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I am submitting herewith a thesis by Nicholas D. Jackson entitled "Exposure and Risk Assessment of the Printed Wiring Board Industry: Making Holes Conductive Process." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Environmental Engineering.

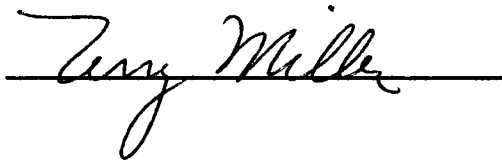


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Accepted for the Council:



Associate Vice Chancellor and
Dean of the Graduate School

Exposure and Risk Assessment of the Printed Wiring Board Industry: Making Holes Conductive Process

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The work described herein was performed for The Center for Clean Products and Cleaner Technologies (CCPCT) at The University of Tennessee. The CCPCT wrote a Cleaner Technologies Substitutes Assessment (CTSA) in 1996 regarding the Printed Wiring Board Industry Making Holes Conductive Process for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics (OPPT). The funding for the project was provided by the OPPT's Design for the Environment (DfE) program.

The DfE program is a cooperative, voluntary effort that OPPT initiated with industry to help develop more environmentally sound technologies. This bold new concept brings together data concerning a specific product or process (a use cluster) for which different chemicals and technologies can substitute for one another to provide the same overall function. The use cluster defines the area or procedure to be studied and allows for comparisons of these similar technologies to be made from a risk, cost, and performance perspective.

I am very fortunate to have been associated with this revolutionary program and project through both the University of Tennessee and the CCPCT, and I thank those with whom I worked there: Mary Swanson and Jack Geibig. The following people deserve special recognition and thanks for all their help and guidance to me: Dr. Chris D. Cox (Env. Eng. Dept.), and in particular Dr. R. Bruce Robinson (Env. Eng. Dept.) for his overall contribution to both my undergraduate and graduate education.

Abstract

The Printed Wiring Board Industry manufactures circuit boards to house wiring layouts containing electrical components. Holes through these boards connect different sections and serve as coupling locations for resistors and various components on the boards. The Making Holes Conductive (MHC) process applies a thin conductive layer to the insides of these holes that facilitates electroplating. The typical MHC process consists of several chemical baths which prepare and clean the boards and then apply this conductive seed coating to the holes.

This thesis compares the respective worker and population health risks associated with seven MHC processes. The MHC alternative technologies reviewed here are: Electroless Copper, Non-Formaldehyde Electroless Copper, Palladium (Tin and Organic Stabilized), Graphite, Carbon, and Conductive Polymer. The risk comparison is achieved by estimating chemical exposure to workers and the general public and then combining these exposures with current toxicity information. The exposure routes quantified in this work are inhalation of chemicals from MHC processing baths, and dermal contact with chemicals in those baths. Risks are quantified for line operators, lab technicians, and the general public living near PWB facilities.

The risks derived in this paper should be viewed as relative comparisons between MHC processes, and are used here as screening-level estimates only. There were many variations associated with the MHC processes, and thus several important assumptions were made to characterize them. Some of the key assumptions were: conveyorized processes had no emissions to inside air; line operators did not wear protective gloves/gear in the process area; reactions and speciation of chemicals in MHC baths were not quantified; and conservative upper-end estimates of exposure variables for receptors were used in the absence of other available data.

An uncertainty and sensitivity analysis was performed on the air transport models used in determining emission rates from MHC baths. The three air transport models utilized in this work were: Surface Desorption, Bubble Desorption, and Aerosol Transport. A Monte Carlo approach was employed to determine which parameters contributed the most to air modeling variance (as measured by Spearman Rank Correlation Coefficients). Several runs were made with varying MHC chemicals and

bath configurations in this Monte Carlo analysis to ensure that results were representative of all processes. The parameters which consistently had the greatest effect on modeling outcome for all chemicals and baths were:

- Air Turnover Rate (ventilation rate divided by room volume) – contributed approximately 58% to model variance
- Process Room Volume – contributed approximately 37% to model variance
- Bath Area – contributed approximately 1-6% to model variance
- Chemical Concentration in MHC Bath – contributed approximately 1.5%

The air turnover rate assumption originally chosen for calculating air concentrations in the MHC process area was revised based on these results. The corrected air turnover rate which provided the 90th percentile frequency distribution was found to be 0.021 air turnovers/minute. A comparison of common design standards was made to validate the revised air turnover rate.

The only known MHC process which had an excess lifetime cancer risk was electroless copper: 1.19×10^{-3} . All other processes were evaluated for noncarcinogenic risks only because electroless copper had the only carcinogen with an established slope factor. The noncarcinogenic risks to Line Operators (the driving receptor) from MHC process baths were derived in terms of Hazard Index (HI) and Margin of Exposure (MOE). These risks are summations (reciprocal summation for MOE) of risk estimates across all pathways and chemicals for the receptor. HI is defined as the potential dose rate (exposure) divided by the reference dose, while MOE is defined as the potential dose rate divided by the No or lowest-observed adverse effect level. The total risks per process are presented in the table below.

Non-Carcinogenic Health Risks to Line Operators

Nonconveyorized MHC Processes	Hazard Index	Margin of Exposure
Electroless Copper	1.76E+02	0.21
Tin Palladium	1.52E+01	1.74
Organic Palladium	NA	NA
Non-Formaldehyde Electroless Copper	3.73E+00	9.20
Conveyorized MHC Processes	Hazard Index	Margin of Exposure
Electroless Copper	1.35E+01	1.78
Tin Palladium	4.75E+00	2.73
Organic Palladium	NA	NA
Conductive Polymer	NA	NA
Graphite	NA	9.0
Carbon	NA	2.64

NA = no toxicity data available

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List of Symbols

A	=	MHC process bath surface area
a	=	interfacial area of sparged bubble per unit volume of liquid
a_s	=	molar area of chemical (solute)
AT	=	averaging time for long-term exposure(days)
BW	=	body weight
C	=	concentration of chemical on skin after contact with bath
$C_{L,Y}$	=	aqueous concentration of chemical Y in process bath
C_W^S	=	saturated aqueous solubility of chemical
C_Y	=	workplace contaminant concentration in air
D	=	dermal exposure intake for chemical
d_b	=	air sparging bubble diameter
D_{O_2}	=	molecular diffusion coefficient for oxygen in water
D_Y	=	molecular diffusion coefficient for compound y in water
$D_{Y, air}$	=	molecular diffusion coefficient of chemical Y in air
ED	=	exposure duration (years)
EF	=	exposure frequency (times/year)
F_A	=	air velocity correction factor for aerosol model
F_D	=	distance between bath surface and tank rim correction factor for aerosol model
f_{IE}	=	fraction of bubble interface ejected as aerosols
F_T	=	temperature correction factor for aerosol model
$F_{Y,A}$	=	emission rate of chemical Y from sparged bath surface due to aerosol ejection and transport
$F_{Y,O}$	=	emission rate of chemical Y from open bath surface due to surface desorption
$F_{Y,S}$	=	emission rate of chemical Y from sparged bath surface due to bubble desorption
$F_{Y,T}$	=	total emission rate of chemical from all combined mechanisms
g	=	gravitational constant
γ_w	=	activity coefficient of chemical in water
h	=	depth of MHC bath tank
H_Y	=	dimensionless Henry's Law constant for chemical Y
HI	=	hazard index
HQ	=	hazard quotient
$\Delta H_{AQUEOUS}$	=	enthalpy of chemical in the aqueous phase
ΔH_{GAS}	=	enthalpy of chemical in the gaseous phase
IR	=	inhalation rate
k	=	dimensionless room air mixing factor
k_{IW}	=	water-interface partitioning coefficient
K_{OW}	=	octanol-water partitioning coefficient
$K_{OL,Y}$	=	overall mass transfer coefficient for compound y
K_{OL,O_2}	=	overall mass transfer coeff. for oxygen in water
K_p	=	skin permeability coefficient (penetration rate)
l_b	=	thickness of sparged bubble film at liquid surface
$LOAEL$	=	lowest observed adverse effect level
M_b	=	mass of contaminant in air sparging bubble
MF	=	modifying factor for toxicity adjustment
M_i	=	mass of contaminant at air-water interface
MOE	=	margin of exposure = $LOAEL$ or $NOAEL/PDR$
MW	=	molecular weight of chemical

NOAEL = no observed adverse effect level
 P_T = total pressure in MHC process area
 Q_G = sparging gas flow rate
 R = universal gas constant
 R_A = aerosol generation rate from sparging
 RfD = reference dose
 R_V = air turnover rate, or process room ventilation rate
 ρ_{AIR} = density of air
 ρ_{H2O} = density of water
 S = surface area of skin contacted by chemical
 $S.G.$ = specific gravity of chemical
 SF = slope factor
 σ_{sa} = surface tension coefficient of the solute-air interface
 σ_{sw} = surface tension coefficient of the solute-water interface
 σ_{wa} = surface tension coefficient of the water-air interface
 T = air temperature in MHC process area
 t_b = bubble rise time from bottom of MHC bath, or from air inflow point
 UF = uncertainty factor for toxicity adjustment
 μ_{H2O} = viscosity of water
 V = volume of liquid in MHC bath
 V_L = molar volume of chemical (solute)
 V_M = percentage volume proportion of MHC product mixture to the total bath volume
 V_R = process room volume
 V_z = air velocity across MHC bath surface
 Wt = chemical concentration in MHC product mixture, by weight
 z = distance across MHC bath surface (shortest length)

List of Acronyms and Abbreviations

CCPCT=	Center for Clean Products and Cleaner Technologies
CEBMEPA=	Chemical Engineering Branch Manual of the Environmental Protection Agency
CFR=	Code of Federal Regulations
CTSA=	Cleaner Technologies Substitutive Assessment
DfE=	Design for Environment Project
DM=	Direct Metallization MHC Process
EPA=	Environmental Protection Agency
HEAST=	Health Effects Assessment Summary Tables
HQ=	Hazard Quotient
HSBD=	Hazardous Substances Data Bank
IRIS=	Integrated Risk Information System
ISCLT=	Industrial Source Complex Long Term Air Dispersion Model
LADD=	Lifetime Average Daily Dose
LOAEL=	Lowest Observed Average Effects Limit
MF=	Modifying Factor
MHC=	Making Holes Conductive
MOE=	Margin of Exposure
MSDS=	Material Safety Data Sheet
NIOSH=	National Institute for Occupational Safety and Health
NOAEL=	No Observed Average Effects Limit
OSHA=	Occupational Safety and Healthy Administration
PDR=	Potential Dose Rate
PDS=	Product Data Sheet
PEL=	Permissible Exposure Limit
PWB=	Printed Wiring Board
RA=	Risk Assessment
RAGS=	Risk Assessment Guidance for Superfund Sites
RfD=	Reference Dose
RME=	Reasonable Maximum Exposure
SF=	Scope Factor
UF=	Uncertainty Factor
USEPA=	United States Environmental Protection Agency
VOC=	Volative Organic Company
WOE=	Weight of Evidence Carcinogen

Introduction

Printed circuit board manufacturing is a large and fast growing industry that impacts most of the globe. Every major industrialized country in the world has a need for the products produced by this industry, and most countries laminate wiring boards themselves. Many technological innovations of the last century require some circuitry, and it is likely that this trend will continue to increase in the future.

