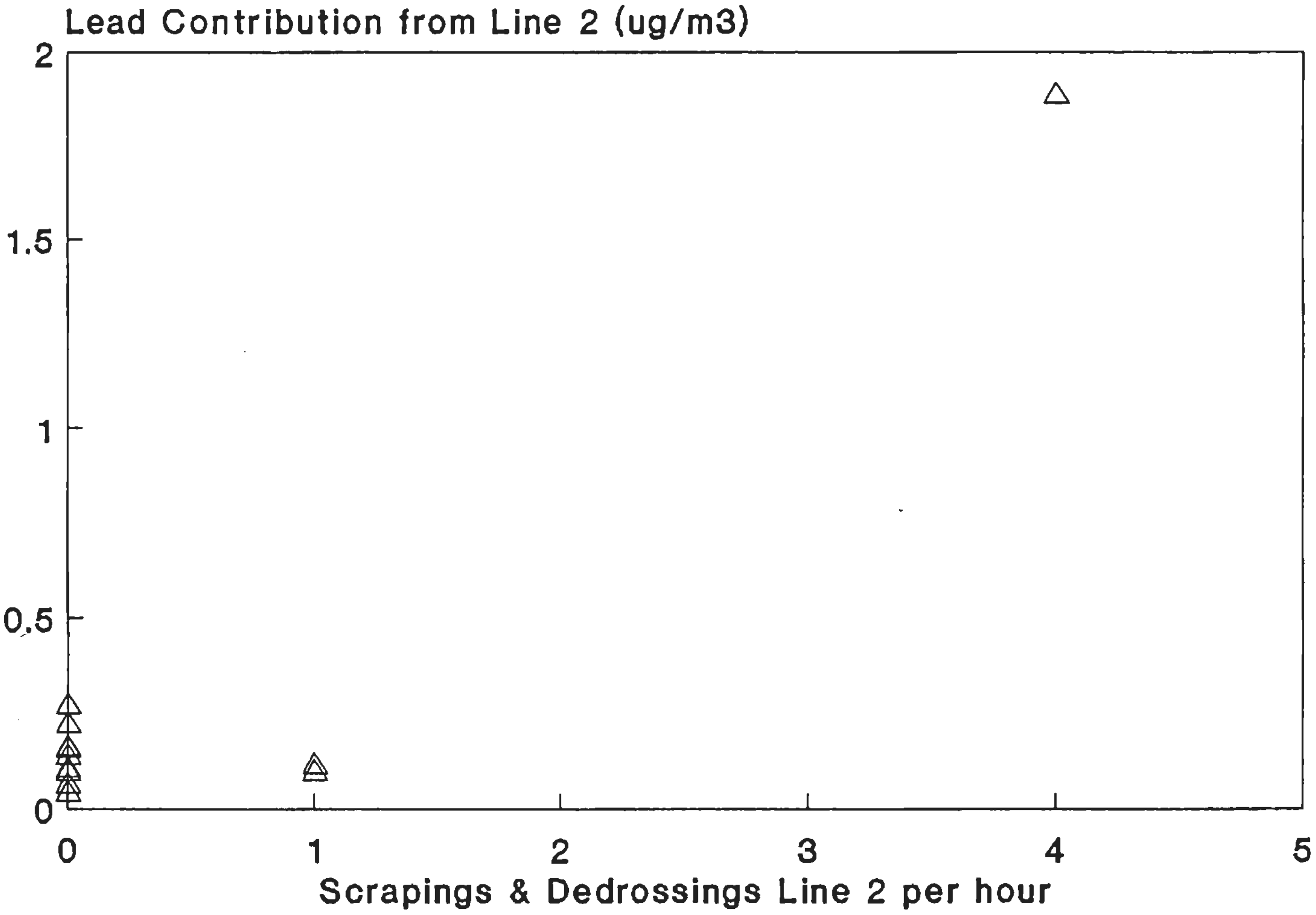

Figure 35. Lead contribution for line 1 (receptor point H) from line 2 (source point F), receptor modeling equation H = C + F + I, versus scrapings and dedrossings from line 2 for the wave soldering area.

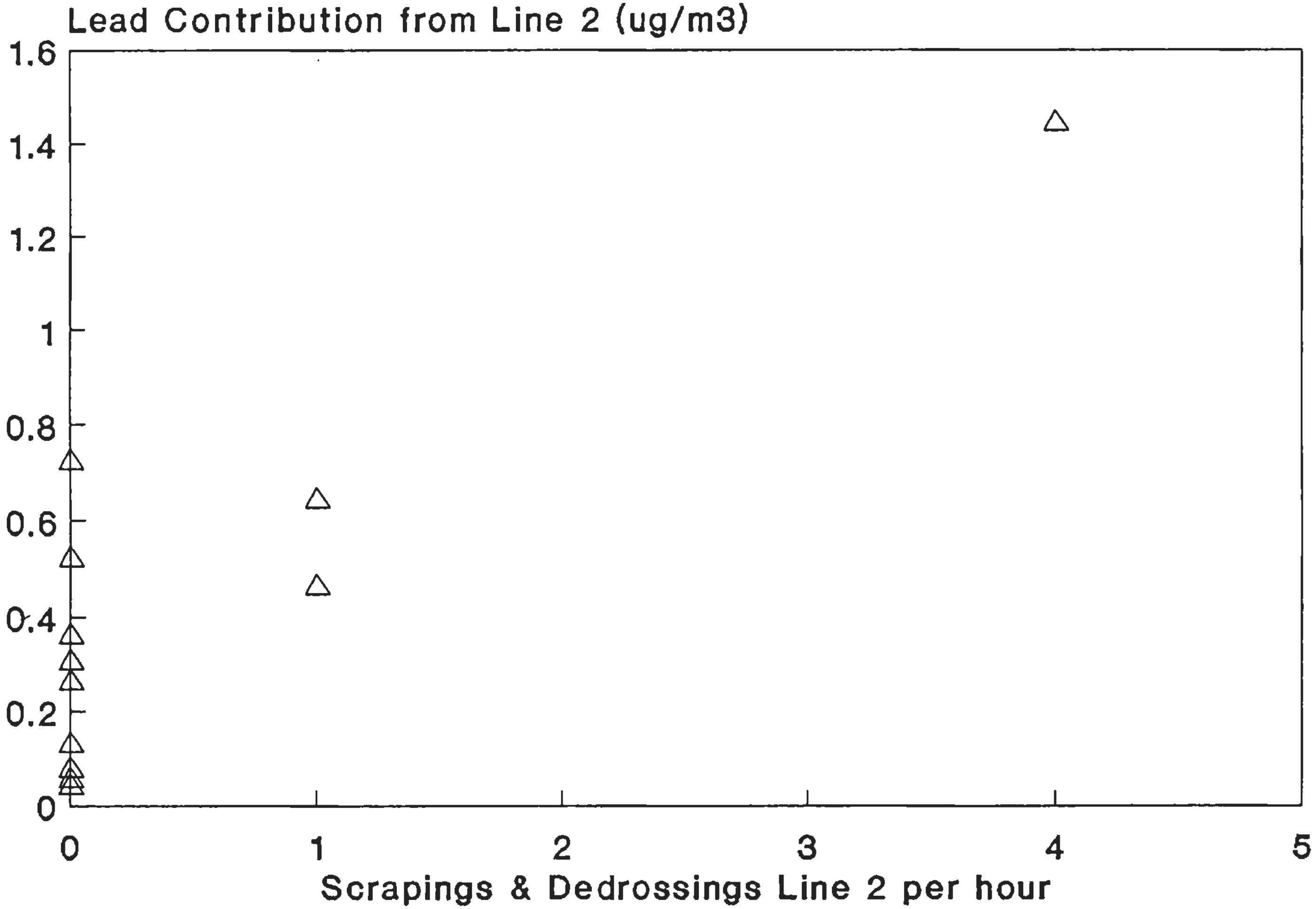

Figure 36. Lead contribution for line 2 (receptor point D) from line 2 (source point F), receptor modeling equation D = C + F + I, versus scrapings and dedrossings from line 2 for the wave soldering area.

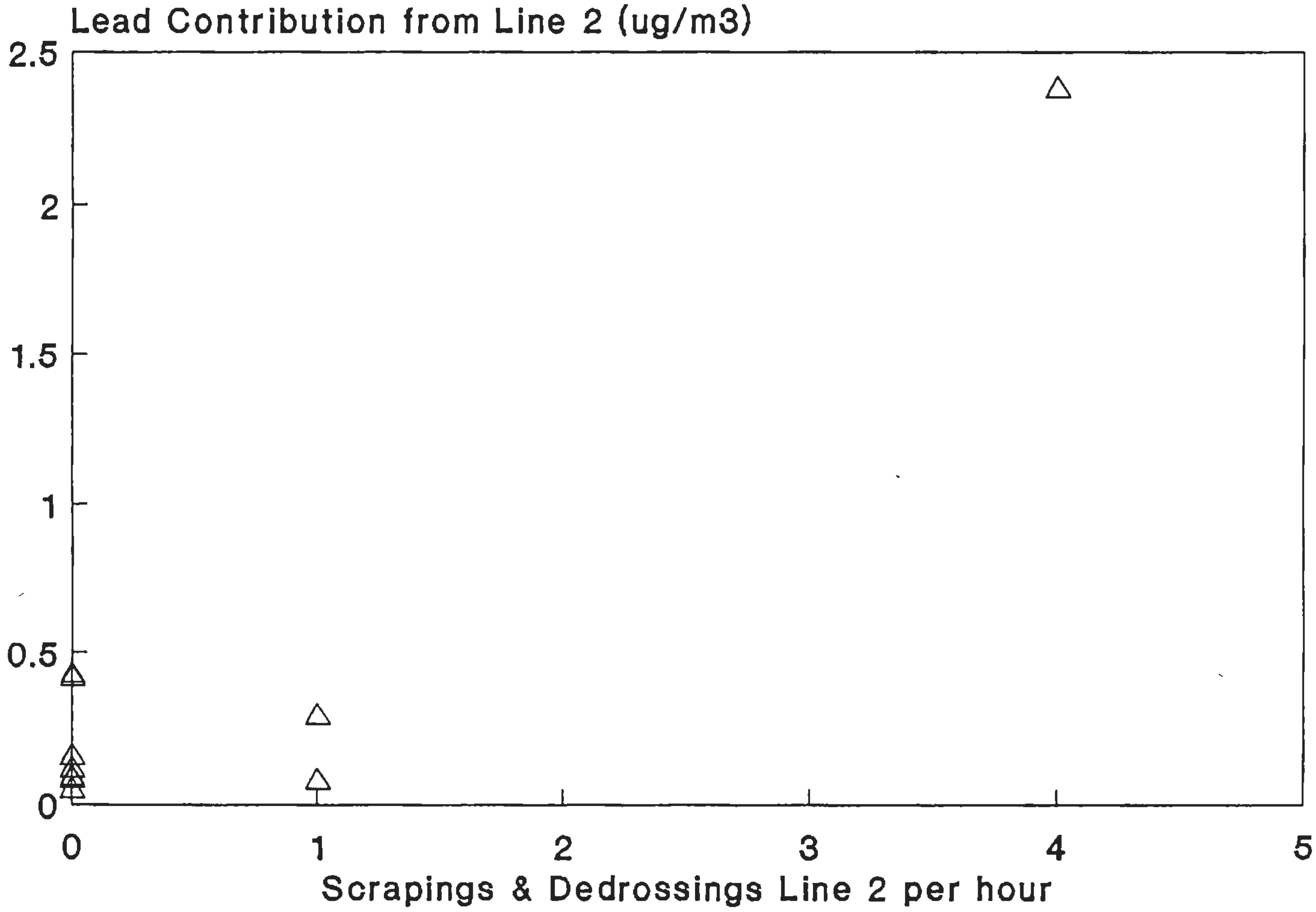

Figure 37. Lead contribution for line 2 (receptor point E) from line 2 (source point F), receptor modeling equation E = C + F + I, versus scrapings and dedrossings from line 2 for the wave soldering area.

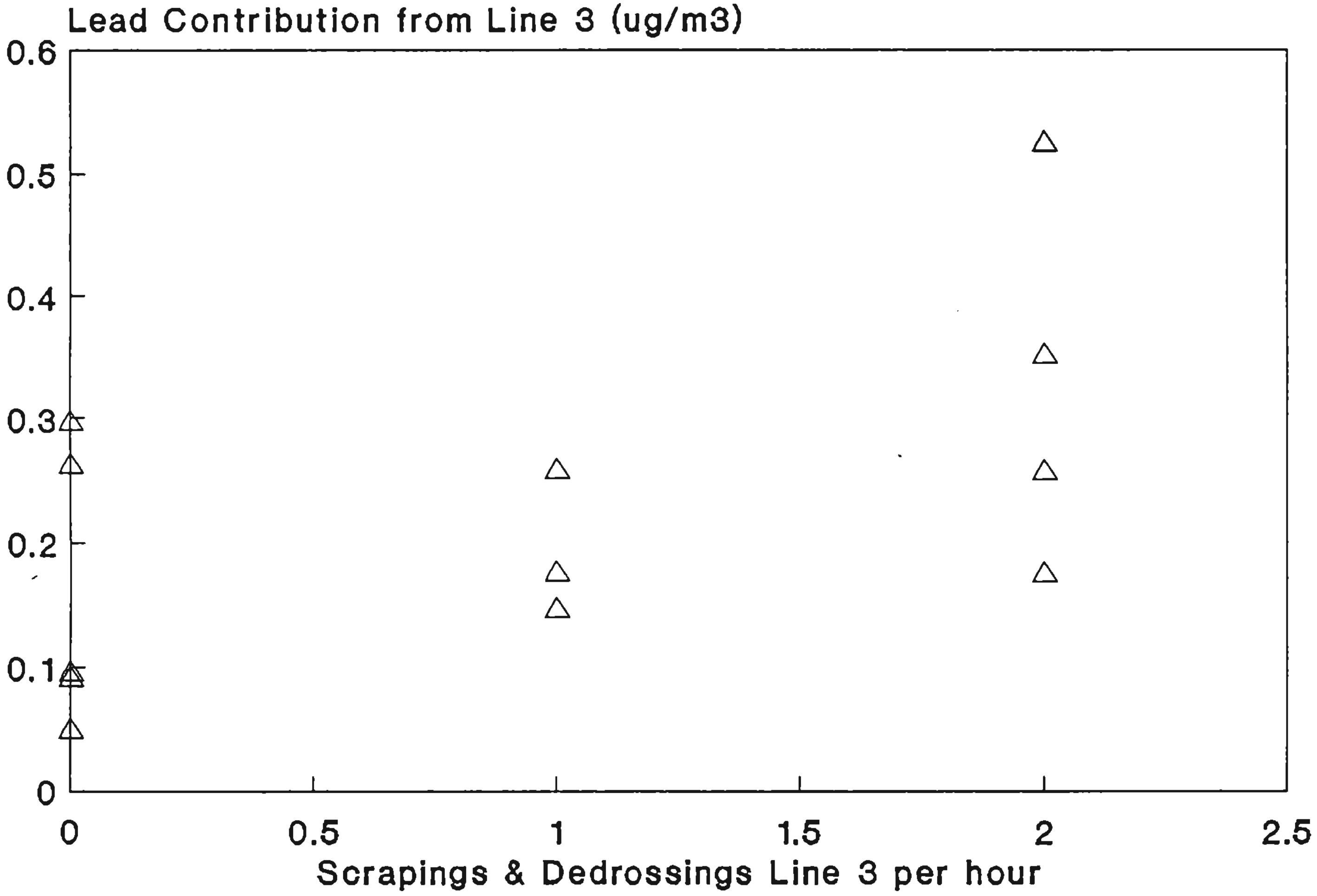

Figure 38. Lead contribution for line 3 (receptor point A) from line 3 (source point C), receptor modeling equation A = C + F + I, versus scrapings and dedrossings from line 3 for the wave soldering area.

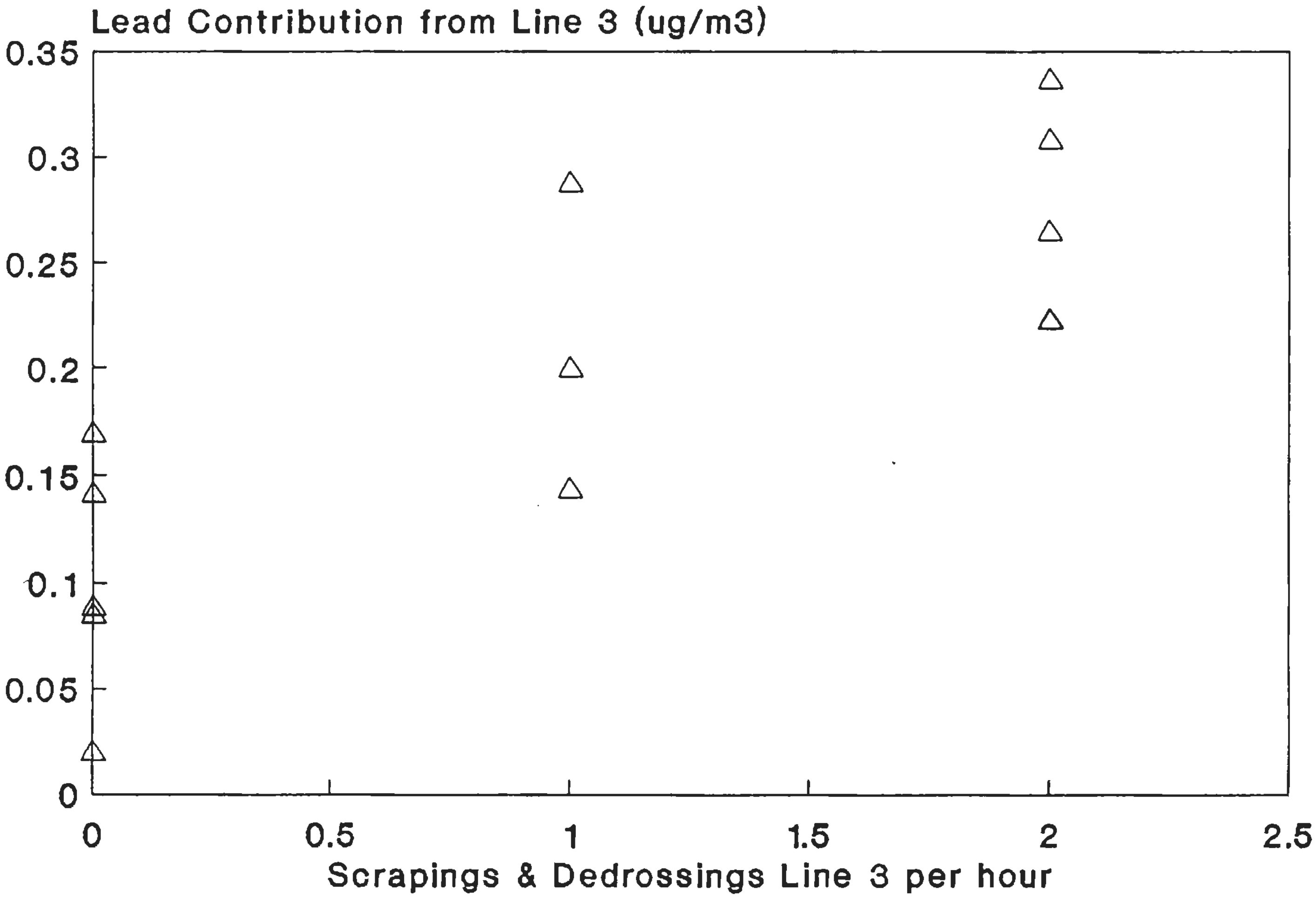

Figure 39. Lead contribution for line 3 (receptor point B) from line 3 (source point C), receptor modeling equation B = C + F + I, versus scrapings and dedrossings from line 3 for the wave soldering area.