The portion of electroplating that is the most time consuming and difficult is the making holes conductive (MHC) process. This procedure applies a conductive layer to the surfaces of holes drilled through two-sided and multi-layer boards. Seven alternative technologies for the MHC process were reviewed and studied; they will be described in the next section.

The process of applying an electronically conductive layer to holes drilled through printed wiring boards has been described more as art than science. The plating quality and efficiency of a process are apt to change rapidly and require constant adjustment and monitoring by skilled operators. This has prompted manufacturers to generally disdain new MHC alternatives once they have successful ones in place, even if these alternatives may save money.

Each alternative consists of a series of steps of MHC process baths with various chemical compositions. The MHC process of each manufacturing shop is unique, owing to subtle variations in contact time, operating procedures, etc. Bath composition varies widely between alternatives, and their exact makeup is often proprietary information.

To date, a comprehensive evaluation of the effect of the MHC process on human health and the environment has not been conducted. Manufacturing facilities could potentially cause adverse health effects to humans and the environment even while complying with existing industry safety regulations and standards. In the past the printed wiring board (PWB) industry has been mainly concerned with the performance of MHC processes, but increased knowledge of chemical toxicity and its importance to worker health has sparked recent interest in this area (DfE Printed Wiring Board Project, 1995). It is important to ascertain the relative safety of these MHC processes so that informed decisions can be made.

The goal of this thesis is to quantitatively determine which MHC alternatives present the lowest health risk to humans given the available toxicity information. The

estimated exposures can also be used to refine the risk calculations as new toxicity information becomes available. This researcher's main contributions to the larger CCPCT project include: compiling information on MHC alternative process chemistries; creating a Visual Basic program automating calculations employing mass transfer models (Robinson, Cox, Swanson, and Jackson, 1997) and Risk Assessment fundamentals (USEPA, 1989); using an air dispersion model (ISCLT) to predict ambient air concentrations from MHC emissions; and performing the sensitivity and uncertainty analysis on the mass transfer models. The determination of human health risk in this work is accomplished through the following steps:

- Compiling manufacturer and supplier process data sheets which contain bath composition and makeup data and combining that information with Workplace Practices Survey data obtained from the CCPCT project (1996) to produce "generic" processes representative of each MHC alternative (Section II)
- Employing mass transfer models with "generic" process alternative characteristics to predict emissions of chemicals from MHC process baths and then using air dispersion models to predict air concentrations in the workplace and ambient air (Section I and II)
- Analyzing parameter assumptions in mass transfer and air models by performing quantitative sensitivity and uncertainty analyses, and validating results by comparison with Occupational Safety and Health Administration (OSHA) standards and existing ventilation guidelines (Section II)
- Calculating worker and general population health risk from MHC alternatives (Section II)
- Identifying 'risk-driving' process steps and chemicals in MHC alternatives so that comparisons about the relative safety of each process might be made (Section III)

There are three main sections in this work covering the above steps. The first section contains a brief overview of the printed wiring board industry including background information on the various MHC process technology alternatives and ends with a comprehensive review of the literature. This Literature Review covers the following topics involved in the quantification of risk: volatilization and air transport mechanisms; outdoor air dispersion modeling; dermal exposure and absorption

processes; exposure and risk assessment methodology; and sensitivity and uncertainty analysis procedures.

The second section covers the actual approach and analysis used in predicting risk to humans from MHC line facilities. This includes: the development of generic systems (parameter assumptions) representing each MHC line, compilation of toxicity information and assumptions, and tables presenting risk estimates for MHC lines.

The third and final section covers the results and conclusions of this work and brief recommendations are made concerning the future of the MHC process as employed in the PWB industry. An appendix is included which contains tables and information used in estimating exposure and risk to humans from the MHC process, and example calculations for all quantitative analyses performed in the work..

Section I: Literature Review

Background Information

Printed Circuit Board Industry

There are many different ways to apply a conductive layer to circuit boards. Multi-layer wiring boards represent the largest section of the industry, and require conductive holes through the layers. These holes are vertically drilled between layers and connect different wiring layouts between boards. The boards are made of non-conductive laminated epoxy-resin or glass material, and an initial layer of conductive material must be applied to them before the holes can be electroplated. This electroplating provides a layer of copper to the interior of the holes for the purpose of soldering compounds to the board. The MHC process begins after a panel has been desmeared¹ and ends once conductive material has been applied to the interior of the hole allowing for electroplating to occur (CCPCT, 1996).

The PWB manufacturing industry has changed a great deal in the past decade. The electroless copper process, a long-time industry standard, is no longer the favorite among all manufacturers, and its dominance of the market has slowly declined since the late 1980's (Carano, 1995). The process, though technically reliable and generally well understood, poses great environmental and human health concerns. It contains formaldehyde, a probable human carcinogen, and produces large amounts of chelated-copper waste. This has caused more stringent regulations to be placed upon the industry and provided the spark for suppliers to research and develop new MHC plating alternatives (Meyer *et al.*, 1994).

These alternatives differ primarily by the type of conductive coating that is applied to the inside walls of a hole. These new alternatives, known as direct metallization (DM) processes, were introduced to industry about ten years ago. Initially, there was a concern over the quality and reliability of boards produced with these direct metallization processes (Goldman, 1994). Once these issues began to be resolved, however, manufacturers saw other reasons for switching processes. DM processes provide significant advantages in the areas of waste reduction, cycle time, automation, product reliability, throughput, and employee safety (Goldman, 1994).

¹ The Desmearing step in MHC processes cleans excess epoxy/laminate material left inside holes after drilling through the board.

MHC Process and Chemistry Review

The main MHC alternatives to formaldehyde-based electroless copper involve the use of carbon black, conductive polymers, metallic coating, and conductive colloids. Electroless copper continues to have the largest usage share of the market followed by palladium-based alternatives, with the newer alternatives (e.g. conductive polymers) being used comparatively less. It is difficult to assign exact usage percentages across industry for each alternative without conducting further research since these numbers are constantly changing. All of these processes incorporate a sequence of MHC tanks, or baths, that have water rinse steps between them. These baths contain the chemicals for the various steps of the overall MHC process. The number of baths in a process can range anywhere from 3-4 to the high teens, depending on the alternative. PWBs are manually or automatically immersed into the baths so that chemicals can contact the surface of the boards, thus placing a conductive seed layer in the holes that can later be made more conductive with acid sulfate MHC baths.

The baths are often heated to maintain optimum conditions for plating. Fluid agitation in the form of air sparging and mixing is also employed in some of the baths to increase chemical contact between boards and through holes. Oxygen also acts as an extra stabilizer in the electroless copper system, and proper air sparging rates are vital to the operation of this process (Mandich and Krulik, 1993). These factors strongly affect the mass transfer rate of chemicals from the process tanks to the atmosphere and will be discussed later.

Electroless Copper Systems

The standard MHC method utilizing formaldehyde operates by applying a tin or palladium colloid onto the through-hole walls. This layer then acts as a catalyst for electroless plating of copper onto the walls of the hole which are now mildly conductive (Haynes and Ryan, 1994). Formaldehyde acts as a reducing agent in the autolytic copper bath, and is one of the main health safety concerns for this alternative (Mandich and Krulik, 1993). Electroless copper is the only alternative that contains formaldehyde. This process is notoriously variable with respect to board quality because of the problems involved with running and controlling a thermodynamically unstable bath (Meyer *et al.*, 1994). The Direct Metallization (DM) alternatives to electroless copper are all designed to remove the electroless copper step, and the basic difference between

DM processes lies in the method used to prepare the dielectric surface of holes for electrolytic coating (Haynes and Ryan, 1994).

Non-Formaldehyde Electroless Copper

This process is very similar to the traditional electroless copper scheme, but typically uses hypophosphite in place of formaldehyde in the electroless copper bath. Hypophosphite promotes the reduction of copper onto palladium catalyzed surfaces before standard electrolytic copper deposition is used to increase plating thickness. Further more it is nonautocatalytic, thereby insuring longer bath life because plate-out, or unwanted plating on boards, does not occur (CCPCT, 1996).

Palladium Systems (Direct Metallization)

This process was one of the earliest commercial successes of direct metallization, and is still a popular alternative to electroless copper (Carano, 1995). The system is similar to electroless copper, but employs palladium as the sole catalyst for subsequent electrolytic copper plating. Pre-conditioning stabilizers are used to cause the substrate to be covered with a higher density palladium coating than in traditional electroless copper systems (Haynes and Ryan, 1994). This denser palladium coating is conductive enough to eliminate the need for an intermediate electroless copper step. There are two basic versions of the DM palladium process in use: organic-stabilized and tin-stabilized.

Carbon Black Systems (Direct Metallization)

This process applies a conductive coating of carbon black to the insides of through holes which must then be oven dried. Micro-etching; a process that penetrates the porous layer of carbon and attacks the copper layer underneath, then removes the carbon black from the copper surfaces, but leaves it on the resin/board surface, which is not underlain by copper (Carano, 1995). There is some question as to whether this process can produce high-end, complex multilayer boards because it tends to leave carbon residues on the innerlayer copper surfaces (Haynes and Ryan, 1994).

Conductive Polymers Systems (Direct Metallization)

This DM alternative applies a conductive polymer film to the insides of through-holes. This polymer is formed and made adherent to the walls in a reaction where an immobile oxidant reacts with an organic compound in solution (CCPCT, 1996). As with

carbon black systems, however, there is some question regarding residues on complex multilayer boards (Haynes and Ryan, 1994).

Conductive Colloid/Graphite Systems (Direct Metallization)

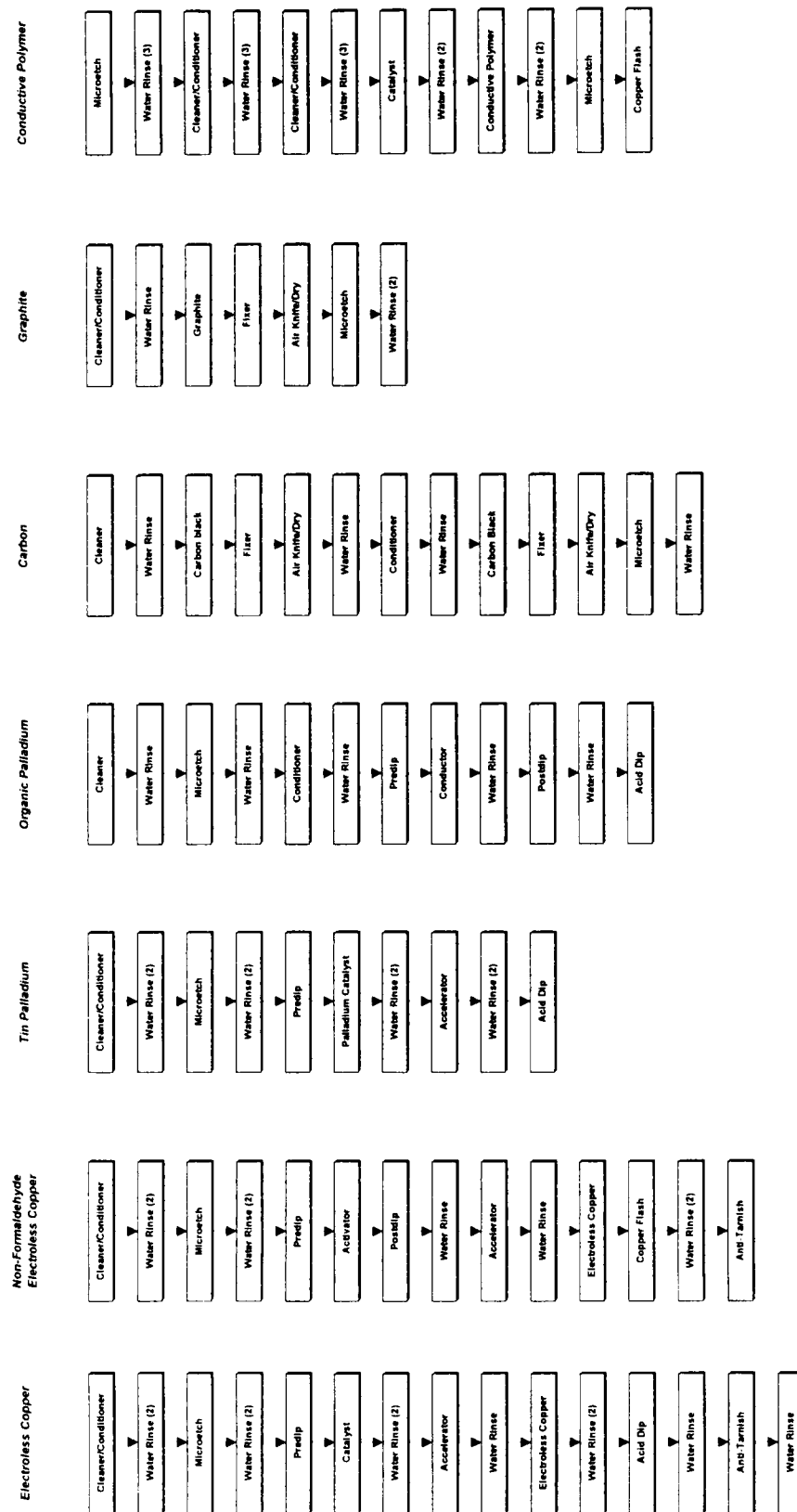
This process uses a colloidal dispersion of graphite particles that deposit on the through-hole walls. The boards are then dried and microetched, again removing the conductive colloid from the copper surfaces, but leaving it intact for very uniform electroplated copper deposits. The structure of colloiddally-based graphite in this system is different than that used in carbon black systems: carbon black is spherical in shape, while graphite is a two-dimensional, hexagonally structured polymer (Carano, 1995). Figure 1 outlines the basic process bath configurations used for each MHC alternative (CCPCT, 1996).

General Process Information

Different forms of automation are used for the alternatives. Methods range from manual hoisting and dipping of the boards to fully conveyorized lines which require human contact only for unloading boards from racks and periodic cleaning. Many of the newer DM alternatives employ conveyors. These conveyorized systems greatly reduce worker inhalation exposure by completely enclosing the system and using ventilation hoods throughout the process area to remove harmful airborne contaminants.

The hoisting and board transport system is important to health risk considerations because there are only two main routes by which contaminants from MHC lines can contact workers: dermal and inhalation exposure (CCPCT, 1996). Inhalation and dermal exposure are estimated using several modeling steps covered in this Literature Review. Chemicals in liquid MHC baths can enter the air phase through a variety of mechanisms. The following section will review volatilization and transport processes that occur in MHC operations, followed by a discussion of air mixing and dispersion.

Process Steps for MHC Process Alternatives



Note: (2) indicates 2 water baths in series, counted as one step

Figure 1. Process Steps for MHC Alternative.

Chemical Transport to Air from Plating Baths

The transfer of chemicals from water to air is of vital importance when studying the environment. There are many different mass transfer mechanisms involved which contribute to the large variability and difficulty associated with modeling these different systems. Volatilization of chemicals from water to air has been investigated by numerous researchers under many conditions (e.g. Liss and Slater, 1974; Smith *et al*, 1980; Roberts, 1983; Peng *et al*, 1993). This section covers research into the volatilization and transport of chemicals into the atmosphere and compares that research to the Printed Wiring Board Industry.

Contaminants can enter the air phase from open aqueous MHC process tanks by several processes: Diffusional Transport (Surface Desorption); Aerated Transport (Bubble Desorption due to aeration and sparging of the water phase); Aerosol Generation and Transport (due to bubble formation and bursting at the surface from sparging and electrolysis of plating tanks); movement of boards into and out of tanks causing splashing and dripping; and volatilization from the surfaces of boards (Robinson, Cox, and Swanson, 1995).

Diffusional Transport (Surface Desorption)

Nernst first developed the film model which Lewis and Whitman (1924) later applied to gas absorption. In this approach, each phase (i.e. gas and liquid) has an imaginary film layer of microscopic thickness at the interface between phases. The imaginary interfacial film in each phase can be considered stationary with respect to the bulk fluid. These boundary films limit the rate of mass transfer between the two phases to the rate of diffusion through each film, since advection controls mass transport in the bulk fluid and the interface itself is considered to have no resistance to transfer. Difficulties sometimes arise when applying this theory, however, because it requires a film layer thickness that is very difficult to measure experimentally in different aqueous systems.

Higbie (1935) proposed a mechanism for mass transfer across the interfacial layer known as the penetration theory. His theory states that a gas (air) near a liquid interface consists of parcels of molecules that move as a single mass for short periods of time, then dissipate and form new parcels due to constantly moving currents. As these parcels drift about, they come into contact with the interface for a brief period.

This allows for molecular diffusion to occur directly across the interface from the liquid to the gas. The parcels can then move away from the interface and dissipate, thereby transporting contaminants into the air phase. A problem associated with this theory occurs when estimating the average exposure time of the parcel with the liquid interface. Like the film theory, this parameter cannot be directly measured or estimated from an experiment.

Danckwerts (1951) revised the penetration theory by assuming that parcels of air could be in contact with the interfacial surface for a variable amount of time. He incorporates this variable, or fractional renewal rate into Higbie's theory. This is done by using a probability distribution function which predicts the amount of time that a parcel is in contact with the liquid surface before it is replaced by another one. There are also uncertainties associated with Danckwerts approach because values of the variable renewal rate are not available.

Toor and Marchello (1958; from Peng *et al.*, 1995) further developed this theory by improving the boundary conditions. They determined that the film and surface renewal theories were the limiting cases for low-turbulent and high-turbulent phase intensity systems, respectively. These methods can be used to bracket volatilization rates in systems which behave somewhere between the two extremes. Peng and Bewtra (1995) offered criticism of this theory because it does not correlate well with the intensity of turbulence in the bulk water phase. They developed a method for predicting the volatilization of compounds from turbulent water by relating the surface renewal process to gas absorption, which behaves similarly.

An equation employing the previous concepts was developed by the Chemical Engineering Branch of the EPA (USEPA 1991) and was validated by an independent laboratory. The foundations of this formula rely upon Higbie's air parcel approach and basic concepts allowing air currents flowing across the surface of a pool to increase the rate of volatilization. A mass balance of a differential element above a liquid surface is used to describe mass transfer. This yields a partial differential equation which is solved for boundary conditions with the following important assumptions (USEPA, 1991):

- Equilibrium is established in the system: this implies that the heat of (energy for) evaporation is provided by the surroundings and system temperature is constant in the area for diffusion.

- Heat transfer does not limit evaporation rate: when a highly volatile chemical evaporates quickly, the loss of heat will cool the liquid pool and may actually limit evaporation through a loss of available energy which makes the above assumption of equivalent system temperature invalid.
- No mixing occurs in the region of diffusion directly above the liquid: airflow is parallel to the pool surface and lower velocity and concentration gradient effects are ignored along the pool edges.
- Vapor pressure is below 5% of the total pressure of the system: at atmospheric pressure conditions this means that a vapor pressure ceiling of 35 Torr is established for chemicals. All chemicals that have a higher vapor pressure will not be modeled to within an order of magnitude accuracy.