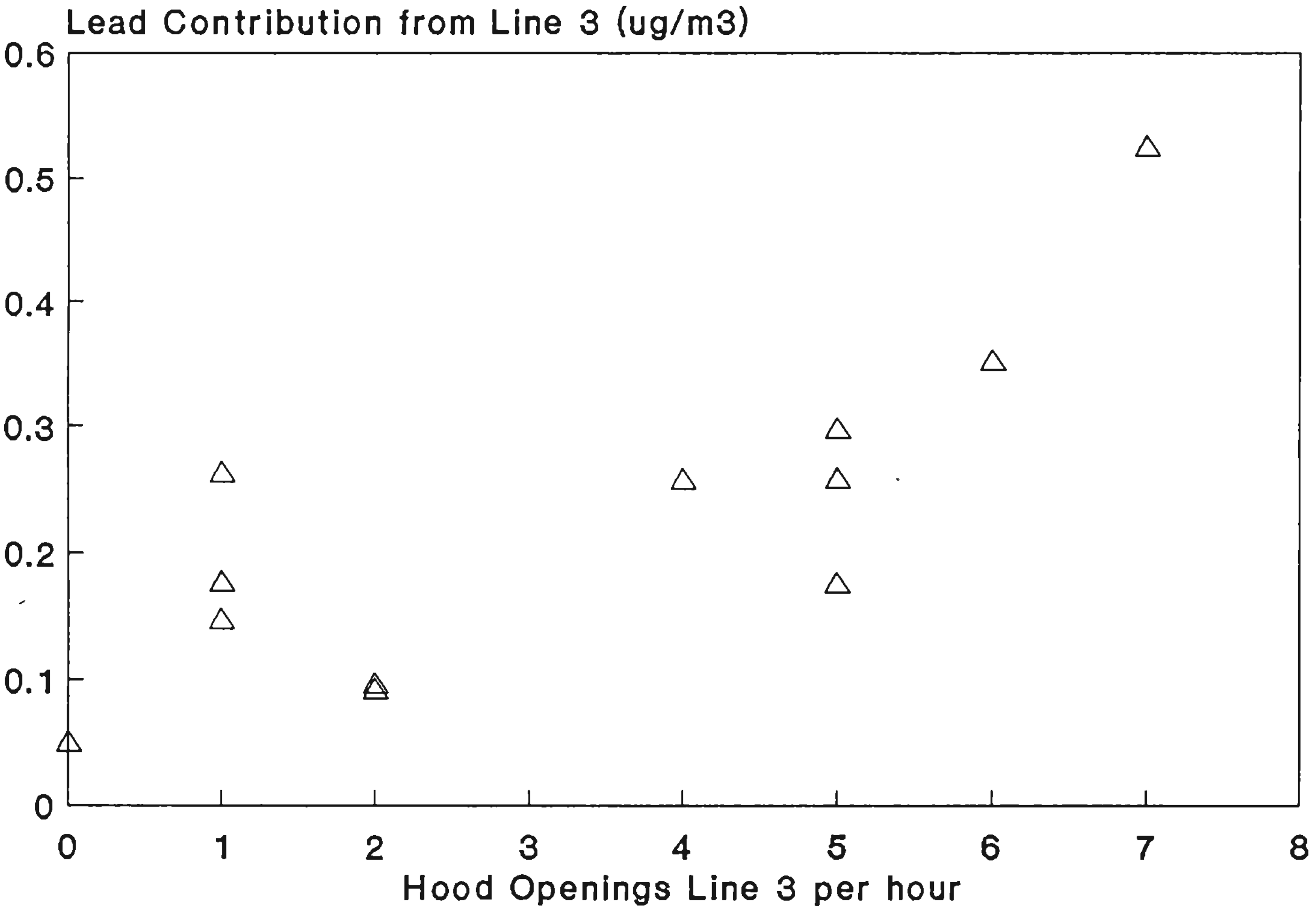

Figure 40. Lead contribution for line 3 (receptor point A) from line 3 (source point C), receptor modeling equation A = C + F + I, versus hood openings from line 3 for the wave soldering area.

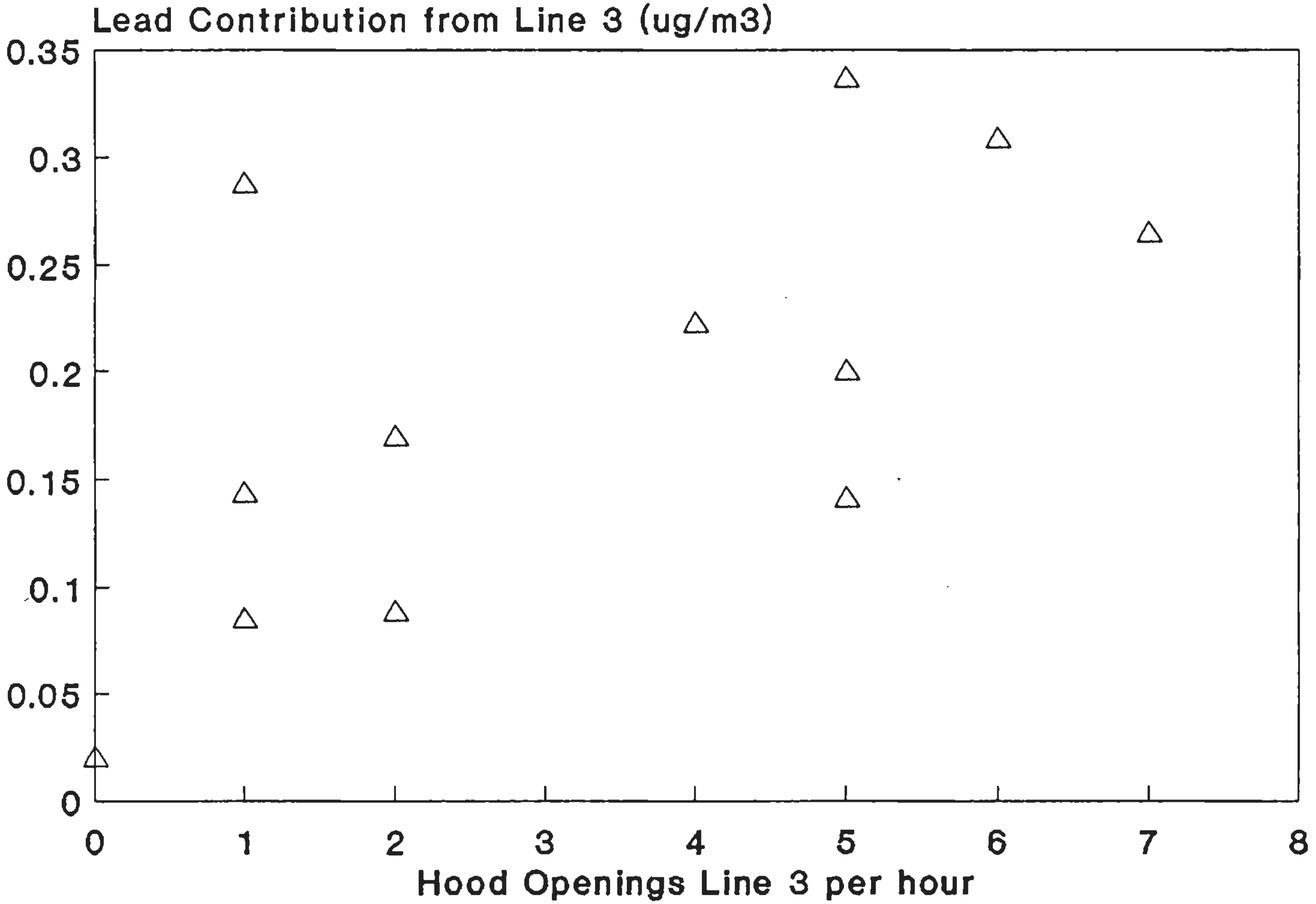

Figure 41. Lead contribution for line 3 (receptor point B) from line 3 (source point B), receptor modeling equation B = C + F + I, versus hood openings from line 3 for the wave soldering area.

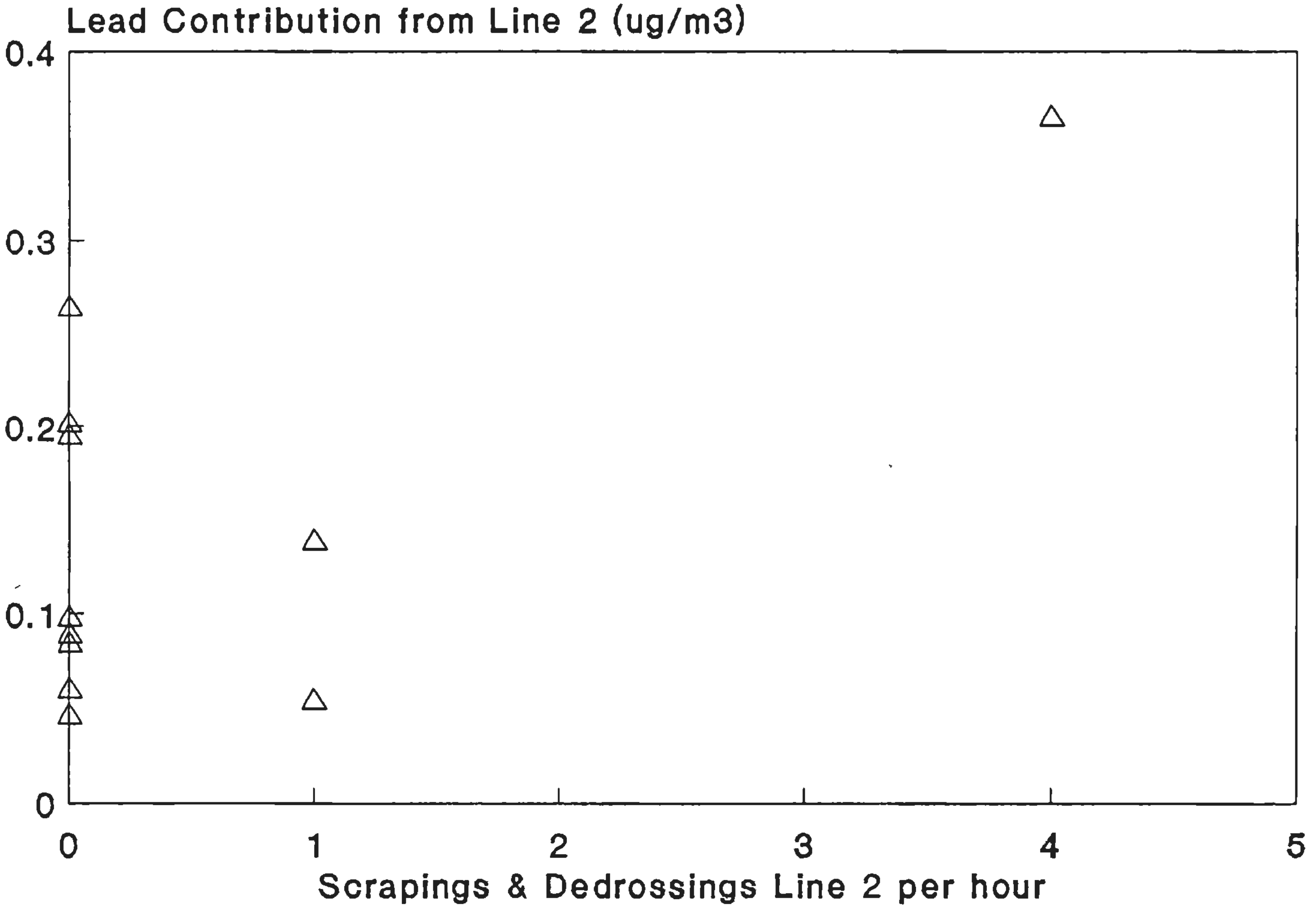

Figure 42. Lead contribution for recirculation air (receptor point J) from line 2 (source point F), receptor modeling equation J = C + F + I, versus scrapings and dedrossings from line 2.

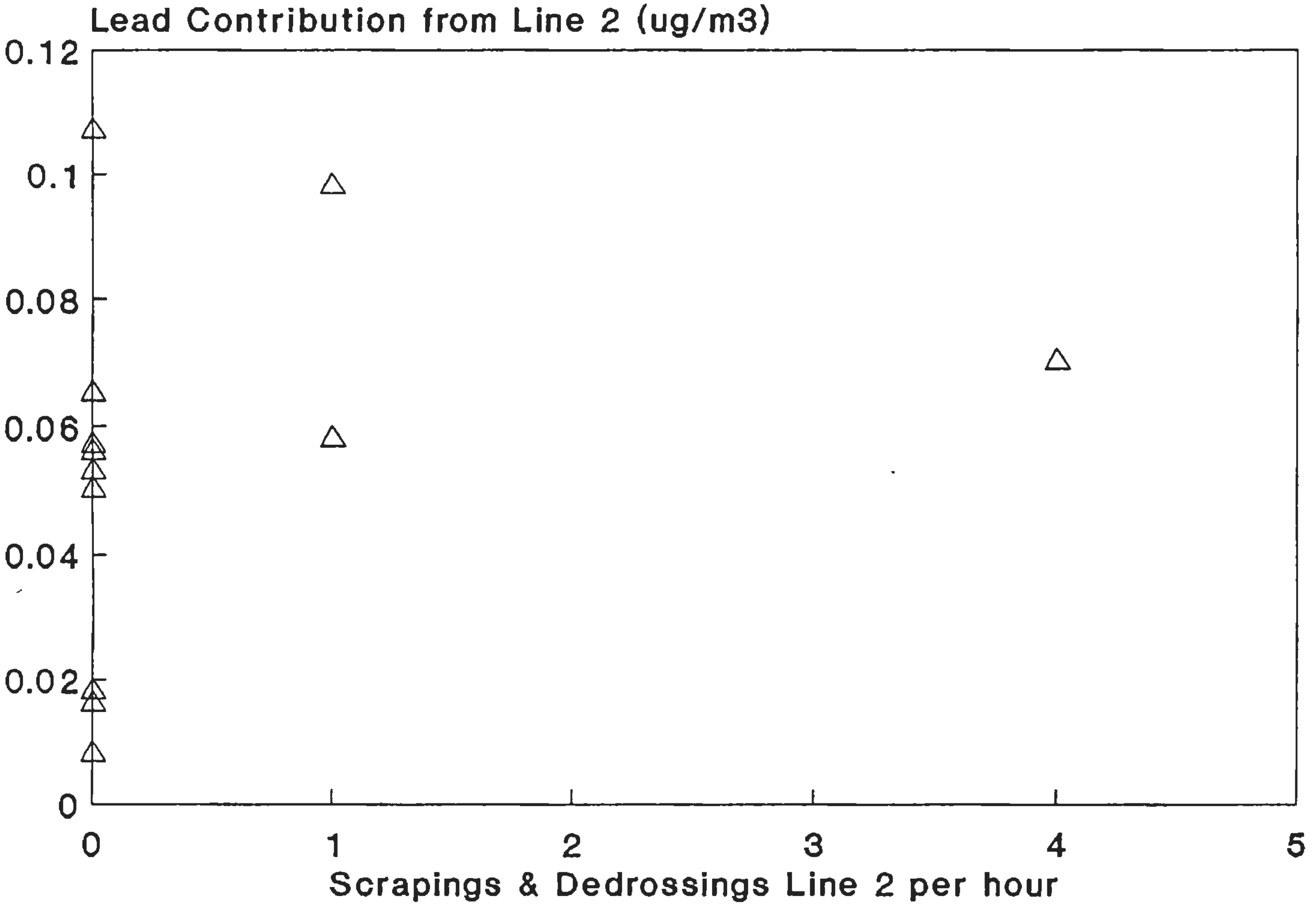

Figure 43. Lead contribution for the air supply (receptor point K) from line 2 (source point F), receptor modeling equation K = C + F + I, versus scrapings and dedrossings from line 2.