The solved partial differential yields the equation that predicts volatilization (surface desorption) of chemicals from the uncovered surfaces of MHC tanks (EPA, 1991):

$$F_{Y,O} = 2 C_{L,Y} H_Y A \left[\frac{D_{Y,AIR} V_Z}{\pi z} \right]^{0.5} \quad (1)$$

where:

- $F_{Y,O}$ = volatilization (emission) rate of chemical Y from open bath surface (m/t) - the subscript O denotes flux due to open surface volatilization (desorption)
- $C_{L,Y}$ = concentration of chemical Y in process bath (m/l³)
- H_Y = dimensionless Henry's constant for chemical Y (adjusted for temperature, see aerated system section)
- A = process bath surface area (l²)
- $D_{Y,air}$ = molecular diffusion coefficient of chemical Y in air (l²/t)
- V_Z = average air velocity across bath surface above a laminar boundary layer (assumed to be of zero height in derivation) (l/t)
- z = distance across bath surface (l)

The air molecular diffusion coefficient, D_Y , can be estimated with the following unit-specific formula derived by linear regression of molecular weight and temperature data (USEPA, 1991):

$$D_{Y,AIR} = 4.09E-5 T^{1.9} (1/29 + 1/M)^{0.5} M^{-0.33} / P_T \quad (2)$$

where:

- $D_{Y,AIR}$ = molecular diffusion coefficient, unit specific (cm²/mol)
- T = air temperature (K)
- M = molecular weight (g/mol)
- P_T = total pressure (atm)

Equation 2 is based on kinetic theory by Chapman and Enskog and consistently provides values for D_v that correlate well with experimental fits of the Lennard-Jones potential versus molecular weight and temperature (USEPA, 1991). Criticism of this model is that it was developed to predict volatilization rates for pure chemicals and thus implicitly assumes that mass transfer resistance on the gas side is limiting. This assumption should hold true in the model for most substances except highly-volatile chemicals where liquid-side mass transfer controls. This approach will slightly overestimate volatilization for highly-volatile substances.

In more dilute solutions (like those encountered in MHC baths) larger concentration gradients are required to sustain steady diffusive fluxes at the air-water interface (Mackay, 1991). Diffusive resistance may not entirely reside in one phase for some substances as well. Again, this only becomes a problem when Henry's Law constant becomes large and flux is dependent on the concentration in water and the water-phase diffusional resistance. The model's propensity to overestimate volatilization with these substances arises from the important vapor pressure assumptions mentioned earlier. The largest errors could occur when using this equation if long pool lengths, slow air wind velocities, or highly-volatile substances are being modeled.

Aerated Transport (Bubble Desorption)

The two-film model of gas transfer was expanded in 1981 to incorporate mass transfer rates in artificially aerated systems (Matter-Müller *et al.*, 1981). It has been used on several occasions to model volatilization rates in systems under low-turbulent intensity conditions (Parker *et al.*, 1993; Hsieh *et al.*, 1994) such as forced aeration or naturally aerated systems (e.g. municipal water treatment facilities). Matter-Müller *et al.* assumed that the system was isothermal, hydraulic conditions were stable, and that pressure and volume changes within bubbles were negligible. Further, an overall mass transfer coefficient was applied to represent transfer of contaminants to the bubbles as they rose through the homogeneous liquid volume. These assumptions are consistent with situations encountered in PWB sparged MHC baths.

The overall liquid mass transfer coefficient is defined below (Pontius *et al.*, 1990):

$$\frac{1}{K_{OL,Y}} = \frac{1}{k_L} + \frac{1}{k_G \cdot H_Y} \quad (3)$$

where:

$K_{OL,Y}$	= overall liquid mass transfer coefficient (cm/s)
k_L	= liquid phase mass transfer coefficient (cm/s)
k_G	= gas phase mass transfer coefficient (cm/s)
H_Y	= Henry's Law constant (dimensionless)

$K_{OL,Y}$ is commonly set equal to the liquid phase coefficient in aerated systems because molecular diffusion of oxygen and nonpolar organic substances is 1000 times greater in air than in water (Emerson, 1975, as cited in Matter-Müller *et al.*, 1981). Theory dictates that the liquid-phase mass transfer coefficient for different compounds can be related by the ratio of their diffusion coefficients, and this approach is applied in the Matter-Müller model. Munz and Roberts (as cited in Parker *et al.*, 1993) reported that a ratio of 20 should be employed for the gas to liquid-phase mass-transfer coefficients (k_G/k_L) for bubble aeration. In the work of Parker *et al.*, and others, this assumption has proved to be accurate in predicting the stripping performance of VOCs from municipal activated sludge plants.

Using the constant ratio between k_L and k_G mentioned above, Parker *et al.* (1993) found that the contribution of variable resistance in the gas phase was minimal because the off-gas fractional saturation (actual amount stripped from bubbles versus the product of water phase concentration and Henry's Law) for almost all compounds was near or at 1. The results of Matter-Müller *et al.* also agree with these findings; at the liquid depths in MHC baths which sparged bubbles would rise through, the percentage of saturation of the exit gas was almost at equilibrium for most chemicals. The assumption of liquid-phase mass-transfer resistance is therefore applicable to these types of systems. Additionally, Parker *et al.* found that the type (fine or coarse) of air diffusers in these systems had virtually no effect on gas-phase partitioning. They reasoned that the lower mass-transfer efficiencies of the coarse bubble diffusers were sufficiently high to attain gas-phase saturation of the compounds and that the fine bubble diffusers did not further increase the gas-phase concentrations, despite the higher mass-transfer capability available (Parker *et al.*, 1993).

As oxygen is liquid-phase mass-transfer controlled, its overall mass transfer coefficient and diffusion coefficient is used to estimate overall mass-transfer coefficients

for volatiles under the same conditions. From these concepts, the mass transfer coefficient of a compound is related to oxygen using the following equation (Matter-Müller *et al.*, 1981):

$$K_{OL,Y} = \left(\frac{D_Y}{D_{O_2}} \right) K_{OL,O_2} \quad (4)$$

where:

- D_Y = Molecular diffusion coefficient for compound y in water (cm²/s)
- D_{O_2} = Molecular diffusion coefficient for oxygen in water (cm²/s)
- $K_{OL,Y}$ = Overall mass transfer coeff. for compound y in water (cm/s)
- K_{OL,O_2} = Overall mass transfer coeff. for oxygen in water (cm/s)

A relationship given in Bailey and Ollis (1977) can be used to estimate K_{OL,O_2} at 25 °C in aerated systems:

$$K_{OL,O_2} = 0.31 \left(\frac{d_b^3 (\rho_{H_2O} - \rho_{AIR}) g}{\mu_{H_2O} D_{O_2}} \right)^{1/3} \frac{D_{O_2}}{d_b} \quad (5)$$

where:

- d_b = bubble diameter (cm)
- ρ_{H_2O} = density of water (m/l³)
- ρ_{AIR} = density of air (m/l³)
- g = gravitational constant (l/t²)
- μ_{H_2O} = viscosity of water (m/l · t)

Molecular diffusion coefficients (D_Y in Eq. 4) are often not available for chemicals in water, necessitating that they be estimated. Hayduk and Laudie have developed an empirical correlation for D_Y (avg. abs. error 5.8%) from Lyman *et al.* (1982):

$$D_Y \text{ (cm}^2 \text{ / sec)} = \frac{13.26E - 5}{\mu_{H_2O}^{1.14} \cdot V_M^{0.589}} \quad (6)$$

where:

- V_M = molar volume of solute (cm³/mol)
- μ_{H_2O} = viscosity of water (centipoise)

Once calculated, the mass transfer coefficient must be corrected for temperature of the bath with the following correlation (Tschabanoglous, 1991):

$$K_{OL,Y @ \text{Temp } T} = K_{OL,Y @ 25^\circ \text{C}} \cdot 1.024^{(T-25)} \quad (7)$$

A relationship predicting the mass transfer rate from an aerated system can then be obtained using the above equations and the following postulations: the liquid-phase concentration remains constant during the rise time for a single bubble and the gas-phase concentration increases as the bubble rises through it. This assumption was proved to be reliable under differing aeration and airflow rates by Parker *et al.* (1993). The equation takes the form:

$$F_{Y,S} = Q_G H_Y c_{L,Y} \left[1 - \exp \left(\frac{K_{OL,Y} a V_L}{H_Y Q_G} \right) \right] \quad (8)$$

where:

- $F_{Y,S}$ = mass transfer rate of compound y out of the system ($M t^{-1}$)
where subscript S denotes flux due to bubble desorption (sparging)
- Q_G = gas flow rate ($l^3 t^{-1}$)
- H_Y = dimensionless Henry's Law constant for substance y
- $c_{L,Y}$ = concentration of substance y in bulk liquid ($M l^{-3}$)
- $K_{OL,Y}$ = overall mass transfer coeff. for compound y ($l t^{-1}$)
- a = interfacial area of bubble per unit volume of liquid ($l^2 l^{-3}$)
- V_L = volume of liquid (l^3)

Henry's law constants are very sensitive to changes in temperature and must first be corrected for bath temperature with the Van't Hoff equation before being used in Eq. 7, or Eq. 1:

$$H_{Y @ TEMP T} = H_{Y @ 25^\circ C} \exp \left[\frac{\Delta H_{GAS} - \Delta H_{AQUEOUS}}{R} \left(\frac{1}{298.15} - \frac{1}{273.15 + T} \right) \right] \quad (9)$$

where:

- ΔH_{GAS} = enthalpy of the chemical in the gaseous phase (cal/mol)
- $\Delta H_{AQUEOUS}$ = enthalpy of the chemical in the aqueous phase (cal/mol)
- R = universal gas constant (1.987 cal/mol · K)

The interfacial area of the bubble (a in Eq. 8) is determined using another correlation given in Bailey and Ollis (1977):

$$a = \frac{6 Q_G t_b}{V_L d_b} \quad (10)$$

where:

- t_b = bubble rise time from bottom of tank, or air inflow point (t)

This t_b is estimated by the following equation:

$$t_b = \frac{18h \mu_{H_2O}}{d_b^2 (\rho_{H_2O} - \rho_{AIR})g} \quad (11)$$

where: h = depth, or height of bath tank (l)

Matter-Müller *et al.* (1981) concluded that surfactants do not significantly alter the rate of volatilization from the water. Some agents did lower the overall mass transfer coefficient, but most showed no appreciable difference. Agents exhibiting a change were thought to increase the specific interfacial area a , while the mass transfer coefficient, or interfacial energy, was decreased.

The transfer rate of VOCs was found to depend heavily upon two things: the type of aerators used; and the degree of VOC saturation of the exit gas with respect to the VOC concentration in the bulk liquid. This exit gas saturation must be relatively high to employ Eq. 8, but this is not a concern unless the liquid depth that bubbles rise through is relatively small. In an experiment by Mackay *et al.* (1979; from Matter-Müller *et al.*, 1981) bubbles reached 80% saturation (liquid conc. in equilibrium with gas phase concentration over bulk liquid conc.) after rising through 10 cm of liquid containing benzene. MHC process baths are much deeper than this, and should provide ample space for exit gas saturation to occur with VOCs.

Matter-Müller's model is sensitive to changes in the air sparging rate, Henry's constant, temperature, and the liquid-phase chemical concentration. A sensitivity and uncertainty analysis of the three combined air models (Surface Desorption, Bubble Desorption and Aerosol Transport) is included later in Section II.

Criticism of this method is offered by Kyosai and Rittman (1991) and Roberts *et al.*, (1983), because the Matter-Müller approach does not address the subject of water-surface desorption. Past studies have not differentiated between bubble and surface desorption for oxygen transfer because it is dominated by bubble desorption, with surface aeration contributing only a few percent of the total oxygen transfer rate (Kashiwaya *et al.*, 1971; from Kyosai and Rittman, 1991). Surface desorption is accounted for, however, in this approach by using the CEBMEPA equation covered

earlier. Adding the effects of these two mechanisms is more accurate and is recommended for VOCs by Kyosai and Rittman (1991), although it may slightly overestimate volatilization.

Aerosol Generation and Transport

Aerosol generation is another important factor when determining the amount of mass transfer from aerated water-bodies to air. Aerosols are created by surface waves, or aeration of the fluid body, or by electrolysis of water. Bubbles are formed at the surface and then burst, ejecting small droplets of water into the air that contain contaminants. These smaller droplets then form aerosols and become stable in the air phase. Many researchers have investigated the formation of droplets from bubbles at the surface (Blanchard, 1963; Tomaidēs, 1976; Newitt, 1953). The results of that work are discussed below.

Blanchard (1963) investigated droplets that formed when bubbles burst at the water surface. The bubbles that formed fall into two categories: film and jet droplets. Jet droplets are formed when a bubble bursts at the surface and the cavity from the bubble rebounds upwards. When this happens, droplets are released to the air. The number of jet droplets created depends upon the bubble size, and the depth from which the bubble rises (Blanchard and Syzdek, 1975). Film droplets are smaller than jet drops, and are created when the film at the bubble surface breaks up. Illustrations showing the jet drop diameter and the number of film droplets produced versus bubble diameter can be seen in Figures 2 and 3, respectively.

Blanchard (1963) was able to estimate the number of film droplets formed, but was unable to measure the size of those drops. He concluded that high temperatures formed larger jet drops, and water salinity had no noticeable effects on film or jet droplet production. Surfactants also seemed to have little effect on film droplet production.

Film droplets would seem to be less important from a mass transfer perspective than jet droplets because the total volume of fluid ejected is small. This is not the case, however, as jet droplets cannot attain escape velocity and fall back into solution while most film droplets are converted into aerosols immediately. Film droplets tend to contribute the most to mass transfer because of their potential for forming stable aerosols. The contribution from jet droplets also decreases as larger bubbles are

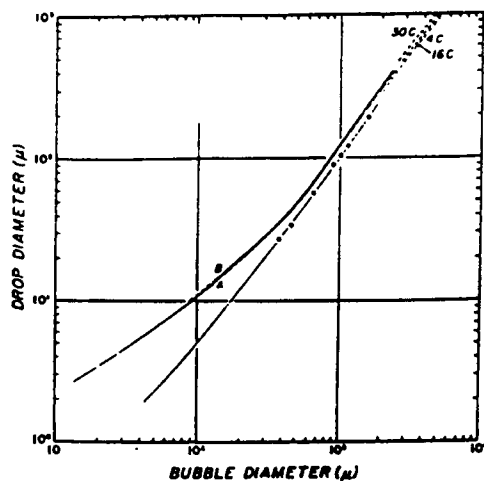
formed at the surface because large bubbles produce fewer jet droplets (Blanchard and Syzdek, 1975).

Blanchard (1981) found that jet droplets are approximately 1/10 the bubble diameter, and that the number of droplets formed per bubble ranges from about 1 for bubbles greater than 6 μm to 6 for bubbles 30 μm in diameter. The first jet drops formed for each bubble are ejected higher into the air than the later ones, and therefore have a higher potential to form stable aerosols than the later ones (Blanchard and Syzdek, 1975). Film droplet size did not vary much, but the number of droplets varied from 100 for a 2 mm bubble to 1,000 for a 6 mm bubble.

Applying this approach to aerosol formation does have problems because the data has been measured under very specific conditions (bubble diameter, bubble rise time, etc.) and may only be accurate under those conditions. It does provide a good estimate for predicting the behavior of aerosol generation though, particularly when considering that data is scarce for these processes. Once an average bubble size has been determined for a particular system, the volume of mist generated for that system can be calculated from basic concepts. If the droplets formed are assumed to have the same concentration of contaminant in them that the water has, then an air concentration of the contaminant can be determined.

Berglund and Lindh (1987), and Wangwongwatana et al. (1988) have conducted research into aerosol formation in sparged electroplating tanks. In electroplating baths, the main sources for airborne contaminants are evaporation (previously discussed), gas generation due to chemical reactions, and mist generation where small droplets of similar makeup to bath concentration become airborne. The third source is composed of three main mechanisms: application of an electric current to the bath for electroplating (electrolysis) which dissociates water and causes bubbles to form, air sparging used to agitate baths, and dripping liquid caused by moving boards between baths (drag-out losses).

Drag-out losses have been shown negligible when compared to the other mist sources (Berglund and Lindh, 1987). In their research, Berglund and Lindh found the aerosol generation rate to be inversely proportional to bubble size. This is consistent with the earlier findings of Blanchard and Syzdek (1975). The bubbles formed by electrolysis are much smaller than those formed by air sparging, causing electrolysis-



CURVE	WATER TYPE	WATER TEMP	JET DROP POSITION
A	SEA WATER	27-28°C	TOP
B	"	"	SECOND
C	"	40	TOP
---	"	4.16 & 30 C	TOP

Figure 2. Jet Drop Diameter as a Function of Bubble Diameter.

Source: Blanchard, D.C., "The electrification of the atmosphere by particles from bubbles in the sea," *Progress in Oceanography*, 1, 1963.

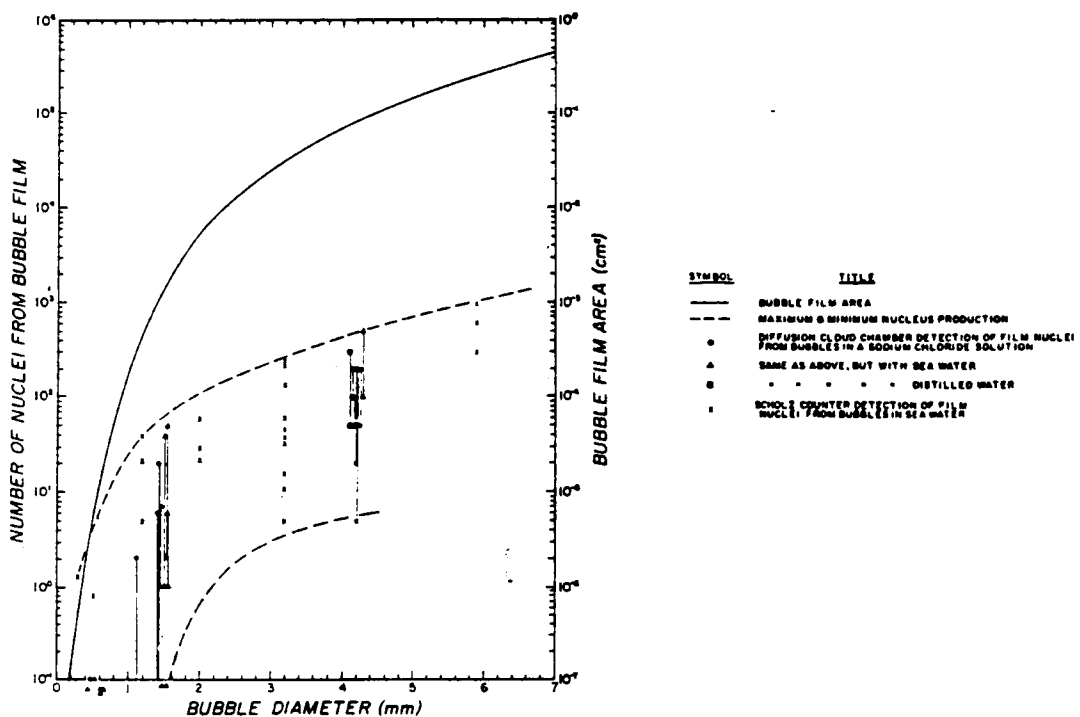


Figure 3. Film Drops and Film Area as a Function of Bubble Diameter.

Source: Blanchard, D.C., "The electrification of the atmosphere by particles from bubbles in the sea," *Progress in Oceanography*, 1, 1963.

induced mist generation to be two orders of magnitude greater than air-sparged mist generation. Interestingly, Berglund and Lindh report that aerosol generation is actually lessened by air sparging in electroplating tanks. This probably occurs because the larger bubbles produced by air sparging combine with the smaller electroplating bubbles and prevent them from escaping to the atmosphere.