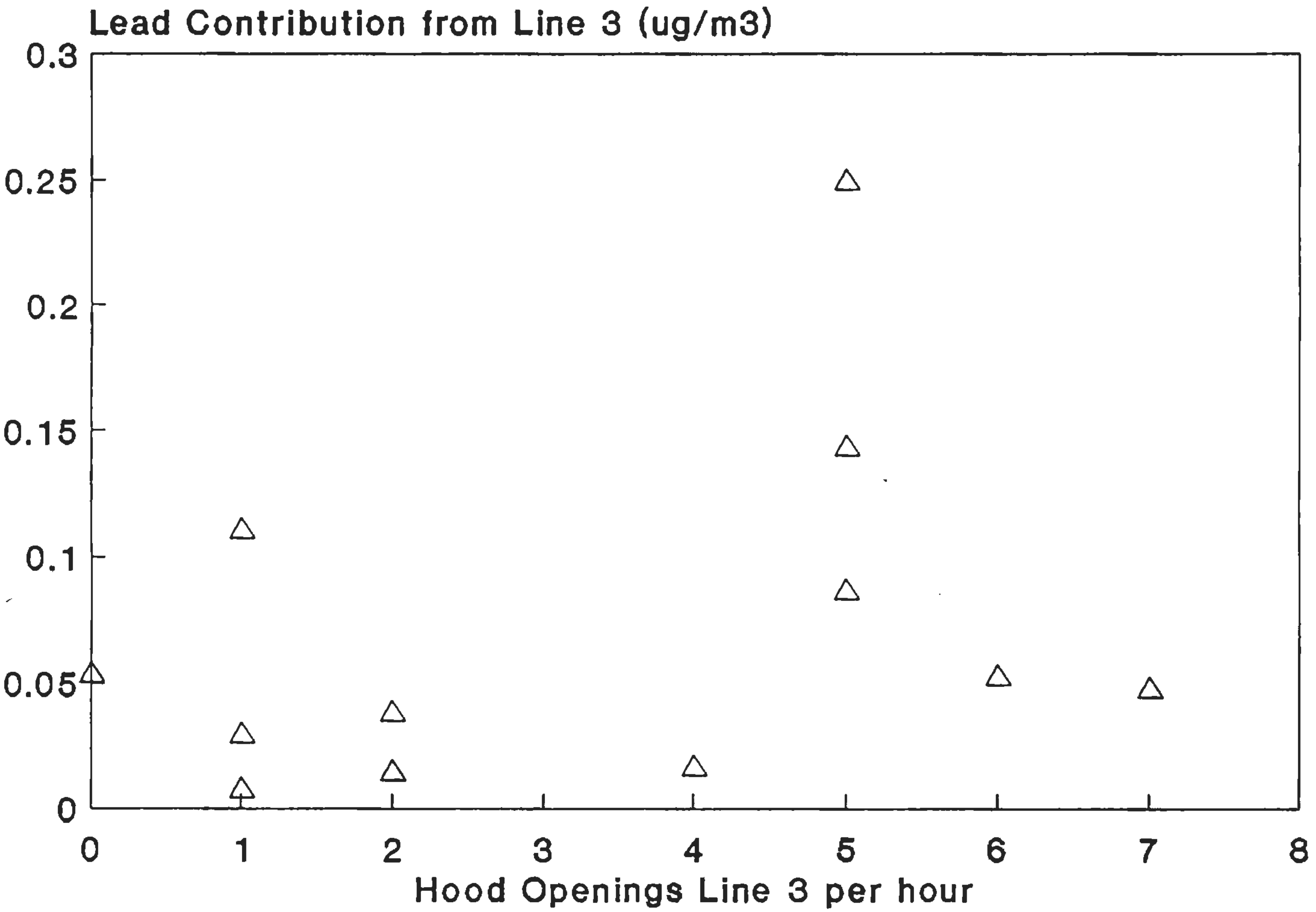

Figure 44. Lead contribution for the air supply (receptor point K) from line 3 (source point C), receptor modeling equation K = C + F + I, versus hood openings from line 3.

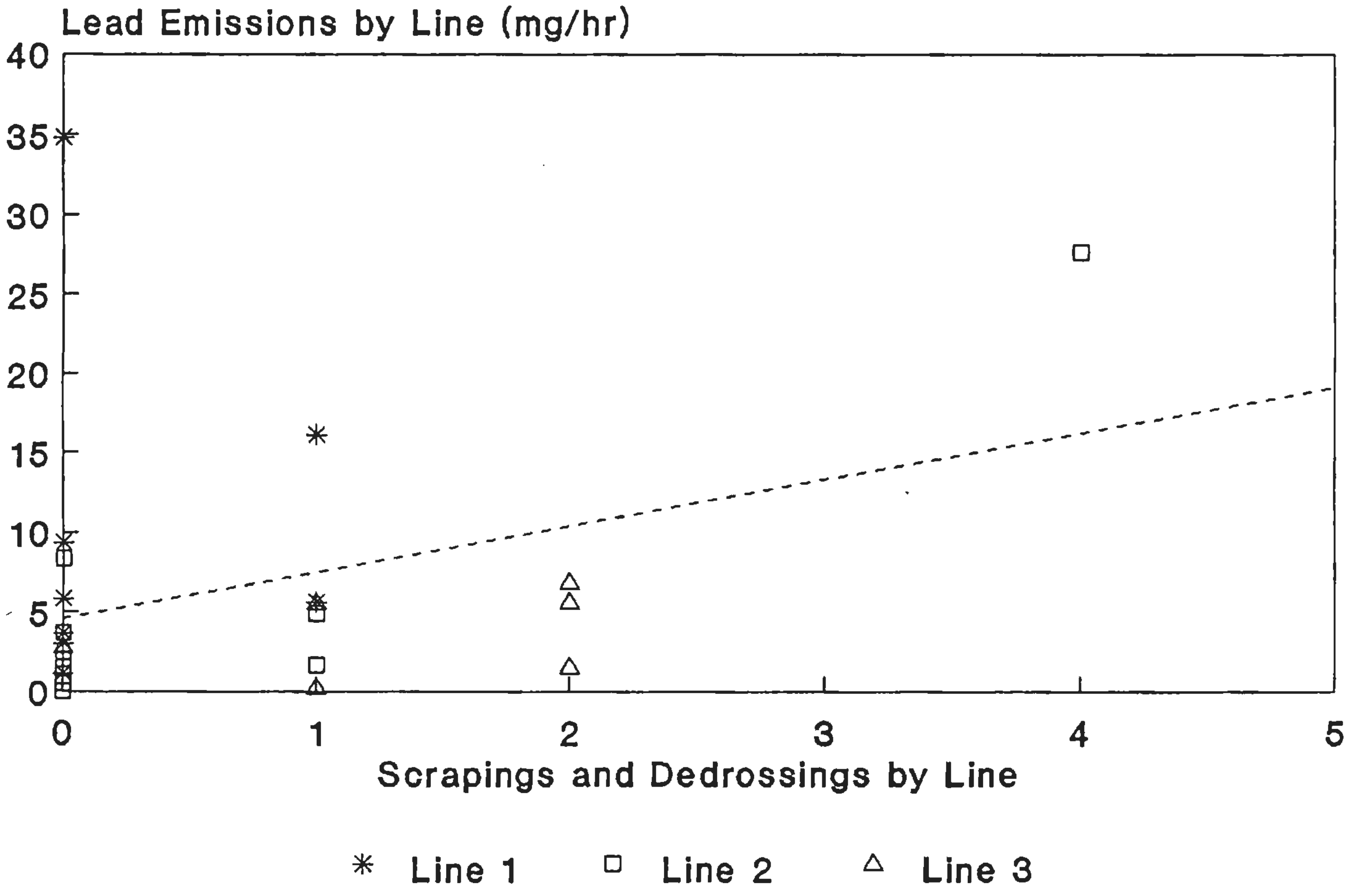

Figure 45. Lead emission rates by line versus scrapings and dedrossings by line for the wave soldering area.

IV. DISCUSSION

In summary, the three processes studied all were open tank processes (i.e., there was an open interface between the hazardous material and the workspace). The three interfaces were the copper ion solution and the air for the copper plating line, the vaporized TCA and the air for the three degreasers, and the molten solder surface and the air for the three wave soldering lines. In addition, all of the workspaces were different so different mass balance models were used to calculate the emission rates. Therefore, the emission factors were determined using different estimates of these emission rates. A summary of all the emission factors can be found in Table XXXVII.

A. Copper Plating

1. Emission Rates

The total emissions estimated from the mass balance and completely mixed space models were essentially identical for both copper and sulfur. The copper emissions into the room were calculated using the two-point diffusion model. In addition, room emissions were estimated from experimental mass balance and the completely mixed space model by subtracting the duct contribution. The linear relationship between the three model estimates is strong, with the smallest r = 0.797. Although the actual estimates of the models differ, the hourly pattern is consistent among the models. The reason for the differences in magnitude may be because the volume described by the two-point model may actually have a large advective component in the

TABLE XXXVII

EMISSION FACTOR SUMMARY FOR THE THREE PROCESS AREA

Process	Activity Variable	Emission Factor
Copper Plating - Total Copper Emissions		
Smb	in2enter	0.021 mg/in^2
Scms	in2enter	0.021 mg/in^2
Smb	ampmin	0.004 mg/amp*min
Scms	ampmin	0.004 mg/amp*min
Copper Plating - Total Sulfur Emissions		
Smb	in2enter	0.046 mg/in^2
Scms	in2enter	0.060 mg/in^2
Smb	ampmin	0.009 mg/amp*min
Scms	ampmin	0.012 mg/amp*min
Copper Plating - Room Copper Emissions		
Stp	in2plate	0.00004 mg/in^2
Smb	in2plate	0.0002 mg/in^2
Scms	in2plate	0.0001 mg/in^2
Stp	ampmin	0.00001 mg/amp*min
Smb	ampmin	0.00003 mg/amp*min
Scms	ampmin	0.00002 mg/amp*min

TABLE XXXVII (CONTINUED)

Process	Activity Variable	Emission Factor
Degreasing - By Line		
Smb1	basket1 + tank2 + part3	225 g + 669 g + 0.57 g/part
Smb2	basket1 + tank2 + part3	134 g + 1070 g + 1.28 g/part
Smb3	basket1 + tank2 + part3	186 g + 731 g + 1.06 g/part
Sav	basket1 + tank2 + part3	920 g + 828 g + 21.5 g/part
S1	basket1 + tank2 + part3	777 g + 1110 g + 7.78 g/part
Scms	basket1 + travel2 + part3	322 g + 219 g + 1.05 g/part
Degreasing - By Variable		
Smb1	part + manual + squarein	0.20 g/part + 9010 g + 0.22 g/in^2
Smb2	part + manual + squarein	0.20 g/part + 5830 g + 0.40 g/in^2
Smb3	part + manual + squarein	0.18 g/part + 6140 g + 0.22 g/in^2
Scms	part + manual + squarein	0.15 g/part + 7020 g + 0.23 g/in^2

TABLE XXXVII (CONTINUED)

Process	Activity Variable	Emission Factor
Degreasing - By Variable		
Sav	part + auto + manual	0.04 g/part + 992 g + 2830 g
S1	part + auto + manual	0.43 g/part + 1070 g + 3160 g
Wave Soldering		
Sbox	boards	0.708 mg/boards
Sbox	scr/ded	10.7 mg/scr + ded

direction of the duct flow (south to north), and only by diffusion-controlled in the east-west direction.

An advantage of calculating the room emissions with experimental mass balance and the completely mixed space model was that the efficiency of the local exhaust ventilation was calculated. The minimum duct efficiency was 0.92 and the average duct efficiency was 0.97 for both models indicating that the majority of the copper emissions were collected by the local exhaust system.

2. Emission Factors

Emission factor equations calculated for total emissions contained only a constant to account for the unexplained emissions and the in2enter variable. The equations were developed with only 11 points because hour 10 was not included in the regressions. Hour 10 was not included because no activity occurred during that hour, but a high emission rate was estimated. We could not determine the reason for the high emission rate and therefore the point was not in included in the regression analysis. An air agitator on the plating tanks was in operation during the survey which could cause release of copper and sulfur into the room. However, we would expect that effect to be relatively constant providing the concentration of copper and sulfur in the tanks did not vary greatly. Although it might contribute to sometime disrupting diffusion controlled mass flow, i.e., the concentration gradient.

Similarly, emission factors were determined using the emission rates into the room. Hour 10 was included during these regressions. The fact that there was some agreement for room emissions, but not for total emissions might suggest that the sample flow rate for the duct sample in hour 10 might have been off because the both copper and sulfur emission rates were high for this hour. However, this was not obvious from the collected data.

B. Degreasing

1. Emission Rates

a. Hourly Estimates

Hourly emission rates were estimated using experimental mass balance and the completely mixed space model. Three estimates of the mass balance emission rate were calculated because the leakage concentration over the partition was not measured. Although the estimated emission rates varied by as much as a factor of three, the linear relationship between the three estimates was strong, with the smallest r = 0.826. In other words, although the magnitude of the emission rates calculated from the three models differ, the hourly pattern is consistent among the models.

A check of the emission rate estimates from the two models was done by calculating an emission rate based on the solvent inventory. The resulting emission rate was 624 g/hr which was between the completely mixed space model average emission rate (393 g/hr) and the mass balance average emission rates (703 -

977 g/hr). The agreement of these estimates indicates that the models are accurately estimating the TCA emissions.

b. Ten-Minute Estimates

The average ten-minute emission rates were approximately four times the average hourly completely mixed space model emission rate and approximately 1 1/2 - 2 times the average hourly mass balance emission rates. The difference between hourly and ten-minute estimates could be due to the adjustments made to the Miran concentrations. As noted previously, the Mirans measured higher TCA concentrations than the charcoal tubes at the same sampling locations. In addition, although two adjustments were made because a relationship existed, neither relationship was perfect ($r^2 < 1.0$). Therefore each time an adjustment was made more uncertainty was added to the result. However, without the room adjustment the emissions were often negative.

2. Emission Factors

a. By Line

The hourly and ten-minute emission rates were used as the dependent variable in multiple regression analysis to calculate emission factors with the activity variables separated by degreasing line. This method was used to determine the fractional contribution of each line to the total emissions which in turn could identify which line needed to be controlled more. The activity variables selected were basket1, tank2, and part3. These three variables best described emissions by having the largest coefficient of determination, r^2, and the smallest statistical significance, p, of any of the seven activity variables that were included in the analysis, without any negative coefficients. These equations did not contain a constant because the objective of this part of the analysis was to determine the fractional contribution of each line to the total emissions.

The emission factor equations for each emission rate estimate were used to calculate the fractional contribution of each line to total emissions. These results suggest that line 2 contributed the majority of the total emissions (63 %) and that, based on the emission factor equations, the fraction of time the degreasing tank in line 2 was uncovered was the best predictor. At the time of the study, the degreasing tank in line 2 was an older model than the degreasing tanks in lines 1 and 3. Therefore it is reasonable that the emissions from line 2 could have been greater than the emissions from the other two lines. Since this study the degreasing tank in line 2 has been replaced by a newer model.

b. By Variable

To determine the effect of total activity on the estimated emissions, emission factors were again calculated, but using the overall activity from all three lines. With the activity variables summed, the emission factor equations could not contain the same independent variables for both the hourly estimates and ten-minute estimates because of negative coefficients. However, both the hourly estimates and the ten-minute estimates could support three independent variables with no negative coefficients. The hourly emission factor equations better predicted the estimated emission rates than the ten-minute emission factor equations because the coefficients of determination, r^2, are larger.

C. Wave Soldering

1. Emission Rates

a. Box Model

Total room emissions were estimated for the wave soldering area using the box model because of the measured advective flow along the wavelines (Figure 11) and the measured concentration of the recirculation air (sampling location J), upwind of the wavelines. Two sampling hours (6 and 12) resulted in negative emission rates because the upwind concentration measured at the recirculation air was greater than the average concentration in the box. Interestingly, both negative results occurred during the final sampling hour each day possibly because the activity decreased during this hour each day and affected the area concentrations downwind; but there was probably a lag for the upwind value. If the upwind concentration was not used in the calculations for the emission rates, the relationships with the source activities produced negative coefficients and therefore did not make physical sense.

b. Receptor Modeling

Eight receptor points were analyzed to determine the contribution from each of three possible sources to the measured lead concentration. The three sources included the duct concentrations from each of the three wavelines. In addition, the concentrations from wavelines 1 and 2 were combined because the same machine model was used for both lines. Line 3 was a different, and older, model. Two source combinations were selected to not only describe the lead concentration at the receptor point, but also to differentiate the fractional contribution of each line to that measured concentration. The fraction of lead measured at the receptor points explained by the equation $Y = C + FI$ ranged from 0.026 to 1.898 and the fraction of lead measured at the receptor points explained by the equation $Y = C + F + I$ ranged from 0.037 to 1.505. No apparent pattern was noted at any of the receptor points.

3. Emission Factors

a. Box Model

Only single activity variables could be included in the emission factor equations without a negative coefficient resulting. The total number of boards and the total number of scrapings and dedrossings appeared to be related to the emission rates. Each variable was a reasonable explanation of the emissions because total boards was a measure of throughput and total scrapings and dedrossings was a measure of the cover openings.

b. Receptor Modeling

The lead contribution at receptor points g and h (line 1) appears to be most related to the scrapings and dedrossings from line 2. This made physical sense because the receptor points were located where they would not be affected by emissions from line 1 from the scrapings and dedrossings because of the direction which the hood on line 1 opened, but could be affected by hood openings on line 2. The lead contribution at receptor points d and e (line 2) appears to be most related to the scrapings and dedrossings from line 2. The placement of the samples were locations which could be affected by emissions from line 2 when the hood was opened for scrapings and dedrossings for this line. The lead contribution at receptor points a and b (line 3) appears to be most related to the total hood openings or the scrapings and dedrossings from line 3. The placement of the samples were locations which could be affected by emissions from line 3, but not from the other two lines. The recirculation air (receptor point J) and the supply air (receptor point k) were much less affected by any individual line than were the receptor points close to each line.

V. CONCLUSIONS

1. Estimates of total emissions for copper and sulfur and estimates of emissions into the room for copper showed agreement between the models for the copper plating line.

2. Three separate source activities from the copper plating line were found to be related to emissions, including in2enter (total square inches of boards entering the plating baths each hour), in2plate (total square inches of boards being plated each hour), and ampmin (an estimate of effective energy - the product of the current of the plating bath upon entry and the total time in the plating bath).

3. Agreement between the average emission rates calculated from experimental mass balance and the completely mixed space model with the emission rate based on the solvent inventory from the degreasing process area.

4. The contribution from each line to emissions in the degreasing process area could be separated out using source activities. Line 1 contributed 25 percent of emissions, line 2 contributed 63 percent of emissions, and line 3 contributed 12 percent of emissions. Line 2 was the oldest and possibly the least well controlled line.

5. Overall emission factor equations were also developed for the degreasing process area which included the total number of parts each hour, the fraction of time each hour a manual degreasing cycle was used, and the total square inches of parts degreased each hour.

6. For all eight receptor points in the wave soldering area, the total lead and tin contributions for the three lines combined showed agreement with the measured lead and tin concentrations.

7. The lead contributions from each line for the wave soldering area at the six receptor points along the lines showed agreement with the line activities.

8. The contribution of each line to the average measured lead concentrations for the wave soldering area could be determined using receptor modeling. Line 1 contributed 28 percent, line 2 contributed 23 percent, and line 3 contributed 25 percent. Line 3 was the oldest and possibly the least well controlled line.

VI. RECOMMENDATIONS FOR FURTHER RESEARCH

1. Additional sampling locations along the copper plating line farther from the source should be evaluated so that a more complete description of room emissions based on the two-point diffusion model could be obtained.

2. Follow-up sampling should be conducted in the degreasing process area to determine the effect of replacing degreasing tank in line 2.

3. Under laboratory conditions, the relationship between the Mirans and the charcoal tube concentrations should be studied fully.

4. In the wave soldering area, additional analysis of the data for the tin contribution to the receptor points.

5. The possibility that the air supply in the wave soldering area could be a source should be studied since measurable amounts of lead and tin were found at this location.

APPENDICES

TABLE XXXVIII

HOURLY ACTIVITY VARIABLES FOR THE COPPER PLATING LINE

Hour	Average Racksize	Total Boards	Average Current	Average Temp	Plattank Fraction	Total In2enter	Total In2plate	Total Ampmin
1	55.2	171	27.5	93.8	0.075	387	387	1970
2	64.0	469	24.7	82.4	0.815	938	1320	4090
3	64.0	407	24.4	83.0	0.948	814	1290	4100
4	64.0	60	24.0	83.0	0.240	120	478	576
5	64.0	411	24.4	83.6	0.558	822	822	4100
6	64.0	517	24.4	83.7	0.918	1030	1370	5280
7	67.0	256	32.0	80.5	0.432	549	549	3070
8	52.0	128	49.7	81.3	0.128	669	669	3580
9	66.2	590	22.8	83.4	0.908	1080	1750	4920
10	0.0	0	0.0	0.0	0.165	0	337	0
11	65.1	410	24.6	83.7	0.518	972	972	4130
12	42.0	302	50.1	83.9	0.860	1620	2260	8424

APPENDIX A (CONTINUED)

TABLE XXXIX

HOURLY ELEMENTAL CONCENTRATION FROM THE COPPER PLATING LINE BY SAMPLING LOCATION[a] ($\mu g/m^3$)

Hour 1	A Near	B Mid	C Far	D Duct	E Hall
Silicon	0.280	0.043	0.105	0.621	0.075
Chlorine	*	0.351	*	*	0.189
Potassium	-	0.175	-	*	-
Calcium	-	-	-	-	0.232
Titanium	0.029	0.016	0.024	0.012	0.006
Vanadium	-	-	-	0.020	0.028
Chromium	0.100	0.024	0.001	0.047	*
Manganese	-	-	*	-	0.008
Iron	0.960	0.116	0.083	0.589	0.273
Nickel	0.014	*	*	0.001	0.002
Zinc	0.021	0.038	0.117	0.006	0.210
Gallium	-	-	-	-	-
Bromine	3.048	*	0.043	*	*
Strontium	-	-	-	-	-
Zirconium	-	-	0.029	-	-
Molybdenum	-	-	0.041	-	-

[a] sampling locations are shown in Figure 5

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 2	A Near	B Mid	C Far	D Duct	E Hall
Silicon	2.120	0.309	0.997	0.686	1.230
Chlorine	*	0.080	0.285	0.219	*
Potassium	-	-	*	-	-
Calcium	-	-	-	-	0.394
Titanium	0.032	*	0.015	0.048	0.022
Vanadium	*	-	0.019	-	-
Chromium	0.077	0.054	0.157	0.029	0.005
Manganese	-	-	*	-	*
Iron	0.192	0.013	0.496	0.045	0.355
Nickel	0.009	*	0.021	0.002	0.009
Zinc	0.090	0.098	0.099	0.021	0.024
Gallium	0.012	-	-	-	-
Bromine	0.639	1.077	*	0.980	*
Strontium	-	-	-	-	-
Zirconium	-	-	-	-	-
Molybdenum	*	-	-	-	-

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 3	A Near	B Mid	C Far	D Duct	E Hall
Silicon	1.199	0.894	1.051	0.163	0.290
Chlorine	0.228	0.059	0.114	0.004	*
Potassium	*	-	-	-	*
Calcium	-	-	-	-	-
Titanium	*	0.148	*	0.025	0.091
Vanadium	0.001	0.074	0.025	*	0.005
Chromium	0.148	0.008	0.040	0.014	0.004
Manganese	0.006	*	-	-	-
Iron	0.403	0.450	0.322	0.173	0.095
Nickel	0.001	0.006	0.003	*	0.003
Zinc	0.049	0.115	0.015	0.100	0.038
Gallium	-	-	-	-	-
Bromine	3.965	*	*	1.988	*
Strontium	-	-	-	-	-
Zirconium	-	-	-	-	-
Molybdenum	*	0.269	-	-	-

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 4	A Near	B Mid	C Far	D Duct	E Hall
Silicon	0.467	1.016	1.018	0.521	0.657
Chlorine	*	0.077	*	*	*
Potassium	-	-	*	*	-
Calcium	-	-	-	-	0.506
Titanium	*	0.034	0.018	0.014	*
Vanadium	0.013	0.001	0.001	0.004	0.021
Chromium	0.048	0.021	0.030	0.037	0.025
Manganese	0.005	*	0.018	-	-
Iron	0.029	0.395	0.954	0.139	0.153
Nickel	*	0.003	0.006	0.002	0.004
Zinc	0.030	0.116	0.076	0.146	0.034
Gallium	-	-	-	0.005	-
Bromine	1.551	*	*	*	*
Strontium	-	-	-	-	-
Zirconium	-	-	-	-	-
Molybdenum	-	-	-	0.002	-

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 5	A Near	B Mid	C Far	D Duct	E Hall
Silicon	0.597	1.393	0.470	*	0.677
Chlorine	0.073	0.021	*	0.187	*
Potassium	-	-	-	-	-
Calcium	-	-	-	-	-
Titanium	-	*	0.036	0.023	0.044
Vanadium	0.043	-	0.001	0.020	0.028
Chromium	0.011	0.045	0.040	0.023	0.010
Manganese	-	0.001	-	-	0.006
Iron	0.078	0.475	0.072	0.593	0.313
Nickel	0.002	*	0.004	0.002	0.003
Zinc	0.084	0.072	0.030	0.939	0.005
Gallium	-	-	-	-	-
Bromine	*	*	*	*	*
Strontium	-	-	-	-	0.012
Zirconium	-	-	-	-	-
Molybdenum	-	-	-	-	-

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 6	A Near	B Mid	C Far	D Duct	E Hall
Silicon	1.202	0.433	0.448	0.077	0.648
Chlorine	0.210	*	*	*	*
Potassium	-	*	*	-	-
Calcium	-	-	-	-	-
Titanium	0.004	0.061	0.010	*	*
Vanadium	0.046	*	0.030	0.005	0.066
Chromium	0.032	0.051	0.042	0.060	0.025
Manganese	-	0.011	*	-	-
Iron	0.167	0.286	0.251	0.145	0.150
Nickel	0.001	*	0.001	0.017	0.001
Zinc	0.051	0.083	0.093	0.026	0.069
Gallium	-	-	-	-	-
Bromine	*	1.637	*	1.087	*
Strontium	0.028	-	-	-	-
Zirconium	-	-	-	-	-
Molybdenum	-	-	-	-	-

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 7	A Near	B Mid	C Far	D Duct	E Hall
Silicon	0.069	0.294	0.562	*	0.052
Chlorine	0.364	0.268	0.268	0.203	0.720
Potassium	-	-	-	-	-
Calcium	-	-	-	-	-
Titanium	0.037	*	-	0.009	*
Vanadium	*	-	0.001	-	0.016
Chromium	0.036	0.006	*	*	0.022
Manganese	-	*	-	-	0.008
Iron	0.383	0.123	0.337	1.148	0.338
Nickel	0.014	0.008	0.001	*	0.028
Zinc	0.100	0.100	*	0.013	0.064
Gallium	-	-	-	-	-
Bromine	*	1.583	1.332	*	4.749
Strontium	0.023	-	0.011	-	-
Zirconium	-	-	-	-	-
Molybdenum	-	-	-	-	-

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 8	A Near	B Mid	C Far	D Duct	E Hall
Silicon	0.280	0.153	0.733	0.575	0.955
Chlorine	0.100	0.358	0.019	0.625	0.048
Potassium	-	0.126	-	-	-
Calcium	0.262	0.607	-	0.281	1.139
Titanium	0.057	0.011	*	*	*
Vanadium	*	-	0.041	-	*
Chromium	0.055	*	*	0.004	0.006
Manganese	-	0.011	-	*	0.011
Iron	0.220	0.669	0.405	0.697	0.550
Nickel	0.009	0.004	0.001	0.020	0.001
Zinc	0.057	0.072	0.229	0.136	0.109
Gallium	-	-	-	-	-
Bromine	1.204	*	3.806	*	0.007
Strontium	-	-	-	-	-
Zirconium	-	-	-	-	-
Molybdenum	-	-	-	*	-

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 9	A Near	B Mid	C Far	D Duct	E Hall
Silicon	0.819	0.843	0.087	0.865	1.245
Chlorine	0.704	0.272	0.071	0.297	2.893
Potassium	-	-	-	-	0.112
Calcium	0.778	0.373	-	-	3.079
Titanium	*	0.033	-	0.088	-
Vanadium	-	0.037	*	0.001	-
Chromium	*	*	*	*	*
Manganese	0.051	0.010	-	0.011	0.008
Iron	0.283	0.228	0.299	0.248	0.427
Nickel	0.016	0.009	0.006	0.004	0.001
Zinc	0.049	0.134	0.073	0.117	0.073
Gallium	-	-	-	-	-
Bromine	*	*	*	*	*
Strontium	-	-	-	-	-
Zirconium	-	-	-	-	-
Molybdenum	-	-	-	-	-

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 10	A Near	B Mid	C Far	D Duct	E Hall
Silicon	0.022	0.536	0.609	0.702	0.600
Chlorine	0.156	0.183	*	0.589	0.453
Potassium	-	-	-	-	0.081
Calcium	-	-	-	-	-
Titanium	*	-	0.025	*	-
Vanadium	-	-	*	-	0.037
Chromium	0.041	0.030	0.001	0.046	*
Manganese	0.009	-	-	-	-
Iron	0.030	0.165	0.242	0.236	0.116
Nickel	0.014	0.010	*	0.023	0.001
Zinc	*	0.032	0.046	0.187	0.094
Gallium	-	-	-	-	-
Bromine	1.123	5.676	2.444	5.794	0.565
Strontium	-	0.015	-	-	-
Zirconium	-	-	-	0.040	-
Molybdenum	-	-	0.020	-	0.012

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 11	A Near	B Mid	C Far	D Duct	E Hall
Silicon	0.714	0.940	1.182	0.149	0.645
Chlorine	0.731	0.691	0.357	0.623	0.636
Potassium	-	0.070	-	-	*
Calcium	0.253	-	-	-	0.382
Titanium	0.072	0.119	*	*	*
Vanadium	-	-	-	*	-
Chromium	*	*	0.026	0.005	*
Manganese	-	0.001	0.002	-	-
Iron	0.139	0.168	0.181	0.313	0.122
Nickel	0.001	*	0.001	0.009	0.008
Zinc	0.038	0.092	0.096	0.177	0.034
Gallium	-	-	-	-	-
Bromine	5.775	0.324	2.506	0.513	3.226
Strontium	-	-	-	-	-
Zirconium	-	-	-	0.014	0.017
Molybdenum	-	*	-	-	-

- not detected

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APPENDIX A (CONTINUED)

TABLE XXXIX (CONTINUED)

Hour 12	A Near	B Mid	C Far	D Duct	E Hall
Silicon	0.970	0.571	1.117	0.794	1.225
Chlorine	0.138	0.386	0.530	0.214	1.001
Potassium	-	-	0.147	-	0.139
Calcium	-	0.169	0.591	-	3.765
Titanium	*	*	*	*	0.071
Vanadium	0.044	-	0.010	-	0.028
Chromium	*	0.018	0.026	*	0.012
Manganese	-	-	*	-	0.009
Iron	0.258	0.344	0.315	0.370	0.542
Nickel	0.005	0.001	0.001	0.011	*
Zinc	0.038	0.036	0.061	0.213	0.227
Gallium	-	-	-	-	-
Bromine	4.689	6.280	3.038	0.168	6.190
Strontium	-	0.032	-	-	-
Zirconium	-	-	-	-	-
Molybdenum	-	-	-	0.092	-

- not detected

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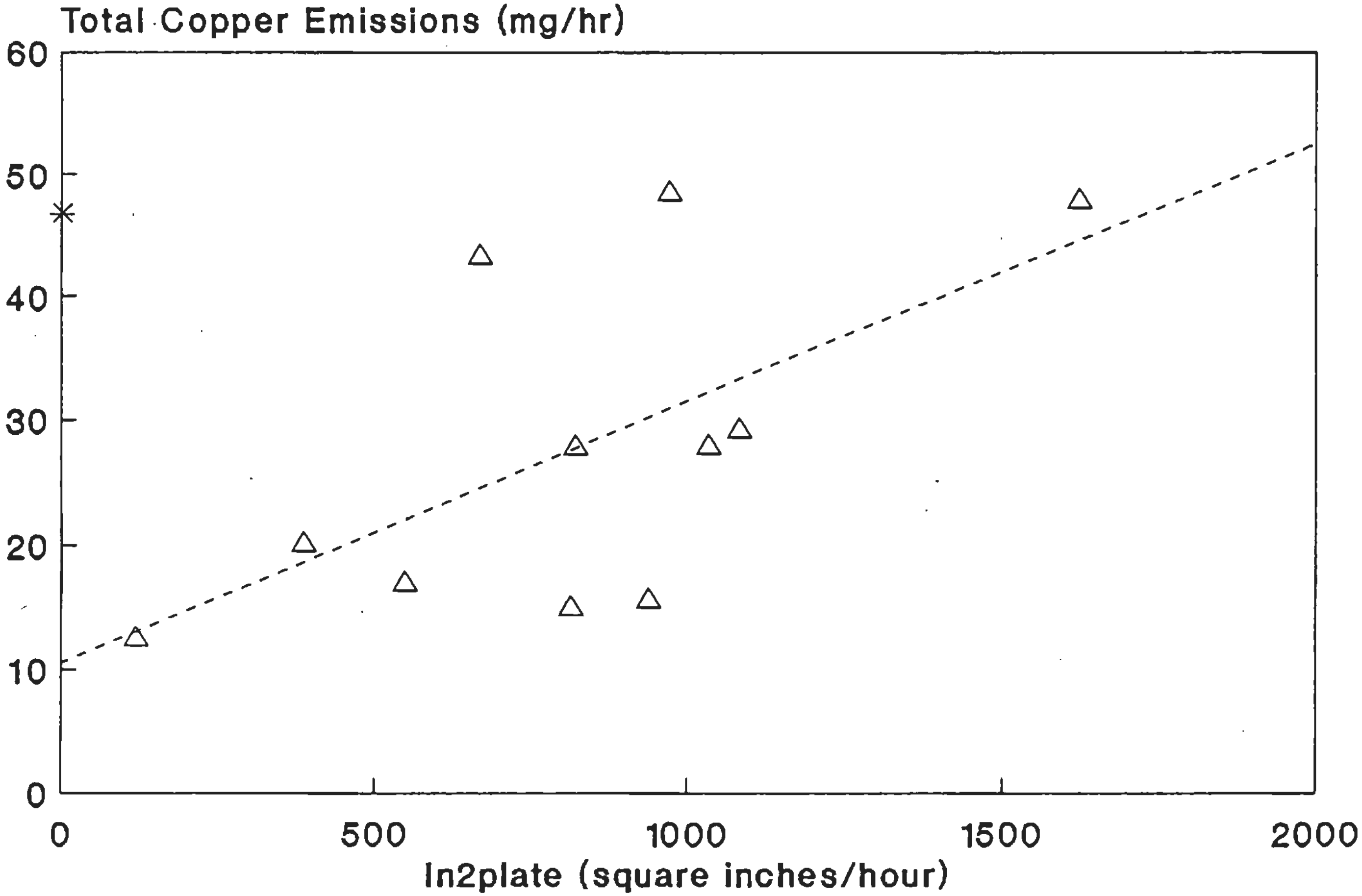

Figure 46. Mass balance total copper emissions versus the in2plate activity variable for the copper plating line.

Emission factor = 0.00902 mg/in^2, n = 12

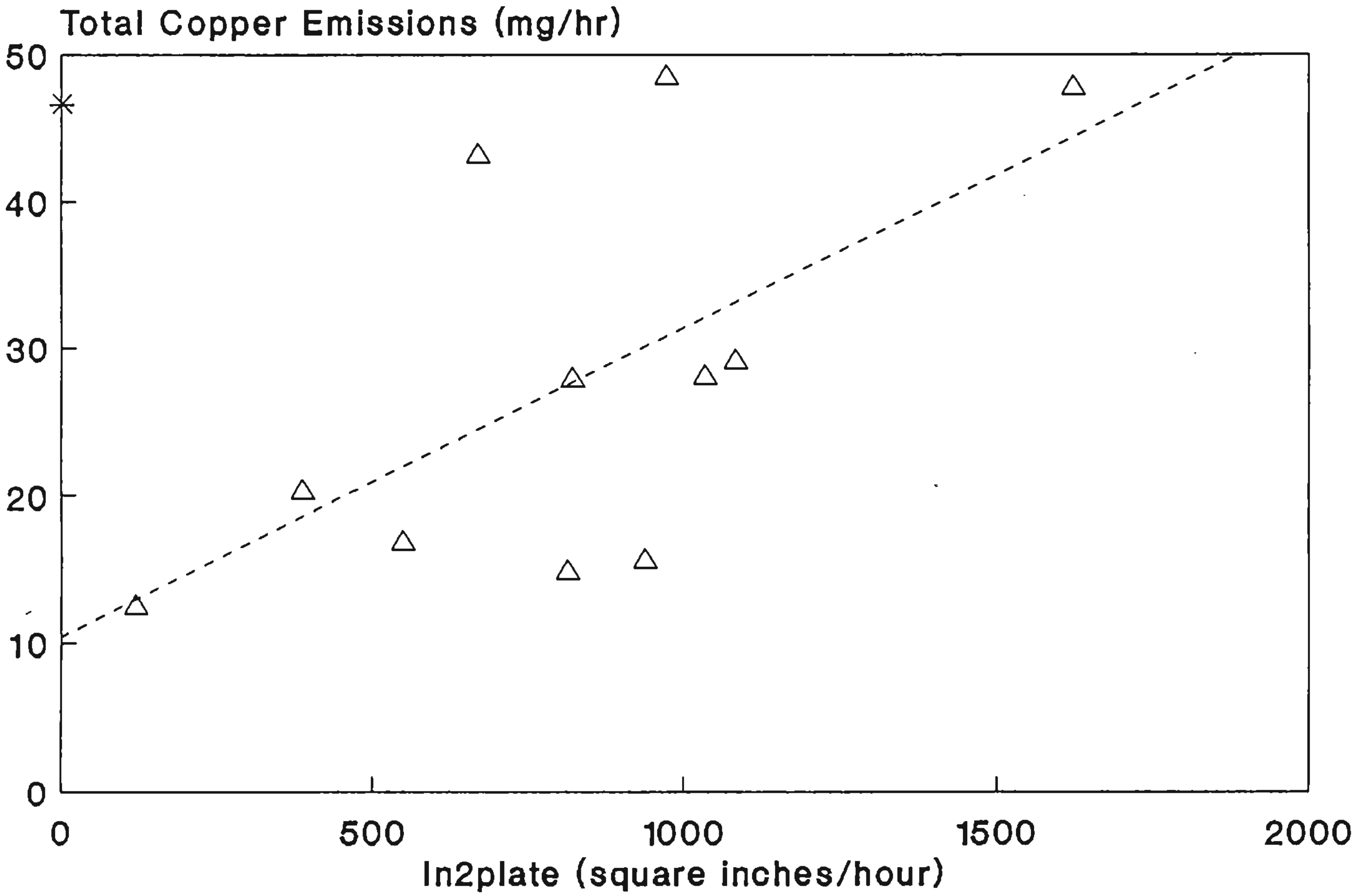

Figure 47. Completely mixed space model total copper emissions versus the in2plate activity variable for the copper plating line.