Wangwongwatana *et al.* (1988) also investigated aerosol generation from baths. Both sets of researchers developed empirical estimation methods that provide similar results. The Berglund and Lindh model is employed in this work because it is simpler to use and provides slightly more conservative estimates (CCPCT, 1996). In this model, mist generation caused by air agitation is related to the effects of bath temperature, air velocity, and distance from the liquid surface to the tank rim. These effects are addressed in this method through the use of correction factors, referenced in the literature with graphs. The effects of surface tension were also studied by Berglund and Lindh (1987) but were found to be negligible where sparging was concerned. Using the graphs outlined above, the following equation can be derived to describe aerosol generation:

$$R_A = \left[\left(5.5 \times 10^{-5} \right) \left(\frac{Q_G}{A} \right) + 0.01 \right] F_T F_A F_D \quad (12)$$

where:

- R_A = aerosol generation rate (ml/min/m²)
- Q_G / A = air sparging rate per unit bath area (L/min/m²)
- F_T = temperature correction factor
- F_A = air velocity correction factor
- F_D = dist. between bath surface and tank rim correction factor

This equation is basically a derivation of the various correction factors outlined in the equation above. Each of the factors, F_T , F_D , and F_A represent a controlled set of experiments with the apparatus where only that factor was varied. The corresponding effect on the aerosol generation rate was then plotted for each of these individual experiments. The air sparging rate per unit of bath area was empirically-fit with the model, so the units above (L/min/m²) must be used in the equation, to maintain continuity with the experimental results. The outcome from this equation will be combined with an estimate of the chemical concentration in a bubble to determine an emission rate.

A best-fit regression can be performed for the three correction factor graphs to provide equations for ease of calculation. Polynomial regressions of these graphs were performed using an Excel® spreadsheet. This is covered in greater detail under section II.

To utilize this equation one must ascertain what concentration of contaminants is present in the aerosols. Wangwongwatana *et al.* (1990) reported that polystyrene spheres representing colloidal contaminants were present in aerosols at approximately 125 times their concentration in the bath. Adhesion of colloidal particles to bubble surfaces and organic partitioning at the air-water interface are two mechanisms that can elevate contaminant concentrations at the interface of bubbles as they rise through the bath.

Hoff *et al.* (1993) developed a ratio relationship to describe enhanced organic partitioning at the air-water interface. This equation relates the mass of contaminant sorbed at the air-water interface to the mass of contaminant in the gas volume of the bubble:

$$\frac{M_i}{M_b} = \frac{k_{IW}}{H_Y(d_b / 6)} \quad (13)$$

where: M_i = mass of contaminant at interface
 M_b = mass of contaminant in bubble
 k_{IW} = water-interface partitioning coefficient (l)

The water-interface partitioning coefficient is defined as a ratio of the mass of contaminant per unit area of interface to the mass of contaminant per unit volume of water. Hoff *et al.* developed two equations defining this coefficient for polar and nonpolar compounds. For nonpolar compounds, the following equation is used to calculate the interfacial partitioning coefficient:

$$\log k_{IW} = -8.58 - 0.769 \log C_w^S \quad (14)$$

where: C_w^S = saturated aqueous solubility of the contaminant (m/l³)

For polar compounds the following equation applies:

$$\log k_{IW} = -7.508 + \log \gamma_w + \frac{a_s(\sigma_{wa} - \sigma_{sa} - 1.35\sigma_{sw})}{2.303RT} \quad (15)$$

where:

γ_w	= activity coefficient of contaminant in water (dimensionless)
a_s	= molar area of the solute (cm ² /mol)
σ_{wa}	= surface tension coefficient of the water-air interface (dyne/cm)
σ_{sa}	= surface tension coefficient of the solute-air interface (dyne/cm)
σ_{sw}	= surface tension coefficient of the solute-water interface (dyne/cm)
R	= universal gas constant (8.314E7 erg/mol K)
T	= temperature of bath (K)

From earlier concepts covered, it is understood that only a fraction of the bubble surface (film interface) will be ejected into the air as aerosols and attain escape velocity. This fraction is calculated from the following equation (CCPCT, 1996):

$$f_{IE} = \frac{R_A A d_b}{6 Q_G l_b} \quad (16)$$

where:

f_{IE}	= fraction of bubble interface ejected as aerosols (unitless)
l_b	= thickness of bubble film (l)

Combining these above concepts, the rate of mass transfer from the tanks contributed by aerosol generation, $F_{Y,A}$, may be calculated:

$$F_{Y,A} = \frac{M_l}{M_b} f_{IE} F_{Y,S} \quad (17)$$

where: $F_{Y,A}$ = mass transfer rate, as above, subscript A denotes aerosol

Air Dispersion Modeling

Calculation of Indoor Chemical Air Concentrations

Concepts covering chemical emissions from process tanks to air have been covered. Three models were presented to predict emissions from air sparged process tanks. These models covered pathways by which contaminants in baths could enter the air phase. These pathways were: direct volatilization from the open surface of tanks; volatilization due to sparging the tanks with air; and aerosol transport due to the bursting of sparging bubbles at the surface. The contributing emission rates from each of these pathways were added to determine chemical concentration in the room. The open surface diffusion equation was used to model process tanks that were not sparged with air while all three models were employed to estimate emissions from sparged baths. To combine the contributions from each of these models and calculate an average air concentration in the workplace the following equation can be used (USEPA, 1991):

$$C_Y = \frac{F_{Y,T}}{(V_R R_V k)} \quad (18)$$

where:

C_Y	= workplace contaminant concentration in air (mg/m ³)
$F_{Y,T}$	= total emission rate of chemical from all sources combined, surface + bubble desorption + aerosol transfer (mg/min)
V_R	= process room volume (m ³)
R_V	= process room ventilation rate, or air turnover rate (min ⁻¹)
k	= dimensionless mixing factor

There are several important assumptions associated with using this equation to predict air-phase chemical concentration. First, air movement in the process room is difficult to characterize given the predominance of eddies and stagnant mixing areas. This leads to the realization that stratification of air will almost always occur in large-scale process rooms, creating zones of higher contaminant concentration. To help account for this EPA (1991) adds the dimensionless mixing factor k . They recommend values ranging from 1 for a best case, or ideal mixing scenario, to 0.1 for a worst case scenario. This may alleviate some of the mixing and stratification problems associated with the CEBMEPA equation, but it also adds additional uncertainty.

A second important assumption with this method is that the emission rates from all three models are additive. Combining these emission rates may overestimate

volatilization. Kyosai and Rittman (1991) used Matter-Müller's (1981) bubble desorption model with volatilization studies of several VOCs. They found that surface desorption can account for as much as 60% of the transfer of VOCs, even though it only accounts for 6% of oxygen transfer. The results of their study concluded that surface desorption is typically more important than bubble desorption in these systems (with VOCs) and that the total desorption rate should be the sum of the rates of bubble and surface desorption. This is consistent with the approach used in this work: the total emission rate is equal to the sum of the surface desorption rate, bubble desorption rate, and aerosol emission rate.

The method proposed for estimating air-phase chemical concentrations in the workplace contains abstract concepts and empirical parameters that are in some cases difficult to estimate. However, combined with an uncertainty analysis, the methods should provide a reasonable estimate of the range of chemical concentrations that could be expected. Addition of volatilization rates from the three mechanisms may include a built-in factor of safety if this approach overestimates the overall rate of volatilization. The air-phase concentrations predicted by these equations will be used to estimate worker exposure by the inhalation pathway as described later.

Calculation of outdoor (ambient) air concentrations using ISCLT2

The general population can be exposed to substances used in MHC processes by breathing contaminated air released from nearby manufacturing facilities. This air, once released, will mix and be carried along by wind currents. The fate of contaminants in outside air is highly dependent on weather conditions, so site conditions greatly affect the predicted ambient air concentrations. Compounds can also be degraded in outside air through a variety of transformation mechanisms such as photooxidation and hydrolysis. Chemical concentrations will decrease as distance from the manufacturing plant increases, but quiescent air conditions near the facility could cause air concentrations to be very high in a localized area.

To simulate outdoor air concentrations resulting from plant releases, a typical, or generic facility must be developed with which the model can be run. This generic plant is chosen to facilitate a conservative estimate for ambient air chemical concentration, since these concentrations will be much lower than indoor ones. This means that risks

associated with outdoor air exposures will likely be several orders of magnitude lower than those associated with breathing indoor air.

To model ambient (outdoor) chemical air concentrations, the Industrial Source Complex Long Term (ISCLT) model can be used. ISCLT was chosen in this work because previous CTSA's had employed this model and it was accepted by EPA. ISCLT can be reviewed under EPA's *User's Guide for the Industrial Source Complex (ISC2) Dispersion Models, Vol. 1 & 2* (EPA, 1992a). It is based on the emission rate of contaminants and local meteorological conditions such as wind speed, direction, and atmospheric stability that influence the mixing of a contaminant stream with a surrounding body of air (Hampshire Research Inst., 1994). Air dispersion models describe the way wind speed and turbulence move contaminants through the atmosphere using a straight-line Gaussian, or "normally-distributed" dispersion equation.

This Gaussian equation describes concentration at a given point as a function of its downwind and crosswind distance from the point of emissions (Hampshire Research Inst., 1994). Crosswind concentrations are represented by a normal, bell-shaped curve with concentrations decreasing as distance (outward) along the crosswind increases.

ISCLT calculates annual-average concentrations from an emissions source based on seasonal, or annual-average wind and meteorological data for a given location. A short-term version of the model uses hourly wind data to determine the concentration plume, but it is not employed in this work. There are two main reasons for using the long-term model variation here: the estimated steady-state emission rates from MHC tanks are obtained with assumptions best characterized as long-term averages of oscillating parameter values, and the ambient air concentrations will be used to calculate exposures which are compared to long-term averages of dose-response rates for both chronic non-carcinogenic hazard indicators and for cancer risk.

ISCLT operates by partitioning seasonal or annual emissions from the source among sectors (divisions occupying an equal amount of degrees) based on the frequency, or probability of wind blowing toward the sectors (Hampshire Research Inst., 1994). The assumption with this approach is that a uniform lateral distribution exists across the sector width. The program uses several implicit assumptions based on EPA's (1992a) default regulatory modeling options that include: final plume rise, stack-tip downwash, buoyancy-induced dispersion, default wind profile exponent values,

default vertical potential temperature gradients, and the use of upper bound estimates for low profile ("super squat") buildings having an influence on lateral dispersion.