Emission factor = 0.00897 mg/in^2, n = 12

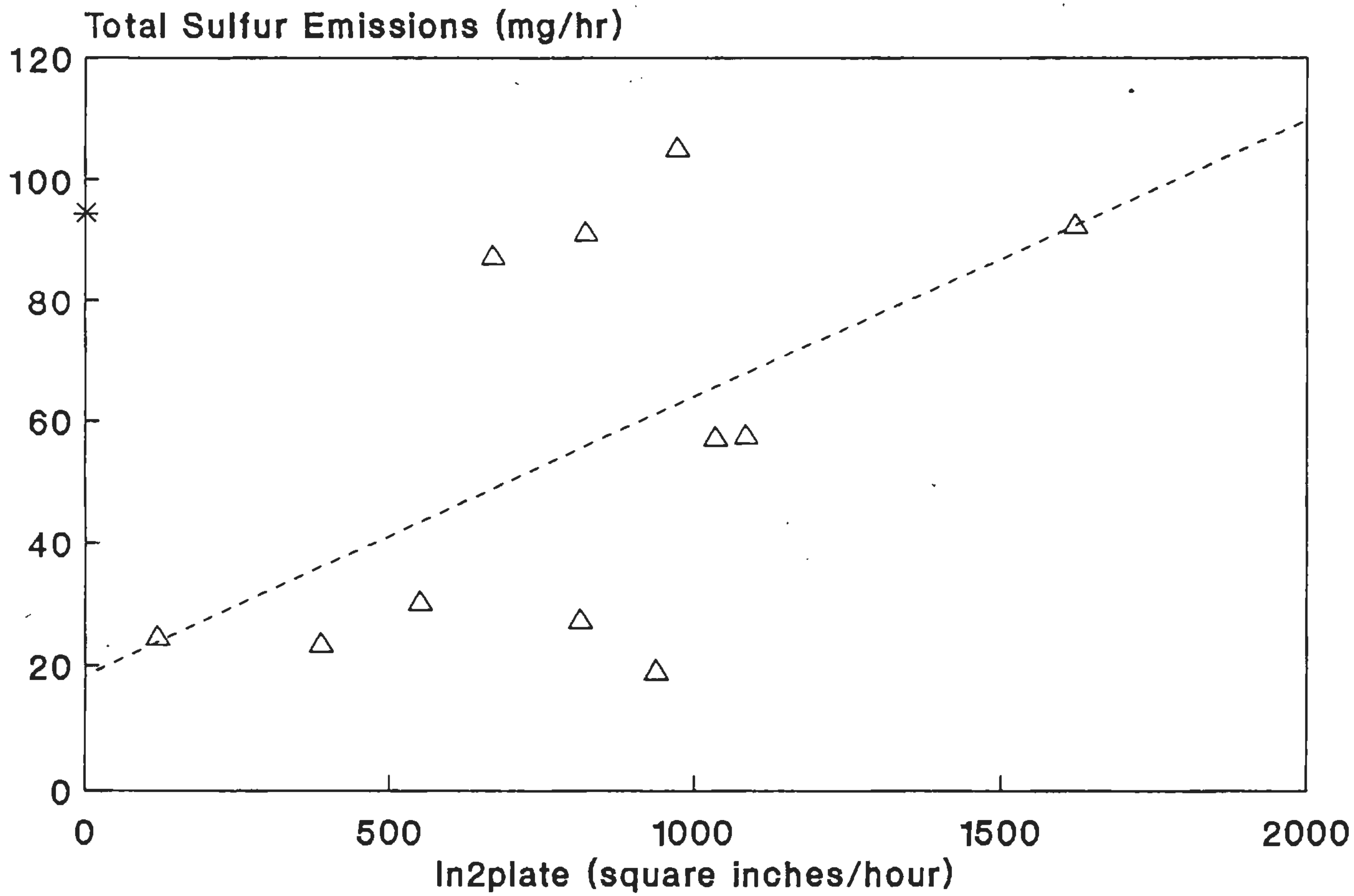

Figure 48. Mass balance total sulfur emissions versus the in2plate activity variable for the copper plating line.

Emission factor = 0.0169 mg/in^2, n = 12

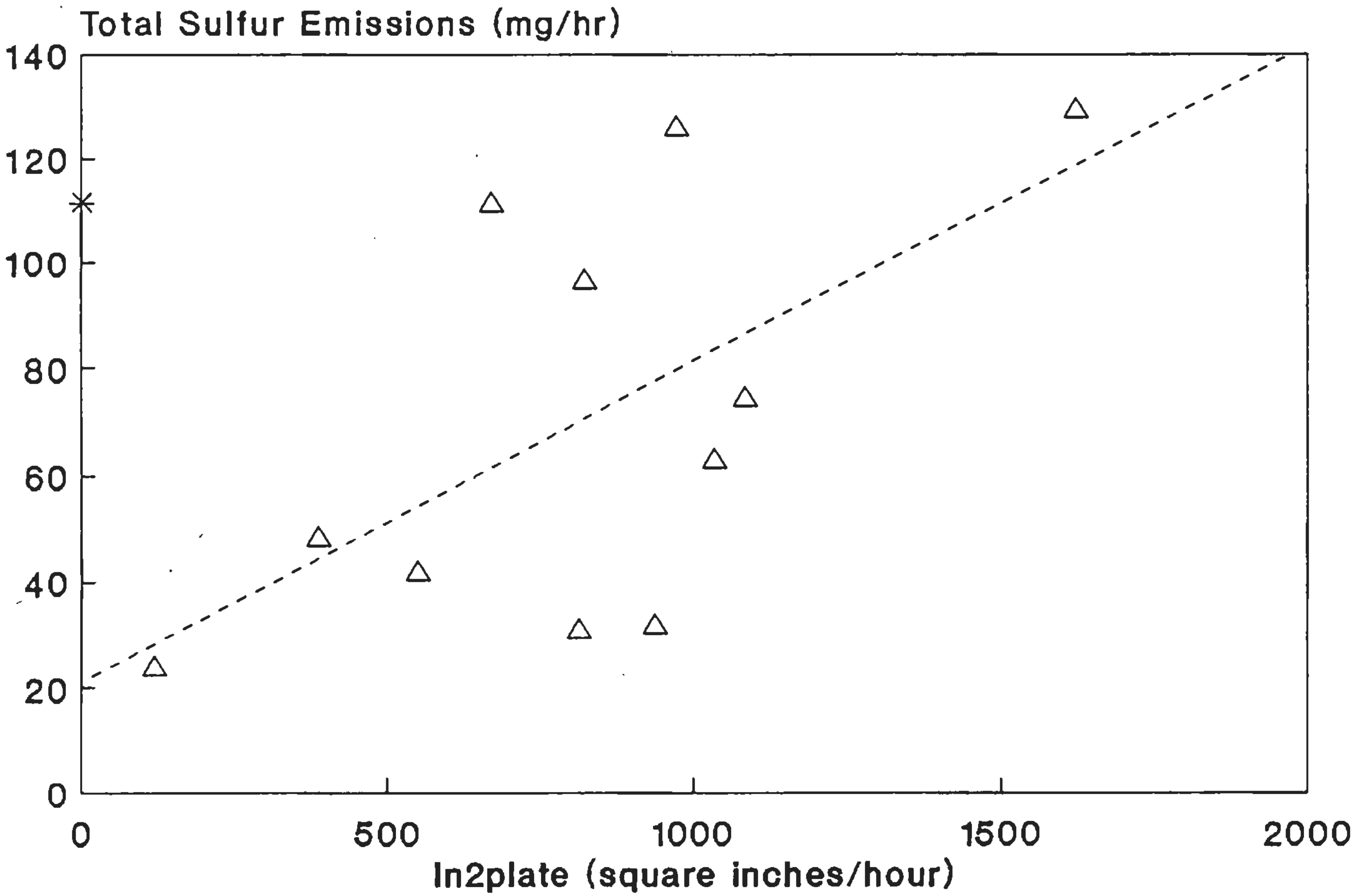

Figure 49. Completely mixed space model total sulfur emissions versus the in2plate activity variable for the copper plating line.

Emission factor = 0.0239 mg/in^2, n = 12

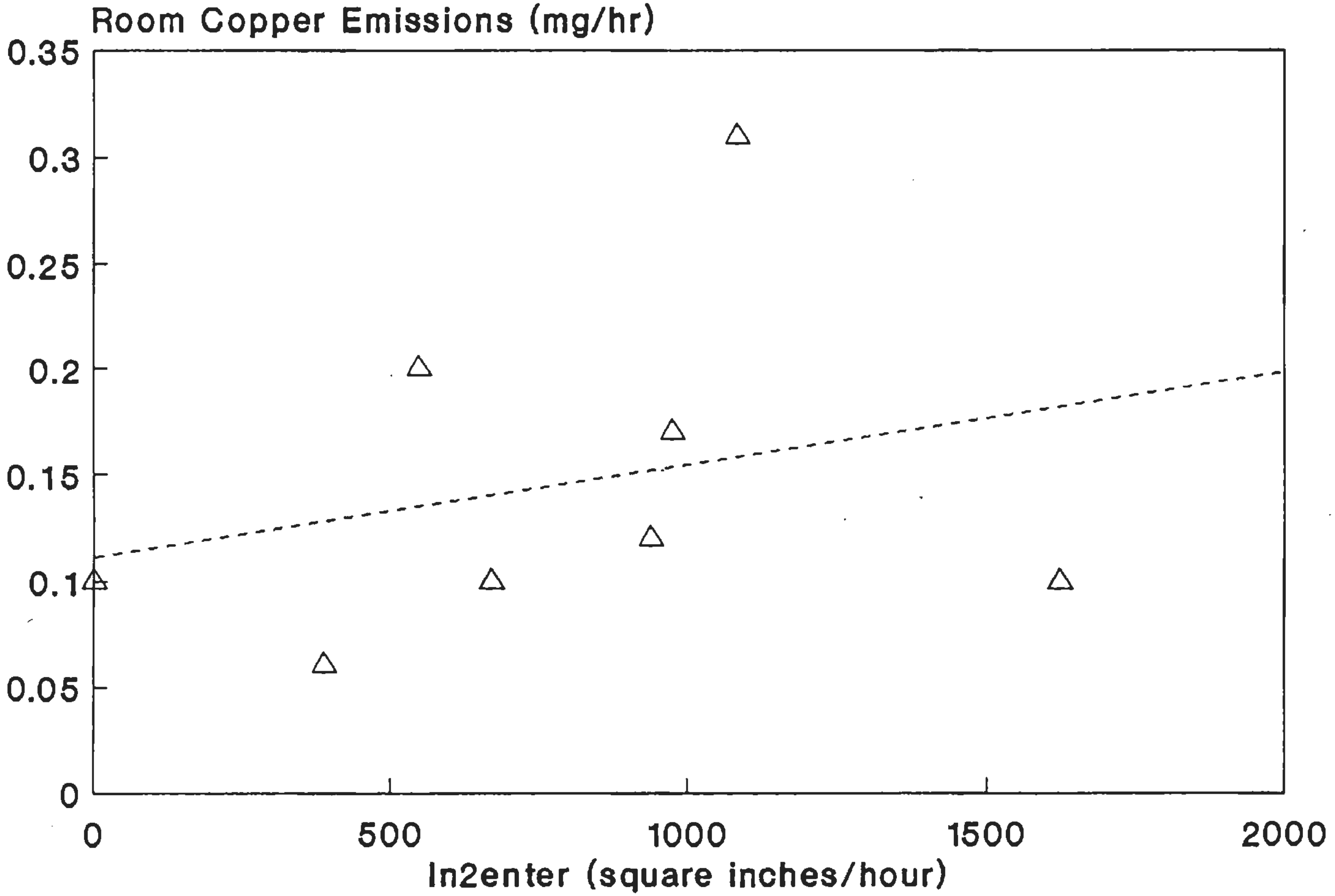

Figure 50. Two-point diffusion model copper emissions into the room versus the in2enter activity variable for the copper plating line.

Emission factor = $4.3*10^{-5}$ mg/in^3, n = 8

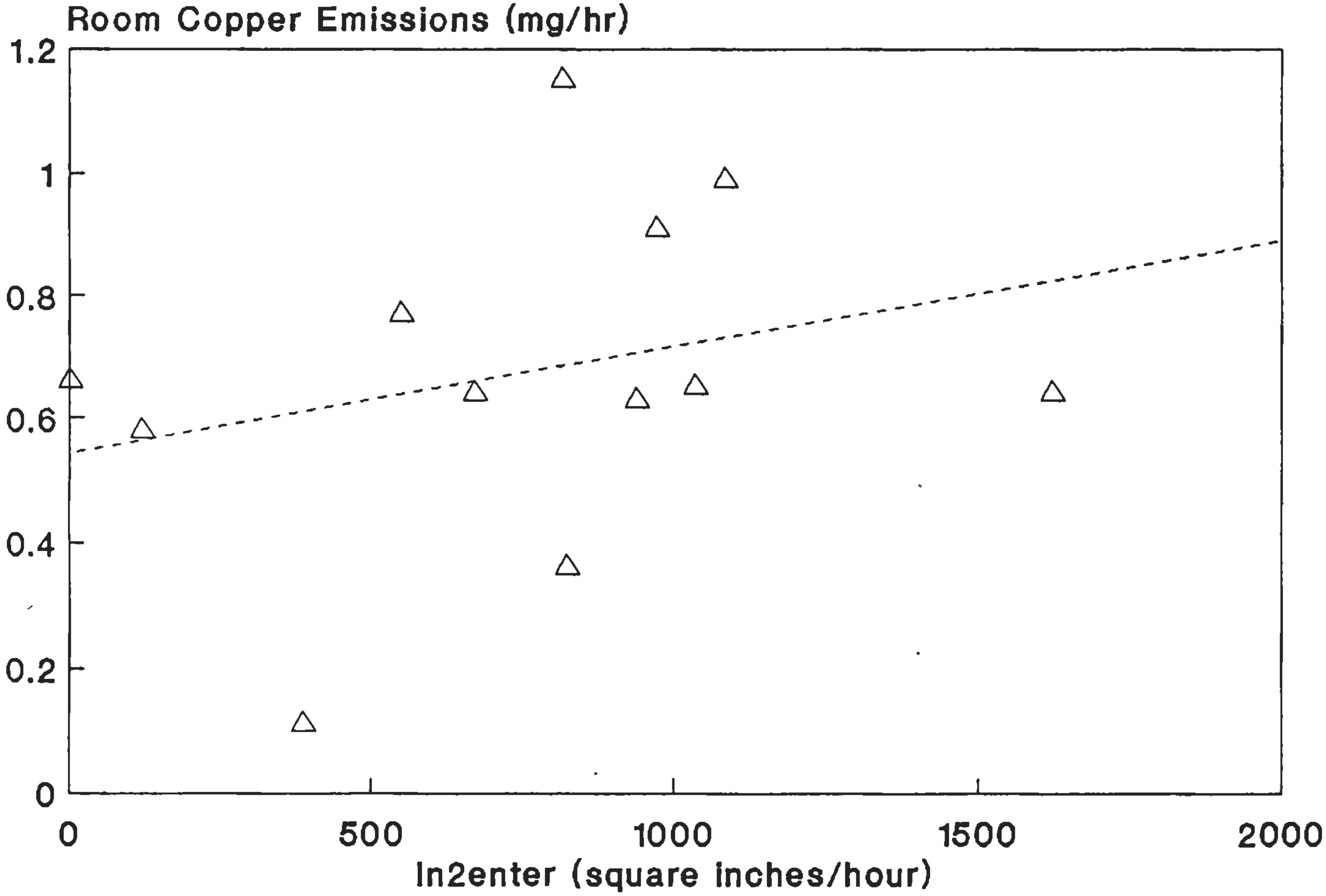

Figure 51. Mass balance copper emissions into the room versus the in2enter activity variable for the copper plating line.

Emission factor = $1.73*10^{-4}$ mg/in^2, n = 12

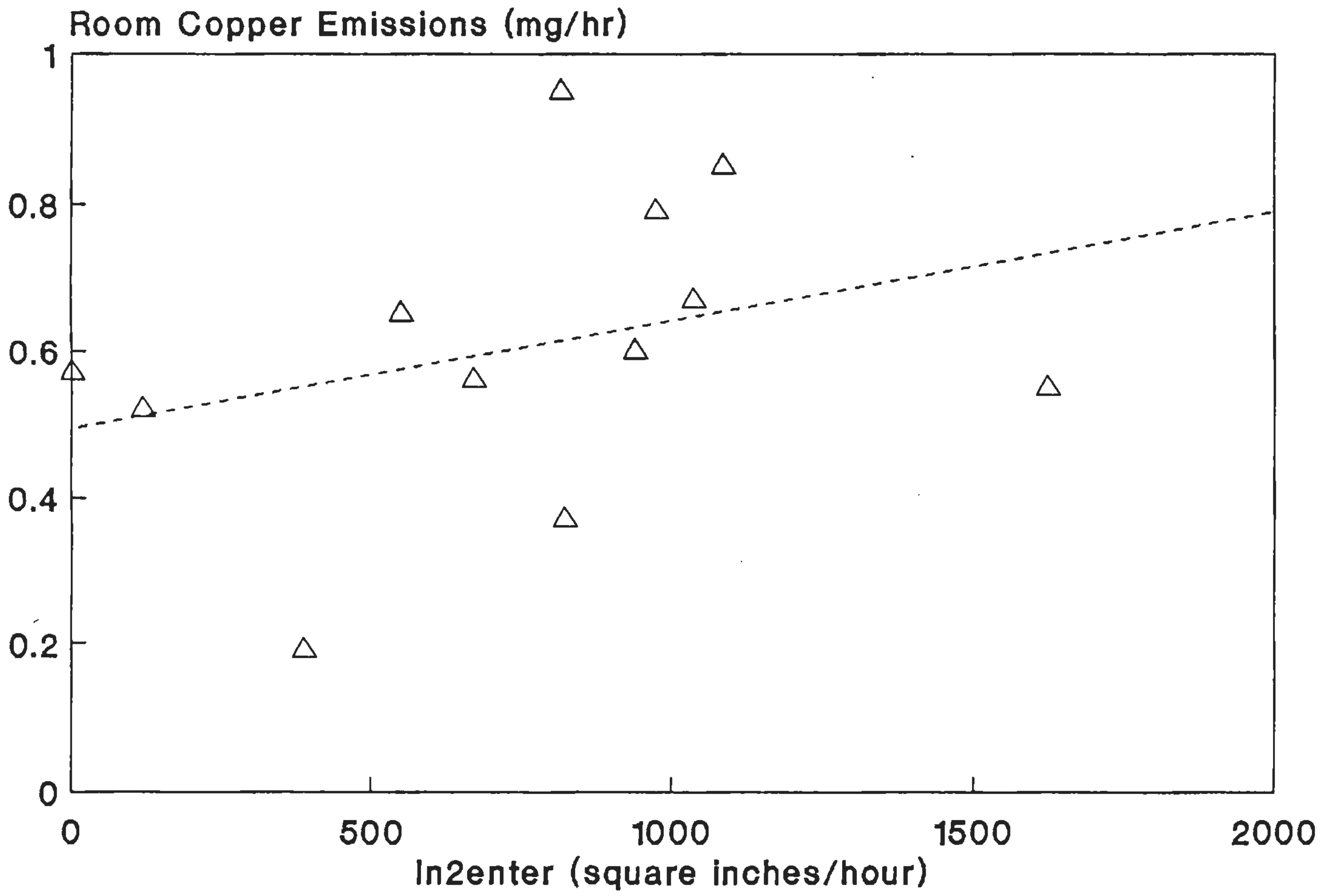

Figure 52. Completely mixed space model copper emissions into the room versus the in2enter activity variable for the copper plating line.

Emission factor = $1.47*10^{-4}$ mg/in^2, n = 12

TABLE XL

HOURLY TOTAL ACTIVITY VARIABLES FOR THE DEGREASING AREA

Hour	Tank	Part	Basket	Auto	Manual	Squarein
1	0.694	83	0.006	0.145	0.021	95.7
2	0.856	499	0.184	0.448	0.035	358
3	1.000	2658	0.366	0.581	0.022	416
4	0.861	438	0.440	0.433	0.032	242
5	0.567	202	0.388	0.259	0.029	80.3
6	0.926	215	0.493	0.366	0.023	907
7	0.896	281	0.272	0.479	0.014	469
8	0.775	108	0.372	0.283	0.035	103
9	1.000	191	0.309	0.319	0.048	389
10	0.857	229	0.385	0.407	0.009	456
11	0.679	86	0.383	0.179	0.033	328
12	0.963	230	0.355	0.473	0.029	472

APPENDIX B (CONTINUED)

TABLE XLI

CROSS-SECTIONAL AREA OF MICROCIRCUITS FOR THE DEGREASING PROCESS AREA

Travel Number	Area (in^2)
0180791B59	0.76
0180700T50	0.081
0180759B10	3.71
0180791B62	3.23
0180796B68	1.28
0180759D21	7.58
TRN4836A	1.20
TRN9867B	0.49
TLF6850A	1.74
TTE6213A	3.76
TRN9868A	0.438
QRN4866A	8.31
TRN7036A	1.20
TRN6777B	1.20
TLF6880A	38.6
SLF4011B	2.60
TLF6830A	2.58
TLE5402B	10.3
TLD9492A	8.75
SLF4061A	1.77
TFN6061A	2.00
8483267P01	1.23

APPENDIX C

TABLE XLII

HOURLY ACTIVITY VARIABLES FOR THE WAVE SOLDERING AREA OVERALL AND BY LINE

Hour	Total Boards	Total Hood Openings	Fraction Open	Total Scrapings and Dedrossings
1	97	17	0.355	5
2	93	12	0.189	1
3	191	18	0.228	6
4	88	12	0.278	1
5	91	16	0.322	4
6	85	11	0.067	1
7	82	9	0.228	3
8	70	15	0.433	3
9	142	14	0.222	0
10	110	13	0.261	5
11	54	11	0.267	1
12	74	21	0.272	3

Hour	Total Boards Line 1	Total Hood Openings Line 1	Fraction Open Line 1	Total Scrapings and Dedrossings Line 1
1	24	5	0.483	3
2	48	7	0.433	1
3	42	7	0.300	0
4	48	4	0.417	1
5	30	6	0.283	2
6	18	7	0.117	1
7	22	3	0.233	1
8	6	4	0.667	1
9	27	6	0.533	0
10	30	5	0.233	3
11	6	1	0.067	1
12	22	9	0.483	2

APPENDIX C (CONTINUED)

TABLE XLII (CONTINUED)

Hour	Total Boards Line 2	Total Hood Openings Line 2	Fraction Open Line 2	Total Scrapings and Dedrossings Line 2
1	26	5	0.367	0
2	2	3	0.083	0
3	46	7	0.217	4
4	33	6	0.367	0
5	31	4	0.383	0
6	42	4	0.083	0
7	5	5	0.433	1
8	13	6	0.100	0
9	45	7	0.133	0
10	11	7	0.517	1
11	30	5	0.133	0
12	50	7	0.133	0

Hour	Total Boards Line 3	Total Hood Openings Line 3	Fraction Open Line 3	Total Scrapings and Dedrossings Line 3
1	47	7	0.217	2
2	43	2	0.050	0
3	103	4	0.167	2
4	7	2	0.050	0
5	30	6	0.300	2
6	25	0	0.000	0
7	55	1	0.017	1
8	51	5	0.533	2
9	70	1	0.000	0
10	69	1	0.033	1
11	18	5	0.600	0
12	2	5	0.200	1

TABLE XLIII

HOURLY ELEMENTAL CONCENTRATIONS FROM THE WAVE SOLDERING AREA BY SAMPLING LOCATION ($\mu g/m^3$)

Hour 1	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	3.47	1.99	-	4.31	-	-	-	-	-	3.61
Silicon	1.40	0.10	0.80	2.00	*	*	*	*	-	1.17
Sulfur	1.51	2.29	-	2.12	1.78	1.36	1.73	2.15	-	1.23
Chlorine	1.95	3.32	26.5	6.34	4.98	38.8	11.2	3.79	34.2	2.97
Potassium	0.49	-	-	-	-	-	-	-	-	-
Calcium	-	-	-	-	-	-	-	-	-	-
Titanium	0.04	*	0.06	*	*	0.06	*	*	*	0.21
Vanadium	-	-	0.08	-	0.08	0.03	0.05	0.09	0.32	0.06
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.03	0.03	-	-	0.05	0.04	-	0.04	0.08	0.05
Iron	0.91	0.49	0.75	0.47	2.72	0.73	1.35	0.43	2.63	0.68
Nickel	0.16	0.20	0.19	0.28	0.22	0.22	0.18	0.27	0.18	0.27
Copper	0.08	*	0.06	0.00	*	0.03	0.01	*	0.11	0.01
Zinc	*	*	*	*	*	*	*	*	*	*
Gallium	-	-	-	-	-	-	-	-	0.04	-
Selenium	-	-	-	-	-	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	-	-	-	0.01	-	0.03	-	0.07	0.06	0.02
Strontium	0.03	0.03	-	0.03	0.01	0.03	0.02	0.03	-	0.01
Yttrium	-	0.06	-	-	0.05	0.08	0.02	-	-	0.03
Zirconium	0.05	0.07	0.08	-	-	0.03	-	-	-	-
Molybdenum	-	0.05	-	0.07	-	0.09	0.03	0.08	-	0.14
Tin	5.51	-	39.9	-	-	42.2	3.00	-	146	-

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 2	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	-	-	-	-	-	-	-	-	-	-
Silicon	*	0.39	*	*	*	-	*	*	-	0.05
Sulfur	2.41	2.45	2.62	2.46	2.21	-	1.70	2.39	0.67	1.34
Chlorine	3.43	7.27	41.1	9.09	6.61	38.9	40.9	10.5	77.4	7.63
Potassium	-	0.40	-	-	-	-	-	-	-	-
Calcium	-	-	-	-	-	-	-	-	-	-
Titanium	0.06	0.15	0.04	0.13	0.05	0.23	*	0.09	*	0.08
Vanadium	0.04	0.09	0.03	0.29	-	0.11	0.05	-	0.09	0.09
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.06	-	0.02	0.06	0.03	0.02	0.05	0.03	0.06	0.05
Iron	0.79	0.72	0.48	0.63	2.46	0.41	1.19	1.32	1.71	0.49
Nickel	0.19	0.26	0.24	0.38	0.24	0.23	0.20	0.25	0.30	0.26
Copper	0.04	0.02	0.03	0.01	0.01	0.01	0.29	0.04	0.12	*
Zinc	*	*	*	*	*	*	*	*	*	*
Gallium	-	-	-	-	-	-	-	-	-	-
Selenium	-	-	-	-	-	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	-	-	0.04	-	-	0.01	-	0.01	0.02	-
Strontium	0.01	-	0.02	-	0.04	0.02	-	0.03	-	0.02
Yttrium	0.03	-	0.02	-	-	-	0.05	0.08	0.10	-
Zirconium	0.03	0.08	-	-	0.02	-	-	0.04	-	0.08
Molybdenum	0.12	-	-	-	-	0.07	0.07	0.15	-	0.08
Tin	-	-	30.0	-	-	29.9	-	-	87.0	-

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 3	A	B	C	D	E	F	G	H	I	J
Magnesium	2.11	-	-	-	-	-	-	-	-	-
Aluminum	2.91	-	-	-	-	-	-	-	-	-
Silicon	1.89	1.03	-	0.46	*	-	*	*	2.43	*
Sulfur	2.22	0.47	1.48	1.25	2.56	-	1.03	0.90	2.12	1.25
Chlorine	3.52	8.86	72.4	17.0	9.80	47.3	13.3	6.34	81.4	9.09
Potassium	-	-	-	-	-	-	-	-	-	0.51
Calcium	-	-	-	-	-	-	-	-	2.36	-
Titanium	0.07	0.09	*	0.15	0.01	0.10	0.02	0.04	0.03	*
Vanadium	-	0.09	0.12	-	-	0.10	-	0.02	-	0.03
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.05	0.05	0.01	0.02	0.05	0.03	-	0.01	0.45	-
Iron	0.97	1.35	0.82	0.61	0.67	0.31	0.19	1.47	55.8	1.01
Nickel	0.27	0.26	0.30	0.21	0.22	0.20	0.06	0.07	0.22	0.26
Copper	0.05	0.02	0.08	0.03	0.11	0.01	0.01	0.02	1.27	0.13
Zinc	*	*	*	*	*	*	*	*	9.74	*
Gallium	-	-	-	-	-	-	-	-	-	-
Selenium	-	-	-	-	-	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	0.04	-	-	-	-	-	0.01	-	0.08	0.03
Strontium	-	-	-	0.01	-	-	-	0.01	0.06	0.04
Yttrium	-	0.05	-	-	-	0.08	-	0.02	-	0.14
Zirconium	0.06	-	-	0.03	0.05	0.03	0.01	0.04	-	-
Molybdenum	0.11	0.14	0.05	0.04	-	-	0.01	0.03	0.28	0.27
Tin	-	1.51	24.6	7.37	83.8	39.7	7.62	11.2	61.4	-

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 4	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	-	-	-	-	-	-	-	-	-	-
Silicon	0.16	*	0.25	*	*	0.11	0.12	*	-	0.25
Sulfur	1.57	1.38	2.19	0.52	0.72	0.36	-	0.68	-	0.97
Chlorine	2.37	1.83	11.0	2.15	0.35	0.81	3.14	0.99	14.4	0.94
Potassium	-	-	-	-	0.11	-	-	-	-	-
Calcium	-	-	-	-	-	-	0.31	1.35	0.96	-
Titanium	0.04	*	*	0.07	*	0.07	*	-	*	*
Vanadium	0.03	0.05	0.16	0.04	-	0.03	-	-	-	-
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.03	0.03	0.02	0.02	0.01	0.01	0.03	0.02	0.05	0.02
Iron	0.85	0.92	0.64	0.60	0.82	0.32	1.86	1.51	2.26	0.35
Nickel	0.14	0.16	0.23	0.11	0.09	0.10	0.07	0.06	0.06	0.13
Copper	0.01	0.03	0.01	*	0.01	0.01	0.03	0.02	0.07	0.01
Zinc	*	*	*	*	*	*	*	*	*	*
Gallium	-	-	-	-	-	-	-	0.01	-	-
Selenium	-	-	-	-	-	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	-	0.02	-	0.01	0.01	-	0.01	0.01	-	-
Strontium	0.02	-	-	-	-	-	0.01	0.02	-	0.01
Yttrium	-	0.05	0.01	0.01	-	0.02	0.02	-	0.03	-
Zirconium	0.03	-	0.07	0.04	-	0.03	-	-	-	0.05
Molybdenum	0.02	-	-	-	-	0.05	-	0.09	-	0.08
Tin	-	-	17.5	1.65	3.63	-	59.4	43.9	84.7	-

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 5	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	2.18	-	-	-	-	-
Aluminum	-	-	-	1.53	3.19	-	-	-	-	-
Silicon	*	*	0.23	0.81	1.47	-	*	0.37	-	*
Sulfur	1.89	2.59	1.04	1.49	1.94	-	1.37	1.02	4.78	1.21
Chlorine	1.99	1.75	7.64	2.75	4.19	70.4	13.0	5.55	99.2	7.32
Potassium	0.41	-	0.86	0.32	-	-	-	0.31	-	-
Calcium	-	-	-	-	-	-	-	-	7.07	-
Titanium	0.05	0.18	*	0.01	0.01	*	*	0.01	-	0.15
Vanadium	0.07	0.09	0.07	0.01	-	-	0.01	-	0.17	0.02
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.01	0.03	0.03	0.02	0.01	-	0.02	0.02	0.03	0.04
Iron	0.77	0.87	1.31	1.26	0.80	0.72	0.87	1.17	1.70	0.65
Nickel	0.16	0.25	0.21	0.12	0.11	0.10	0.08	0.11	0.06	0.24
Copper	0.03	0.01	0.02	0.01	0.01	0.21	0.03	0.03	0.23	0.01
Zinc	*	*	*	*	*	*	*	*	*	*
Gallium	-	-	-	-	-	0.01	-	-	0.05	-
Selenium	-	-	-	-	-	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	0.01	0.05	0.02	0.01	-	-	-	0.01	0.09	-
Strontium	0.03	-	0.02	0.02	0.02	-	0.01	0.01	-	0.11
Yttrium	-	-	0.06	0.01	0.03	-	0.02	-	-	-
Zirconium	0.08	0.06	0.04	-	-	-	-	0.03	-	-
Molybdenum	-	-	-	0.02	-	-	0.05	-	-	-
Tin	1.96	-	34.2	3.15	3.27	101	3.99	0.97	275	-

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 6	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	-	-	-	1.43	-	-	-	-	-	-
Silicon	0.09	*	0.18	0.67	*	-	0.01	*	-	1.06
Sulfur	0.22	0.70	-	1.68	0.77	-	0.95	0.65	1.13	2.67
Chlorine	0.63	*	2.25	2.56	2.26	56.0	6.67	3.36	41.7	6.68
Potassium	-	-	-	0.33	0.30	-	-	0.19	1.53	-
Calcium	1.48	4.72	-	-	-	-	0.53	-	0.56	-
Titanium	*	0.11	*	*	*	0.07	0.01	0.01	*	*
Vanadium	-	0.11	0.09	0.01	-	-	-	-	-	-
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.13	0.27	0.05	0.02	0.02	0.03	0.04	0.01	0.03	0.07
Iron	0.54	0.68	0.31	0.62	0.76	1.74	*	0.34	3.94	1.19
Nickel	0.15	0.23	0.23	0.08	0.08	0.13	0.07	0.08	0.07	0.28
Copper	0.02	0.01	0.02	0.01	0.01	0.13	0.02	0.01	0.16	0.02
Zinc	*	*	*	*	*	*	*	*	0.17	*
Gallium	-	-	-	-	-	-	-	-	0.01	-
Selenium	-	0.02	-	-	-	-	-	0.01	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	-	-	-	0.01	-	-	-	0.03	0.02	-
Strontium	0.28	0.63	0.03	0.01	0.02	-	0.08	0.01	-	0.04
Yttrium	0.01	0.15	0.08	-	-	-	-	-	-	0.02
Zirconium	0.01	0.12	0.10	0.01	0.02	-	-	-	-	-
Molybdenum	-	0.18	-	-	-	-	-	0.03	-	0.33
Tin	-	-	30.8	-	-	52.0	0.51	-	77.6	-

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 7	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	-	-	-	-	-	-	-	-	-	-
Silicon	0.09	0.46	*	*	*	*	0.30	0.50	*	*
Sulfur	1.65	1.64	0.63	0.57	-	-	0.84	0.82	-	1.02
Chlorine	4.07	2.74	6.56	1.12	0.84	5.82	2.12	1.36	10.4	0.89
Potassium	-	-	-	-	-	-	-	0.31	-	0.34
Calcium	-	-	-	-	-	-	-	-	-	-
Titanium	0.14	0.02	*	0.01	*	*	0.01	*	*	*
Vanadium	-	-	-	0.01	-	-	0.02	-	-	0.08
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.03	0.02	0.01	0.01	0.01	0.01	0.01	-	0.01	0.01
Iron	0.79	0.79	0.16	0.43	0.57	0.44	0.81	0.58	0.28	0.30
Nickel	0.20	0.16	0.10	0.07	0.06	0.06	0.07	0.07	0.07	0.17
Copper	0.01	0.02	0.01	0.03	0.02	0.01	0.01	0.01	0.02	*
Zinc	*	*	*	*	*	*	*	*	*	*
Gallium	-	-	-	-	0.01	-	-	-	-	-
Selenium	-	-	-	-	0.02	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	0.03	0.02	-	-	0.03	-	0.01	0.01	-	0.01
Strontium	0.01	-	-	0.03	-	0.01	0.01	-	-	0.02
Yttrium	-	0.06	0.06	-	-	-	0.00	0.01	-	0.01
Zirconium	0.06	0.06	-	-	0.01	-	0.03	0.01	0.02	-
Molybdenum	0.14	-	0.03	-	-	-	0.02	-	-	-
Tin	-	1.35	11.5	12.1	41.2	13.0	2.00	-	22.9	-