The final plume rise and buoyancy assumptions employ the notion that as a contaminant plume moves downwind, it not only becomes dispersed laterally (Gaussian dispersion), but also becomes elevated and disperses vertically because of momentum and increased temperature from the stack. Stack tip downwash effects attempt to account for winds blowing across the mouth of a stack and causing the initial release height of contaminants to be lower (EPA, 1992a).

Wind profile exponents and vertical temperature gradients relate recorded wind data to the Pasquill atmospheric stability rating (Hampshire Research Inst., 1994). This stability rating system classifies the dispersive capacity of the atmosphere based on wind speed, insolation, and cloudiness, and uses six stability classes. The wind power law is used to adjust observed wind speeds from reference anemometer heights to the heights where contaminants are released. The vertical temperature gradient correction is used in the same manner. Buildings that are close to a release source may influence dispersion by creating wakes and causing concentrations to elevate locally. These default assumptions are recommended by EPA (1992a) for use with ISC-LT and are used to provide upper end, conservative estimates of air concentration.

Risk Assessment

The models presented previously were used to provide estimates of chemical air concentration. The results from these models are employed to assess the impact of the MHC process on humans by calculating exposures (intakes) and comparing them to dose levels which have been shown to cause adverse effects. In risk assessment (RA), this is accomplished through a series of four steps: hazard identification, toxicity evaluation, exposure assessment, and risk characterization (EPA, 1989a). These steps are designed to provide the most scientifically valid estimates of the potential for adverse effects from a site or occupational exposure. Several works presented by EPA and other researchers provide guidance in conducting risk assessments: *Risk Assessment Guidance for Superfund (RAGS): Human Health Evaluation Manual Part A and Part B* (EPA, 1989a and 1989c); *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors* (EPA, 1991a); *Health Effects Summary Tables* (HEAST) (EPA, 1993b); *CTSA Guidance Manual* (CCPCT, 1996).

Hazard Identification

The first step of a risk assessment as defined by EPA (1989a) is the two part process of data collection and hazard identification. In this phase of a risk assessment, the assessor collects data on contaminants and the environmental media in which they reside, addresses modeling parameter needs, and conducts a preliminary exposure assessment. Quality assurance and control measures should be implemented throughout the risk assessment. Hazard identification classifies chemicals that are of potential concern to human health and begins to identify how they may come into contact with the body.

Exposure Assessment

The objective of the exposure assessment is to estimate the type and magnitude of exposures to chemicals of concern that originate from the process or site being studied. A conceptual site model is created to describe all potential exposure pathways where a contaminant can encounter humans. The magnitude of exposure as potential dose rate (PDR) is defined as the amount of toxic agent that is available at exchange boundaries such as the lungs, skin, intestinal tract, or other target organ (EPA, 1988). Each pathway should be considered before modeling and data collection or monitoring begins. An exposure pathway must have four parts it can be considered complete: a

source of contamination, a transport or release mechanism, and an exposure point and exposure route (EPA, 1989a). For example, a buried waste might volatilize and contaminate the air and then be inhaled by a receptor that is within the zone of contamination. This example represents a complete exposure pathway, but if the exposure route is removed, it is no longer a complete pathway. This refers to the point at which the receptor is exposed to the media; i.e. the receptor wears a gas mask, thereby eliminating the intrusion of contaminated air which he would have contacted otherwise. By eliminating pathways in this manner, the calculation efforts can be reduced by only addressing those pathways which are complete and provide the majority of exposure potential.

The two pathways where occupational exposure from MHC chemicals can occur are inhalation and dermal contact (CCPCT, 1996). Quantification techniques for these two exposure mechanisms are discussed below.

Dermal Contact with Chemicals in Water

Dermal contact with chemicals from MHC processing tanks can occur during sampling, replenishment, regular maintenance, and wiring board transit (CCPCT, 1996). When these activities take place the potential exists for skin to become temporarily coated with the chemicals in solution. These chemicals can evaporate from the skin and sorb onto the outermost layer of the epidermis, the stratum corneum. Once sorbed, chemicals can permeate the skin's diffusional barriers and enter the circulation system through capillaries at the inner dermal boundary. This process is very complicated and skin absorption studies have traditionally focused on physico-chemical and biophysical factors due to a lack of knowledge regarding absorption (EPA, 1992). Recent discoveries have expanded knowledge of the functional characteristics of this organ, however, and suggest that it should be viewed as having permeability attributes which are susceptible to great change (EPA, 1992).

Several methods exist for determining exposure to chemicals from dilute aqueous solutions which employ numerous assumptions. The stratum corneum is thought to provide the main barrier to absorption of substances deposited on the skin (EPA, 1992). It is typically modeled as a two-phase (lipid and protein) system; several researchers provide results consistent with this assumption (Raykar, 1988; Elias, 1987). This method attempts to relate the absorption of compounds through the skin to

diffusivities in different phases of the skin. The two phases provide several passive diffusion routes through which contaminants can enter the bloodstream. Compounds with low ($< 1,000$) octanol-water partition coefficients (K_{ow}) are taken up by the protein domain in the stratum corneum, while more lipophilic substances move through the lipid phase. Micheals (1975; as cited in EPA, 1992) stated that the more lipophilic compounds were better skin penetrants. Skin appendages like hair follicles and sweat glands provide another route for compounds to penetrate, but their effects are largely negligible since they occupy less than 1% of the skin surface.

The key parameter for estimating dermal absorption and associating these concepts to chemical intake is the permeability coefficient, K_p (EPA, 1992). Other important parameters are skin thickness, age, hydration, and temperature. It is commonly assumed that K_p and absorption values obtained for one part of the body are applicable to skin locations otherwise, but this assumption has been shown to be invalid for some chemicals (Feldman and Maibach, 1967; as in EPA, 1992). In the absence of specific absorption information, however, this assumption must be used.

Numerous researchers have developed theoretical skin permeation models based on the two-phase stratum corneum assumption controlling diffusion (Scheuplein et al., 1965; Micheals, 1975; Berner and Cooper, 1987; Albery and Hadgraft, 1979; Kasting, Smith, and Cooper, 1987). The following assumptions are made concerning the two-phase approach in these models (EPA, 1992):

- the full thickness of the stratum corneum (SC) contributes to the diffusion barrier
- no active transport occurs
- the stratum corneum is a homogeneous medium
- penetrant and vehicle molecules diffuse across SC as individual molecules meaning that there is no carrier effect occurring
- the SC is not changed by the penetrant
- penetrant concentration changes do not alter SC

Each of the theoretical skin permeation models was fitted to experimental data indicating that permeability coefficients are highly dependent on the lipophilicity of compounds. Potts and Guy (1992) fitted an equation to the whole of the data from the aforementioned skin permeation studies relating K_p to K_{ow} and molecular weight:

$$\log K_p = -2.72 + 0.71 \log K_{ow} - 0.0061MW \quad (19)$$

where: K_p = permeability coefficient (cm/hr)

K_{OW} = octanol-water partition coefficient
MW = molecular weight

This permeability coefficient is analogous to the velocity at which a chemical penetrates the skin. For inorganics, a default assumption of 1×10^{-03} cm/hr is recommended by EPA. This estimate is a conservative upper bound of flux through the skin; the majority of inorganics had values near 1×10^{-03} or lower. The accuracy of Eq. 18 is judged to be within one order of magnitude (EPA, 1992).

To estimate the dermal exposure from contact with chemical solutions the following equation is applied (EPA, 1992):

$$D = S \cdot C \cdot K_p \cdot h \cdot 0.001 \quad (20)$$

where:

D	= dermal exposure, or intake for chemical (mg/d)
S	= surface area of skin contacted by chemical (cm ²)
C	= concentration of chemical on skin & in bath (mg/L)
K_p	= penetration rate of chemical into skin, Eq. 19 above (cm/hr)
h	= duration of contact event per bath, assumed to be equal to total number of hours spent in process area divided by the number of baths (hr/d)

This equation is based on a steady-state application of Fick's first law assuming that diffusion occurs in one direction and that convection is negligible. It provides conservative estimates of exposure to dilute chemical solutions that are accurate enough for screening-level risk estimates. More advanced non-steady state approaches are currently under development, but are not used here because of a lack of acceptance in the scientific community (USEPA, 1992).

Inhalation contact occurs when receptors inhale air contaminated with MHC chemicals. The mechanisms for chemical transfer from MHC tanks into the air have already been covered, and calculation of actual dose rates for this contact route and dermal absorption will be reviewed below.

Exposure and Intake Estimation

The ultimate objective of this step in the risk assessment is to quantify intake or dose for all contaminants and pathways of concern. As mentioned before, the pathways of concern for this work are inhalation and dermal contact. The common and accepted

method for determining potential dose rates (for noncarcinogenic health risks) or lifetime average daily doses (for carcinogenic health risks) is as follows (EPA, 1989a):

$$\text{Inhalation: Dose Rate} = \frac{C_Y \cdot IR \cdot EF \cdot ED}{BW \cdot AT} \quad (21)$$

where:

- C_Y = air concentration in the workplace, mg/m³
- IR = inhalation rate, m³/day
- EF = exposure frequency, days/yr
- ED = exposure duration, years
- BW = body weight, kg
- AT = averaging time, days (different for carcinogens and non-carcinogens - see below)
- $AT_{\text{NON-CARCINOGEN}} = ED \cdot 365 \text{ days/yr}$
- $AT_{\text{CAR}} = 70 \text{ yrs} \cdot 365 \text{ days/yr}$

$$\text{Dermal: Dose Rate} = \frac{D \cdot EF \cdot ED}{BW \cdot AT} \quad (22)$$

where:

- D = dermal dosage rate, mg/day
- EF = exposure frequency, days/yr
- ED = exposure duration, years
- BW = body weight, kg
- AT = averaging time, days (same as above)

The averaging time (AT) used in the above equations is dependent upon the toxicity classification of the chemical (EPA, 1989a). For carcinogens, currently accepted theory states that any dose over a receptor's lifetime may cause cancerous effects. This dictates the use of a 70-year averaging time (the average human lifetime) in determining dose. The accepted non-carcinogen theory postulates that a certain amount of chemical can be absorbed before effects are seen. This causes the averaging time used to be for the exposure duration only. These concepts will be covered in detail below.