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 8	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	12.2	-	-	-	1.86	-	-	-	-	-
Silicon	6.89	*	*	0.57	0.80	-	*	0.54	*	0.39
Sulfur	2.18	0.97	1.50	1.63	1.81	0.28	1.26	0.53	-	0.12
Chlorine	1.58	2.17	10.6	2.20	4.35	27.9	3.48	2.66	3.60	1.84
Potassium	0.85	0.97	-	-	0.45	-	0.17	0.40	-	-
Calcium	1.88	-	-	-	-	-	-	-	-	-
Titanium	0.26	0.10	0.13	0.09	0.07	0.07	0.01	*	*	0.01
Vanadium	0.18	0.02	0.03	0.05	0.01	-	0.02	0.04	0.03	0.03
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.13	0.01	0.03	0.02	-	0.03	0.01	0.01	0.01	0.03
Iron	8.26	0.67	0.55	0.51	0.74	0.78	0.71	1.04	0.32	0.98
Nickel	0.34	0.16	0.19	0.11	0.10	0.13	0.08	0.09	0.07	0.14
Copper	0.97	0.01	0.02	0.02	0.03	0.03	0.02	0.02	0.04	0.04
Zinc	4.75	*	*	*	*	*	*	*	*	*
Gallium	-	-	-	-	-	-	-	-	-	-
Selenium	-	-	-	-	-	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	0.01	0.02	0.01	-	-	-	-	0.01	0.01	0.02
Strontium	0.09	0.02	0.03	0.01	-	0.01	-	-	-	0.02
Yttrium	0.29	0.04	-	0.02	0.02	0.02	0.01	-	-	0.02
Zirconium	2.37	0.04	0.04	0.01	-	0.05	0.01	0.03	-	0.06
Molybdenum	0.21	0.51	0.06	-	0.06	0.03	0.01	0.01	0.03	0.08
Tin	-	2.14	18.5	4.04	5.10	32.5	6.15	8.01	25.0	1.99

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 9	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	-	-	-	-	-	-	-	-	-	-
Silicon	*	0.31	-	0.20	*	-	0.62	*	0.16	*
Sulfur	3.33	5.05	2.20	2.08	0.87	0.83	2.11	1.27	1.90	1.84
Chlorine	4.51	14.5	122	5.80	4.12	21.7	5.82	3.26	7.47	3.46
Potassium	-	-	-	-	0.17	-	-	0.37	-	-
Calcium	-	-	-	-	-	-	-	-	0.45	-
Titanium	0.14	0.01	*	*	*	*	0.02	*	*	*
Vanadium	0.06	0.05	0.09	0.02	0.01	-	0.02	-	-	-
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.03	0.02	0.01	0.01	0.01	0.01	0.02	-	0.01	0.01
Iron	0.35	1.05	0.70	0.29	0.36	0.21	0.63	0.38	0.24	0.40
Nickel	0.24	0.15	0.28	0.07	0.07	0.09	0.08	0.07	0.06	0.13
Copper	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.03
Zinc	*	*	*	*	*	*	*	*	*	*
Gallium	-	-	-	-	-	-	-	-	0.01	-
Selenium	-	-	-	-	-	-	-	0.02	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	0.01	-	0.02	0.01	0.01	-	-	0.02	0.01	0.01
Strontium	0.07	0.01	0.01	0.01	0.01	-	0.01	0.01	-	0.03
Yttrium	0.03	0.01	-	0.01	0.01	-	-	-	-	-
Zirconium	0.08	0.04	-	0.01	0.02	0.07	0.02	0.05	-	0.04
Molybdenum	0.04	-	-	0.03	0.01	0.03	-	0.03	-	0.07
Tin	-	-	35.0	-	-	21.3	-	-	24.8	-

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 10	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	-	-	-	-	-	-	-	-	-	-
Silicon	*	*	0.68	0.55	0.11	0.01	0.26	0.28	-	*
Sulfur	1.58	0.74	3.58	1.70	1.27	1.36	1.10	0.88	1.87	2.30
Chlorine	3.95	5.49	46.3	4.81	5.91	7.25	4.86	5.96	39.7	10.3
Potassium	-	-	-	-	-	-	-	-	-	0.63
Calcium	-	-	-	-	1.23	-	0.42	0.37	-	-
Titanium	*	0.01	*	*	-	0.01	*	0.03	0.01	0.01
Vanadium	0.14	0.04	-	0.03	0.08	0.01	0.02	0.01	-	-
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	-	0.02	0.05	0.02	0.01	0.02	0.01	0.02	0.01	0.01
Iron	0.49	0.32	0.58	0.30	0.49	0.13	0.48	0.81	0.27	0.77
Nickel	0.21	0.15	0.16	0.07	0.06	0.08	0.06	0.09	0.08	0.11
Copper	0.01	*	0.03	0.01	0.03	0.01	0.01	0.02	0.03	0.03
Zinc	*	*	*	*	*	*	*	*	*	*
Gallium	-	-	-	-	-	-	-	-	-	-
Selenium	-	-	-	-	-	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	0.05	-	-	-	-	-	-	-	-	0.02
Strontium	0.05	0.04	-	-	-	0.01	-	-	-	0.01
Yttrium	0.06	0.05	0.11	-	-	-	-	-	-	0.05
Zirconium	0.14	0.04	0.04	-	-	-	-	0.03	0.01	0.05
Molybdenum	-	0.11	0.10	-	-	0.05	-	0.02	-	0.02
Tin	-	-	27.4	6.66	56.1	11.1	0.86	0.86	48.2	-

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 11	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	-	-	-	-	-	-	-	-	-	-
Silicon	*	*	*	*	0.43	-	0.36	-	-	0.86
Sulfur	1.26	1.88	1.87	0.60	1.41	1.34	1.34	5.72	2.01	1.42
Chlorine	0.92	0.51	6.61	2.42	2.72	117	4.34	4.46	58.5	2.94
Potassium	-	-	-	0.11	-	-	-	7.27	-	1.01
Calcium	-	-	-	-	0.80	-	1.16	15.6	1.07	1.14
Titanium	*	0.13	*	*	*	*	*	-	0.01	*
Vanadium	-	0.06	-	0.01	0.02	0.05	0.04	-	-	0.04
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.01	0.04	0.01	-	0.01	0.01	0.01	0.03	0.01	0.02
Iron	0.58	0.36	0.23	0.26	0.55	0.89	0.56	0.85	0.75	0.46
Nickel	0.20	0.14	0.17	0.08	0.08	0.15	0.05	0.04	0.04	0.09
Copper	0.02	0.01	0.01	0.01	0.03	0.03	0.04	0.13	0.09	0.05
Zinc	*	*	*	*	*	*	*	*	*	*
Gallium	-	-	-	-	0.01	-	0.01	0.01	0.02	-
Selenium	-	-	-	-	-	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	0.02	0.01	-	-	0.02	0.01	0.02	0.08	0.03	-
Strontium	0.03	0.03	0.05	0.02	-	0.03	0.01	-	-	-
Yttrium	-	0.04	0.03	-	-	0.05	0.02	-	-	-
Zirconium	0.12	0.01	-	0.03	-	0.01	0.04	0.04	0.01	0.01
Molybdenum	-	0.03	0.04	0.07	0.03	-	-	-	-	0.08
Tin	4.04	0.85	5.90	3.41	23.2	37.1	57.6	251	127	42.5

- not detected

* less than filter blank

TABLE XLIII (CONTINUED)

Hour 12	A	B	C	D	E	F	G	H	I	J
Magnesium	-	-	-	-	-	-	-	-	-	-
Aluminum	-	-	-	1.62	-	-	-	-	-	-
Silicon	1.11	*	0.56	0.88	0.08	-	0.84	0.74	0.26	0.89
Sulfur	6.00	8.52	0.95	1.47	0.92	2.16	0.78	0.88	1.55	2.34
Chlorine	2.56	1.80	9.45	2.78	2.59	110	8.57	3.47	39.2	7.52
Potassium	-	0.84	-	0.41	-	-	-	-	-	0.28
Calcium	-	0.87	-	-	-	-	-	-	-	-
Titanium	0.12	0.13	0.03	0.01	0.01	*	0.01	*	*	0.13
Vanadium	0.02	0.05	-	-	-	-	0.03	0.01	0.01	-
Chromium	*	*	*	*	*	*	*	*	*	*
Manganese	0.03	-	0.04	0.01	0.02	0.02	0.01	0.01	0.02	0.01
Iron	0.44	0.47	1.70	0.37	0.49	1.38	0.57	0.50	0.41	0.85
Nickel	0.23	0.15	0.16	0.08	0.07	0.13	0.08	0.07	0.09	0.14
Copper	0.01	0.02	0.06	0.02	0.02	0.06	0.03	0.02	0.05	0.04
Zinc	*	*	0.11	*	*	*	*	*	*	*
Gallium	-	-	-	-	-	0.01	-	-	-	-
Selenium	-	-	-	-	-	-	-	-	-	-
Bromine	*	*	*	*	*	*	*	*	*	*
Rubidium	-	-	0.01	0.01	-	-	0.01	0.01	0.02	-
Strontium	0.04	-	-	0.02	-	-	0.01	0.01	0.01	0.02
Yttrium	0.06	0.01	0.03	0.03	0.01	-	0.01	0.02	0.02	0.02
Zirconium	-	0.04	-	-	-	-	0.02	0.01	0.02	0.06
Molybdenum	-	-	0.04	0.03	0.02	0.05	0.04	0.02	-	-
Tin	-	1.91	47.2	1.18	0.99	57.7	1.48	1.11	19.6	1.71

- not detected

* less than filter blank

APPENDIX C (CONTINUED)

TABLE XLIV

LEAD CONTRIBUTION BY LINE FOR THE WAVE SOLDERING AREA FROM RECEPTOR MODELING EQUATION Y = C + FI FOR EACH RECEPTOR POINT ($\mu g/m^3$)

Location	Lines 1 and 2	Line 3	Predicted Concentration	Measured Concentration
Hour 1a	1.24	0.704	1.95	2.08
Hour 1b	0.451	0.253	0.847	0.704
Hour 1d	0.781	0.420	1.20	1.62
Hour 1e	0.112	0.117	0.229	0.183
Hour 1g	0.937	0.778	1.71	1.76
Hour 1h	0.129	0.135	0.264	0.205
Hour 2a	0.127	0.136	0.263	0.187
Hour 2b	0.265	0.253	0.518	0.385
Hour 2d	0.525	0.420	0.945	0.748
Hour 2e	0.223	0.228	0.451	0.328
Hour 2g	0.391	0.316	0.707	0.955
Hour 2h	0.321	0.305	0.626	0.485
Hour 3a	0.759	0.005	0.764	0.594
Hour 3b	0.458	0.381	0.839	1.18
Hour 3d	0.530	2.14	2.67	3.96
Hour 3e	0.696	1.11	1.81	30.1
Hour 3g	0.005	1.36	1.36	4.53
Hour 3h	1.29	0.513	1.80	4.02
Hour 4a	0.585	0.026	0.611	0.341
Hour 4b	0.753	0.029	0.782	0.412
Hour 4d	0.952	0.033	0.985	0.813
Hour 4e	0.318	0.004	0.322	1.19
Hour 4g	0.437	0.535	0.972	18.5
Hour 4h	0.395	0.181	0.576	12.7

APPENDIX C (CONTINUED)

TABLE XLIV (CONTINUED)

Location	Lines 1 and 2	Line 3	Predicted Concentration	Measured Concentration
Hour 5a	0.536	0.526	1.06	1.07
Hour 5b	0.269	0.672	0.941	0.763
Hour 5d	0.749	0.787	1.53	1.12
Hour 5e	0.629	0.646	1.27	0.875
Hour 5g	1.00	0.984	1.98	1.61
Hour 5h	0.248	0.233	0.481	0.539
Hour 6a	0.082	0.072	0.154	0.118
Hour 6b	0.030	0.029	0.059	0.054
Hour 6d	0.110	0.109	0.219	0.158
Hour 6e	0.065	0.060	0.125	0.098
Hour 6g	0.116	0.157	0.273	0.511
Hour 6h	0.088	0.081	0.169	0.127
Hour 7a	0.214	0.218	0.432	0.309
Hour 7b	0.347	0.431	0.778	1.23
Hour 7d	0.737	0.691	1.42	4.49
Hour 7e	0.455	0.415	0.870	17.5
Hour 7g	0.484	0.552	1.03	0.870
Hour 7h	0.176	0.196	0.372	0.327
Hour 8a	0.279	0.261	0.540	0.463
Hour 8b	0.529	0.504	1.03	0.936
Hour 8d	0.842	0.751	1.59	1.32
Hour 8e	1.05	0.956	2.01	1.59
Hour 8g	1.31	0.908	2.21	2.37
Hour 8h	0.817	1.40	2.21	2.71

APPENDIX C (CONTINUED)

TABLE XLIV (CONTINUED)

Location	Lines 1 and 2	Line 3	Predicted Concentration	Measured Concentration
Hour 9a	0.208	0.136	0.344	0.346
Hour 9b	0.140	0.126	0.266	0.273
Hour 9d	0.096	0.083	0.179	0.285
Hour 9e	0.101	0.081	0.182	0.317
Hour 9g	0.104	0.088	0.192	0.396
Hour 9h	0.043	0.202	0.245	0.228
Hour 10a	0.309	0.262	0.571	0.467
Hour 10b	0.240	0.215	0.255	0.426
Hour 10d	1.85	0.276	2.13	2.43
Hour 10e	0.594	0.250	0.844	18.3
Hour 10g	0.168	0.142	0.310	0.550
Hour 10h	0.169	0.149	0.318	0.488
Hour 11a	0.153	0.445	0.598	1.95
Hour 11b	0.087	0.212	0.299	0.799
Hour 11d	0.004	1.48	1.48	1.23
Hour 11e	0.479	0.950	1.42	7.38
Hour 11g	0.625	1.55	2.18	14.5
Hour 11h	0.751	1.09	1.84	70.5
Hour 12a	0.354	0.260	0.614	0.535
Hour 12b	0.246	0.304	0.550	0.427
Hour 12d	0.379	0.138	0.517	0.698
Hour 12e	0.374	0.021	0.395	0.485
Hour 12g	0.319	0.325	0.644	0.625
Hour 12h	0.241	0.271	0.512	0.520

APPENDIX C (CONTINUED)

TABLE XLV

LEAD CONTRIBUTION BY LINE FOR THE WAVE SOLDERING AREA FROM RECEPTOR MODELING EQUATION Y = C + F + I FOR EACH RECEPTOR POINT ($\mu g/m^3$)

Location	Line 1	Line 2	Line 3	Predicted Concentration	Measured Concentration
Hour 1a	1.21	0.463	0.524	2.20	2.08
Hour 1b	0.288	0.306	0.264	0.858	0.704
Hour 1d	0.508	0.520	0.408	1.43	1.62
Hour 1e	0.072	0.078	0.078	0.228	0.183
Hour 1g	0.618	0.619	0.509	1.74	1.76
Hour 1h	0.083	0.091	0.090	0.264	0.205
Hour 2a	0.081	0.089	0.090	0.260	0.187
Hour 2b	0.173	0.180	0.169	0.522	0.385
Hour 2d	0.330	0.358	0.280	0.968	0.748
Hour 2e	0.147	0.150	0.152	0.449	0.328
Hour 2g	0.287	0.268	0.193	0.748	0.955
Hour 2h	0.213	0.216	0.203	0.632	0.485
Hour 3a	0.401	0.232	0.256	0.889	0.594
Hour 3b	0.317	0.234	0.222	0.773	1.18
Hour 3d	0.185	1.44	1.66	3.29	3.96
Hour 3e	0.227	2.37	0.627	3.23	30.1
Hour 3g	0.019	2.82	0.626	3.46	4.53
Hour 3h	0.259	1.88	0.387	2.53	4.02
Hour 4a	0.113	0.263	0.094	0.470	0.341
Hour 4b	0.097	0.411	0.088	0.596	0.412
Hour 4d	0.354	0.304	0.127	0.785	0.813
Hour 4e	0.397	0.078	0.020	0.495	1.19
Hour 4g	7.38	0.079	0.230	7.69	18.5
Hour 4h	1.38	0.152	0.063	1.59	12.7

APPENDIX C (CONTINUED)

TABLE XLV (CONTINUED)

Location	Line 1	Line 2	Line 3	Predicted Concentration	Measured Concentration
Hour 5a	0.369	0.327	0.350	1.04	1.07
Hour 5b	0.319	0.293	0.308	0.920	0.763
Hour 5d	0.010	0.722	0.746	1.47	1.12
Hour 5e	0.408	0.411	0.431	1.25	0.875
Hour 5g	0.681	0.639	0.656	1.97	1.61
Hour 5h	0.170	0.158	0.155	0.483	0.539
Hour 6a	0.055	0.052	0.048	0.155	0.118
Hour 6b	0.020	0.020	0.019	0.059	0.054
Hour 6d	0.072	0.075	0.072	0.219	0.158
Hour 6e	0.043	0.045	0.040	0.128	0.098
Hour 6g	0.082	0.072	0.105	0.259	0.511
Hour 6h	0.058	0.060	0.054	0.172	0.127
Hour 7a	0.140	0.146	0.145	0.431	0.309
Hour 7b	0.254	0.210	0.287	0.751	1.23
Hour 7d	0.508	0.462	0.461	1.43	4.49
Hour 7e	0.317	0.286	0.277	0.880	17.5
Hour 7g	0.336	0.307	0.368	1.01	0.870
Hour 7h	0.125	0.109	0.131	0.365	0.327
Hour 8a	0.190	0.123	0.174	0.487	0.463
Hour 8b	0.393	0.203	0.336	0.932	0.936
Hour 8d	0.648	0.260	0.500	1.40	1.32
Hour 8e	0.738	0.423	0.637	1.79	1.59
Hour 8g	1.28	0.224	0.821	2.33	2.37
Hour 8h	2.60	0.266	0.649	3.51	2.79

APPENDIX C (CONTINUED)

TABLE XLV (CONTINUED)

Location	Line 1	Line 2	Line 3	Predicted Concentration	Measured Concentration
Hour 9a	0.035	0.041	0.261	0.337	0.346
Hour 9b	0.102	0.070	0.084	0.256	0.273
Hour 9d	0.078	0.041	0.055	0.174	0.285
Hour 9e	0.083	0.043	0.054	0.180	0.317
Hour 9g	0.087	0.044	0.059	0.190	0.396
Hour 9h	0.015	0.038	0.188	0.241	0.228
Hour 10a	0.212	0.188	0.175	0.575	0.467
Hour 10b	0.167	0.139	0.143	0.449	0.426
Hour 10d	0.863	0.642	0.362	1.86	2.436
Hour 10e	3.48	0.075	0.047	3.61	18.3
Hour 10g	0.132	0.088	0.095	0.315	0.550
Hour 10h	0.127	0.090	0.099	0.316	0.488
Hour 11a	0.333	0.027	0.296	0.656	1.95
Hour 11b	0.125	0.016	0.141	0.282	0.799
Hour 11d	0.634	0.054	0.724	1.41	1.23
Hour 11e	1.12	0.086	0.633	1.84	7.38
Hour 11g	1.54	0.071	1.48	3.10	14.5
Hour 11h	1.44	0.100	1.07	2.62	70.5
Hour 12a	0.223	0.137	0.257	0.617	0.535
Hour 12b	0.143	0.107	0.199	0.449	0.427
Hour 12d	0.259	0.128	0.139	0.526	0.698
Hour 12e	0.150	0.110	0.150	0.410	0.485
Hour 12g	0.245	0.180	0.217	0.642	0.625
Hour 12h	0.192	0.132	0.181	0.505	0.520

APPENDIX C (CONTINUED)

TABLE XLVI

HOURLY LEAD RESIDUALS AND THE FRACTION OF LEAD EXPLAINED BY THE RECEPTOR MODELING EQUATION Y = C + FI FOR THE WAVE SOLDERING AREA

A = C + FI	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	1.95	2.08	0.130	0.938
Hour 2	0.263	0.187	-0.076	1.40
Hour 3	0.765	0.594	-0.171	1.28
Hour 4	0.611	0.341	-0.270	1.79
Hour 5	1.06	1.07	0.016	0.985
Hour 6	0.154	0.118	-0.036	1.30
Hour 7	0.432	0.309	-0.123	1.39
Hour 8	0.540	0.463	-0.077	1.16
Hour 9	0.344	0.346	0.002	0.993
Hour 10	0.572	0.467	-0.105	1.22
Hour 11	0.599	1.95	1.35	0.306
Hour 12	0.614	0.535	-0.079	1.14

B = C + FI	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.847	0.704	-0.143	1.20
Hour 2	0.518	0.385	-0.133	1.34
Hour 3	0.839	1.18	0.342	0.710
Hour 4	0.782	0.412	-0.370	1.89
Hour 5	0.941	0.763	-0.178	1.23
Hour 6	0.059	0.054	-0.005	1.09
Hour 7	0.778	1.23	0.461	0.628
Hour 8	1.03	0.936	-0.097	1.10
Hour 9	0.266	0.273	0.007	0.974
Hour 10	0.455	0.426	-0.029	1.06
Hour 11	0.299	0.799	0.500	0.374
Hour 12	0.550	0.427	-0.123	1.28

APPENDIX C (CONTINUED)

TABLE XLVI (CONTINUED)

D = C + FI	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	1.39	1.62	0.233	0.857
Hour 2	0.945	0.748	-0.197	1.26
Hour 3	2.67	3.96	1.29	0.675
Hour 4	0.985	0.813	-0.172	1.21
Hour 5	1.53	1.12	-0.414	1.36
Hour 6	0.219	0.158	-0.061	1.38
Hour 7	1.42	4.49	3.06	0.318
Hour 8	1.59	1.32	-0.269	1.20
Hour 9	0.179	0.285	0.106	0.628
Hour 10	2.13	2.43	0.305	0.875
Hour 11	1.48	1.23	-0.250	1.20
Hour 12	0.517	0.698	0.181	0.741

E = C + FI	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.229	0.183	-0.046	1.25
Hour 2	0.451	0.328	-0.123	1.37
Hour 3	1.81	30.1	28.3	0.060
Hour 4	0.322	1.19	0.873	0.269
Hour 5	1.27	0.875	-0.400	1.45
Hour 6	0.125	0.098	-0.027	1.27
Hour 7	0.870	17.5	16.6	0.050
Hour 8	2.01	1.59	-0.423	1.26
Hour 9	0.182	0.317	0.135	0.574
Hour 10	0.844	18.3	17.5	0.046
Hour 11	1.42	7.38	5.96	0.193
Hour 12	0.395	0.485	0.090	0.814

APPENDIX C (CONTINUED)

TABLE XLVI (CONTINUED)

G = C + FI	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	1.71	1.76	0.046	0.974
Hour 2	0.707	0.955	0.248	0.740
Hour 3	1.36	4.53	3.16	0.302
Hour 4	0.972	18.5	17.5	0.052
Hour 5	1.98	1.61	-0.372	1.23
Hour 6	0.273	0.511	0.238	0.534
Hour 7	1.03	0.870	-0.166	1.19
Hour 8	2.21	2.37	0.156	0.934
Hour 9	0.192	0.396	0.204	0.485
Hour 10	0.310	0.550	0.240	0.564
Hour 11	2.18	17.6	15.4	0.124
Hour 12	0.644	0.625	-0.019	1.03

H = C + FI	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.264	0.205	-0.059	1.29
Hour 2	0.626	0.485	-0.141	1.29
Hour 3	1.80	4.02	2.21	0.450
Hour 4	0.576	12.7	12.1	0.045
Hour 5	0.482	0.539	0.057	0.894
Hour 6	0.169	0.127	-0.042	1.33
Hour 7	0.371	0.327	-0.044	1.13
Hour 8	2.21	2.79	0.572	0.795
Hour 9	0.244	0.228	-0.016	1.07
Hour 10	0.317	0.488	0.170	0.651
Hour 11	1.84	70.5	68.5	0.026
Hour 12	0.513	0.520	0.007	0.986

APPENDIX C (CONTINUED)

TABLE XLVI (CONTINUED)

J = C + FI	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.745	0.491	-0.254	1.51
Hour 2	0.184	0.143	-0.041	1.28
Hour 3	1.22	1.10	-0.113	1.10
Hour 4	0.546	0.754	0.203	0.724
Hour 5	0.511	0.559	0.048	0.914
Hour 6	0.757	0.546	-0.211	1.38
Hour 7	0.154	0.117	-0.037	1.31
Hour 8	0.842	1.40	0.560	0.600
Hour 9	0.263	0.239	-0.024	1.10
Hour 10	0.459	0.484	0.025	0.948
Hour 11	1.63	16.0	14.3	0.102
Hour 12	0.714	0.686	-0.028	1.04

K = C + FI	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.172	0.468	0.296	0.368
Hour 2	0.151	0.468	0.317	0.323
Hour 3	0.125	0.468	0.343	0.267
Hour 4	0.168	0.468	0.300	0.359
Hour 5	0.168	0.468	0.300	0.359
Hour 6	0.167	0.468	0.301	0.357
Hour 7	0.320	0.320	0.000	1.000
Hour 8	0.281	0.320	0.039	0.878
Hour 9	0.127	0.320	0.193	0.397
Hour 10	0.185	0.320	0.135	0.578
Hour 11	0.235	0.320	0.085	0.734
Hour 12	0.296	0.320	0.024	0.925

APPENDIX C (CONTINUED)

TABLE XLVII

HOURLY LEAD RESIDUALS AND THE FRACTION OF LEAD EXPLAINED BY THE RECEPTOR MODELING EQUATION Y = C + F + I FOR THE WAVE SOLDERING AREA

A = C + F + I	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	2.20	2.08	-0.121	1.05
Hour 2	0.261	0.187	-0.074	1.39
Hour 3	0.890	0.594	-0.296	1.49
Hour 4	0.471	0.341	-0.130	1.38
Hour 5	1.04	1.07	0.032	0.970
Hour 6	0.155	0.118	-0.037	1.31
Hour 7	0.432	0.309	-0.123	1.39
Hour 8	0.487	0.463	-0.024	1.05
Hour 9	0.337	0.346	0.009	0.973
Hour 10	0.575	0.467	-0.108	1.23
Hour 11	0.657	1.95	1.30	0.335
Hour 12	0.616	0.535	-0.081	1.15

B = C + F + I	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.858	0.704	-0.154	1.21
Hour 2	0.522	0.385	-0.137	1.35
Hour 3	0.773	1.18	0.408	0.654
Hour 4	0.596	0.412	-0.184	1.44
Hour 5	0.920	0.763	-0.157	1.20
Hour 6	0.059	0.054	-0.005	1.09
Hour 7	0.751	1.23	0.488	0.606
Hour 8	0.932	0.936	0.004	0.996
Hour 9	0.256	0.273	0.017	0.938
Hour 10	0.449	0.426	-0.023	1.05
Hour 11	0.282	0.799	0.517	0.353
Hour 12	0.449	0.427	-0.022	1.05

APPENDIX C (CONTINUED)

TABLE XLVII (CONTINUED)

D = C + F + I	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	1.43	1.62	0.189	0.884
Hour 2	0.968	0.748	-0.220	1.29
Hour 3	3.29	3.96	0.676	0.830
Hour 4	0.785	0.813	0.028	0.965
Hour 5	1.47	1.12	-0.356	1.31
Hour 6	0.219	0.158	-0.061	1.38
Hour 7	1.43	4.49	3.06	0.318
Hour 8	1.40	1.32	-0.084	1.06
Hour 9	0.174	0.285	0.111	0.610
Hour 10	1.86	2.43	0.569	0.766
Hour 11	1.41	1.23	-0.175	1.14
Hour 12	0.526	0.698	0.172	0.753

E = C + F + I	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.228	0.183	-0.045	1.24
Hour 2	0.449	0.328	-0.121	1.36
Hour 3	3.23	30.1	26.9	0.107
Hour 4	0.495	1.19	0.700	0.414
Hour 5	1.25	0.875	-0.375	1.42
Hour 6	0.128	0.098	-0.030	1.30
Hour 7	0.880	17.5	16.6	0.050
Hour 8	1.79	1.59	-0.208	1.13
Hour 9	0.180	0.317	0.137	0.568
Hour 10	3.61	18.3	14.7	0.197
Hour 11	1.84	7.38	5.54	0.250
Hour 12	0.410	0.485	0.075	0.847

APPENDIX C (CONTINUED)

TABLE XLVII (CONTINUED)

G = C + F + I	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	1.74	1.76	0.015	0.991
Hour 2	0.748	0.955	0.207	0.783
Hour 3	3.46	4.53	1.06	0.766
Hour 4	7.69	18.5	10.8	0.414
Hour 5	1.97	1.61	-0.364	1.22
Hour 6	0.259	0.511	0.252	0.507
Hour 7	1.01	0.870	-0.141	1.16
Hour 8	2.33	2.37	0.043	0.982
Hour 9	0.190	0.396	0.206	0.480
Hour 10	0.315	0.550	0.235	0.573
Hour 11	3.10	17.6	14.5	0.176
Hour 12	0.642	0.625	-0.017	1.02

H = C + F + I	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.264	0.205	-0.059	1.28
Hour 2	0.633	0.485	-0.148	1.30
Hour 3	2.53	4.02	1.49	0.630
Hour 4	1.59	12.7	11.1	0.125
Hour 5	0.484	0.539	0.055	0.898
Hour 6	0.172	0.127	-0.045	1.35
Hour 7	0.365	0.327	-0.038	1.11
Hour 8	3.51	2.79	-0.727	1.26
Hour 9	0.242	0.228	-0.014	1.06
Hour 10	0.317	0.488	0.171	0.649
Hour 11	2.62	70.5	67.8	0.037
Hour 12	0.505	0.520	0.014	0.972

APPENDIX C (CONTINUED)

TABLE XLVII (CONTINUED)

J = C + F + I	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.739	0.491	-0.248	1.50
Hour 2	0.180	0.143	-0.037	1.25
Hour 3	1.08	1.10	0.022	0.908
Hour 4	0.501	0.754	0.253	0.664
Hour 5	0.496	0.559	0.063	0.887
Hour 6	0.765	0.546	-0.219	1.40
Hour 7	0.154	0.117	-0.037	1.31
Hour 8	0.826	1.40	0.576	0.589
Hour 9	0.258	0.239	-0.019	1.07
Hour 10	0.541	0.484	0.033	0.932
Hour 11	1.95	16.0	14.0	0.122
Hour 12	0.708	0.686	-0.022	1.03

K = C + F + I	Predicted Concentration ($\mu g/m^3$)	Measured Concentration ($\mu g/m^3$)	Residual ($\mu g/m^3$)	Fraction Explained
Hour 1	0.176	0.468	0.292	0.376
Hour 2	0.164	0.468	0.304	0.350
Hour 3	0.136	0.468	0.332	0.290
Hour 4	0.220	0.468	0.248	0.470
Hour 5	0.168	0.468	0.300	0.359
Hour 6	0.168	0.468	0.300	0.359
Hour 7	0.316	0.320	0.004	0.988
Hour 8	0.255	0.320	0.065	0.797
Hour 9	0.267	0.320	0.053	0.834
Hour 10	0.163	0.320	0.157	0.509
Hour 11	0.286	0.320	0.034	0.894
Hour 12	0.296	0.320	0.024	0.925

APPENDIX C (CONTINUED)

TABLE XLVIII

ACTIVITY REGRESSION EQUATIONS FOR THE RECEPTOR MODELING EQUATIONS FROM THE WAVE SOLDERING AREA FOR LINE 1

Receptor Point[a]	Receptor Equation	Activity Regression	r^2[b]
G	G = C + F + I	F = 0.015boards - 1.148	0.589
H	H = C + FI	FI = 0.003boards + 0.049	0.114
H	H = C + F + I	F = 0.011boards - 0.774	0.582
G	G = C + F + I	F = 0.097hood - 0.917	0.187
H	H = C + F + I	F = 0.055hood - 0.499	0.138
G	G = C + F + I	F = 0.255scr/ded - 0.250	0.416
G	G = C + F + I	F = 0.599scr/ded2 + 0.152	0.815
H	H = C + F + I	F = 0.138scr/ded - 0.105	0.280
H	H = C + F + I	F = 0.406scr/ded2 + 0.072	0.861

[a] sampling locations are shown in Figure 11

[b] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the lead contribution.

APPENDIX C (CONTINUED)

TABLE XLIX

ACTIVITY REGRESSION EQUATIONS FOR THE RECEPTOR MODELING EQUATIONS FROM THE WAVE SOLDERING AREA FOR LINE 2

Receptor Point[a]	Receptor Equation	Activity Regression	r^2[b]
D	D = C + F + I	C = 0.007boards - 0.177	0.285
D	D = C + FI	C = 0.115hood3 + 0.254	0.181
D	D = C + F + I	C = 0.075hood3 + 0.219	0.154
E	E = C + FI	C = 0.071hood3 + 0.174	0.133
E	E = C + F + I	C = 0.054hood3 + 0.088	0.250
D	D = C + FI	C = 0.155scr/ded + 0.201	0.230
D	D = C + FI	FI = 0.143scr/ded + 0.237	0.315
D	D = C + FI	total = 0.298 scr/ded + 0.439	0.621
D	D = C + F + I	C = 0.144scr/ded + 0.065	0.404
D	D = C + F + I	F = 0.164scr/ded - 0.033	0.658
D	D = C + F + I	total = 0.341scr/ded + 0.311	0.634
D	D = C + FI	C = 0.313scr/ded3 + 0.340	0.199
D	D = C + FI	FI = 0.237scr/ded12 + 0.196	0.363
D	D = C + F + I	C = 0.283scr/ded3 + 0.202	0.328
D	D = C + F + I	F = 0.291scr/ded2 + 0.272	0.739
D	D = C + F + I	I = 0.119scr/ded1 + 0.213	0.192
E	E = C + FI	C = 0.076scr/ded + 0.195	0.133
E	E = C + FI	FI = 0.069scr/ded + 0.234	0.218
E	E = C + FI	total = 0.145scr/ded + 0.429	0.187
E	E = C + F + I	F = 0.190scr/ded - 0.177	0.326
E	E = C + F + I	total = 0.376scr/ded + 0.176	0.381
E	E = C + FI	C = 0.215scr/ded3 + 0.207	0.224
E	E = C + F + I	C = 0.127scr/ded3 + 0.145	0.208
E	E = C + F + I	F= 0.519scr/ded2 + 0.087	0.860
E	E = C + F + I	I = 0.466scr/ded1 - 0.021	0.227

[a] sampling locations are shown in Figure 11

[b] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the lead contribution.

APPENDIX C (CONTINUED)

TABLE L

ACTIVITY REGRESSION EQUATIONS FOR THE RECEPTOR MODELING EQUATIONS FROM THE WAVE SOLDERING AREA FOR LINE 3

Receptor Point[a]	Receptor Equation	Activity Regression	r^{2b}
A	A = C + F + I	C = 0.021hood - 0.073	0.301
A	A = C + FI	C = 0.066hood3 + 0.041	0.531
A	A = C + F + I	C = 0.045hood3 + 0.077	0.631
B	B = C + FI	C = 0.021hood + 0.002	0.140
B	B = C + F + I	C = 0.010hood + 0.052	0.114
B	B = C + FI	C = 0.053hood3 + 0.122	0.423
B	B = C + F + I	C = 0.027hood3 + 0.099	0.420
A	A = C + FI	C = 0.035scr/ded + 0.159	0.104
A	A = C + F + I	C = 0.032scr/ded + 0.135	0.223
A	A = C + FI	C = 0.105scr/ded3 + 0.158	0.200
A	A = C + F + I	C = 0.083scr/ded3 + 0.147	0.319
B	B = C + FI	C = 0.059scr/ded + 0.133	0.364
B	B = C + F + I	C = 0.030scr/ded + 0.106	0.355
B	B = C + FI	C = 0.179scr/ded3 + 0.131	0.705
B	B = C + F + I	C = 0.092scr/ded3 + 0.104	0.699

[a] sampling locations are shown in Figure 11

[b] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the lead contribution.

APPENDIX C (CONTINUED)

TABLE LI

ACTIVITY REGRESSION EQUATIONS FOR THE RECEPTOR MODELING EQUATIONS FROM THE WAVE SOLDERING AREA FOR THE RECIRCULATION AIR

Receptor Point[a]	Receptor Equation	Activity Regression	r^{2b}
J	J = C + F + I	F = 0.001boards + 0.029	0.205
J	J = C + FI	FI = 0.003boards12 + 0.123	0.140
J	J = C + F + I	F = 0.003boards2 + 0.062	0.285
J	J = C + FI	FI = 0.021hood + 0.011	0.138
J	J = C + F + I	F = 0.014hood - 0.040	0.214
J	J = C + FI	FI = 0.041scr/ded + 0.200	0.164
J	J = C + F + I	F = 0.026scr/ded + 0.082	0.246
J	J = C + FI	FI = 0.067scr/ded12 + 0.191	0.180
J	J = C + F + I	F = 0.048scr/ded2 + 0.130	0.303

[a] sampling locations are shown in Figure 11

[b] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the lead contribution.

APPENDIX C (CONTINUED)

TABLE LII

ACTIVITY REGRESSION EQUATIONS FOR THE RECEPTOR MODELING EQUATIONS FROM THE WAVE SOLDERING AREA FOR THE AIR SUPPLY

Receptor Point[a]	Receptor Equation	Activity Regression	r^{2b}
K	K = C + FI	C = 0.005hood + 0.011	0.069
K	K = C + F + I	C = 0.006hood - 0.015	0.091
K	K = C + FI	C = 0.012hood3 + 0.048	0.163
K	K = C + F + I	C = 0.010hood3 + 0.038	0.113
K	K = C + F + I	F = 0.004scr/ded + 0.043	0.070
K	K = C + F + I	F = 0.007scr/ded2 + 0.051	0.078

[a] sampling locations are shown in Figure 11

[b] r^2 is the coefficient of determination which describes how well the regression equation has accounted for the total variability in the lead contribution.

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