Toxicity Assessment

This section in the RA evaluates the inherent toxicity of contaminants to humans using various toxicological information databases such as IRIS [Integrated Risk Information System], HEAST [Health Effects Assessment Summary Tables], and HSDB [Hazardous Substances Data Bank]. The standard toxicity measures used in assessing risk combine data on dose and observed effect:

- carcinogenic slope factors (SFs) for various routes of exposure and cancer-causing effects - used to calculate excess lifetime cancer risk (ELCR)
- reference doses (RfDs) for noncarcinogenic chronic and subchronic effects and various routes of exposure - used to calculate hazard quotients (HQ)
- no observed or lowest observed adverse effect levels (NOAEL or LOAEL) for noncarcinogenic chronic and subchronic effects and various routes of exposure - used to calculate margin of exposure (MOE)

These measures of toxicity are all based on the results of human or animal tests where chemicals are introduced through various routes of exposure to receptors and the doses which cause statistically significant effects on endpoints, or organs in the body are recorded.

RfDs are derived from the no observed adverse effect level (NOAEL) to a species and uncertainty factors associated with them (EPA, 1989a):

$$\text{RfD} = \frac{\text{NOAEL or LOAEL}}{\text{UF} \cdot \text{MF}} \quad (23)$$

where: NOAEL = no observed effect level (mg chemical/kg body weight/day)
 UF = uncertainty factor (unitless)
 MF = modifying factor (unitless)

These uncertainty and modifying factors attempt to account for the great variability, uncertainty, and sensitivity of these tests. Different animals behave differently with respect to the dose at which they exhibit the same effect from a chemical, and sometimes there are even differences with respect to sex or race in a species. This makes it very difficult to determine what doses are applicable to humans when testing has not been performed on human subjects (this is usually the case for most chemicals). After reviewing those studies which are available for a chemical, the EPA selects those judged to be of high quality for development of RfDs and SFs.

Non-carcinogenic health effects theory is founded on the presumption that the body can absorb, or process a certain amount of chemical before adverse or chronic effects are realized. Slope factors for carcinogenesis, however, are based on the assumption that there is no certain threshold dose which causes carcinomas to develop in individuals (EPA, 1989a). This means that small changes in a single cell can lead to uncontrolled cellular proliferation and disease, and that a small dose of carcinogen may eventually initiate tumor production in an organism, no matter how small the dose may

be. A weight of evidence classification is assigned to each carcinogen to account for uncertainties and lack of available data in humans. Slope factors are then calculated for chemicals that are classified as potential carcinogens.

The slope factor is defined as a plausible upper boundary estimate of the probability of developing cancer per unit intake of a chemical over a lifetime (EPA, 1989a). This is accompanied by the weight of evidence (WOE) classification to show the strength of supporting data. The EPA WOE classifications are as follows (a new set of revisions to this system is proposed which uses different descriptors, EPA 1994):

- Group A - Human Carcinogen (sufficient evidence of carcinogenicity in humans)
- Group B - Probable Human Carcinogen (B1 - limited evidence of carcinogenicity; B2 - sufficient evidence of carcinogenicity in animals with inadequate or lack of evidence in humans)
- Group C - Possible Human Carcinogen (limited evidence of carcinogenicity in animals and inadequate or lack of human data)
- Group D - Not classifiable as to Human Carcinogenicity (inadequate or no evidence)
- Group E - Evidence of Noncarcinogenicity for Humans (no evidence of carcinogenicity in adequate studies)

The WOE system places chemicals into classes based on their carcinogenic potential, or probability. In order to obtain a statistically significant number of cancer responses in an experiment, much higher exposures than normally encountered in the environment are used. This entails the second most important assumption with slope factors: that a model of an available data set with high dose response information will be applicable to doses which are several orders of magnitude smaller. The assumption of linearity over this large dose range is unproven.

Toxicity values are commonly calculated from critical effects levels based on administered, rather than absorbed, doses (EPA, 1989a). An absorbed dose is the intake that actually enters the blood stream across a boundary (epidermal skin layer, lung alveoli, etc.) rather than an administered dose which measures the actual intake (mass of chemical entering the body) regardless of absorption efficiency. This difference becomes important because intakes are commonly calculated as absorbed doses for some exposure pathways, such as dermal contact. Adjustments should be made to convert administered doses to adsorbed ones with the following equations (EPA, 1989b):

$$\text{Dermal RfD} = \text{Oral RfD} \cdot \% \text{ absorption efficiency}$$

and:
$$\text{Dermal Slope Factor} = \text{Oral Slope Factor} / \% \text{ absorption efficiency}$$

The oral toxicity measures used above are unadjusted for absorption, and the percentage absorption efficiency comes from pharmacological data and studies. An assumed oral absorption efficiency should be used in the absence of information, because the assumption of 100 percent absorption is not conservative. The true absorbed dose from an oral study might have been much lower than 100 percent and hence the RfD and SF should reflect that. The actual absorption rate may be significantly lower than 100 percent for polar compounds (EPA, 1989a).

Risk Characterization

This final phase of the RA pulls together information from the previous sections in an attempt to quantify risks from chemicals and exposure pathways. Carcinogen and chronic effect risk calculations are made separately due to their differing methodologies.

Carcinogenic risks are estimated as the incremental probability of an individual developing cancer over a lifetime because of exposure to a carcinogen. This is the risk of cancer that is in excess of that risk which is already present from background sources. This excess lifetime cancer risk (ELCR) is viewed to be in addition to common background cancer risks. There are differing views regarding the specific amount of background cancer risk to individuals, but it is generally agreed to be around 30%, based on long-term epidemiological studies. The linear-no-threshold-dose-response relationship mentioned earlier should only be applied when low risk levels are going to be encountered (EPA, 1989b). For processes or sites where high carcinogen risks are expected, EPA recommends that a different equation be used to relate intake and slope factor. This equation implements an exponential relationship instead of a linear one to simulate the increased risk at lower doses. The cancer risk equation used in this work is (EPA, 1989a):

$$\text{Risk} = \text{Dose Rate} \cdot \text{SF} \quad (24)$$

where: Risk = unitless probability of developing cancer ($1 \cdot 10^{-6}$ implies that approximately 1 out every 1,000,000 people that contact a chemical at the dose rate will contract cancer)
Dose Rate = chronic daily intake averaged over 70 years (mg/kg/d)
SF = slope factor ((mg/kg/d)⁻¹)

The measure used to describe the potential for noncarcinogenic toxicity is not a probability of adverse effects occurring for an individual, but a comparison of an exposure level and reference dose that are both derived over a similar time period. This methodology assumes that there is a level of exposure which represents the threshold where noncancer effects may be seen. Below this exposure threshold it is unlikely that even sensitive subpopulations in a species will exhibit noncancer adverse or toxic effects. It is important to note that the level of concern for noncancer hazard quotients does not increase linearly as cancer risks do. An HQ of 1 represents a concern, but an HQ of 10 does not necessarily represent a concern level that is one order of magnitude greater. The noncancer hazard quotient equation is:

$$\text{Noncancer Hazard Quotient (HQ)} = \text{Dose Rate} / \text{RfD} \quad (25)$$

where: HQ = measure of toxic effect potential (a number greater than 1 is potentially hazardous to receptors)
Dose Rate = exposure level, or intake (mg/kg/d)
RfD = reference dose (mg/kg/d)

When reference doses are not available or are not established, the margin of exposure (MOE) estimate can be used to compare non-cancer health risk potential. This measure of toxic potential is not as accurate or widely accepted as a hazard quotient, but is commonly used in industrial health risk assessments because so many of the chemicals used have not been studied extensively and thus have very little information available for them. MOEs do not have the level of certainty associated with them as HQs do, however. This is because NOAELs and LOAELs are used to describe toxic health risk in MOEs, whereas RfDs are developed from NOAELs/LOAELs and have uncertainty and safety factors applied to them based on the quality of data. They are then peer reviewed and revised. The MOE allows for additional relative comparisons to be made between alternatives when RfDs are not available, but should not be considered equivalent, or as valuable an indicator as a HQ. The equation for calculating MOES is (CCPCT, 1995):

$$\text{Margin of Exposure (MOE)} = \text{NOAEL or LOAEL} / \text{Dose} \quad (26)$$

where: MOE = measure of toxic effect potential to receptors
Dose Rate = exposure level, or intake, same as above (mg/kg/d)
NOAEL/LOAEL = no observed or lowest observed adverse effect level, dose in study (mg/kg/d)

The NOAEL-based MOEs are considered more conservative than LOAEL-based MOEs because additional safety is inherent at a measurement level which produced no noticeable effect. An MOE less than 100 for NOEALs (1,000 for LOAELs) is considered potentially harmful, and warrants investigation.

Summing Risks from Multiple Chemicals

The calculations presented are used to calculate risks from single chemical species. However, a risk assessment generally assesses risks for multiple chemical exposures. The EPA (1986b) presents *Guidelines for the Health Risk Assessment of Chemical Mixtures* that outlines a method for combining risks from multiple chemicals. Both noncancer and cancer risk effects are assumed to be additive in the absence of toxicity and dose information on specific mixtures. The cancer risk summation is as follows:

$$\text{Risk}_T = \sum \text{Risks}_i \quad (27)$$

where: Risk_T = total cancer risk
 Risk_i = risk estimate for chemical i

There are several caveats and limitations associated with this method of combining risks (EPA, 1989). The equation approximates a precise relationship which accounts for the joint probabilities of the same individual developing cancer as a result of exposure to multiple carcinogens. The difference between this approximation and the actual equation is negligible as long as the total cancer risk is less than 0.1. Another limitation is that slope factors are upper 95th percentile estimates of potency. Because probability frequency distributions are not additive, this may cause the total cancer risk to become overly conservative when summing multiple chemicals.

The approach does not account for differences between cancer weight of evidence classifications, or animal and human data discrepancies. A final problem with this method is that the effects may not be independent between two chemicals, and some carcinogen combinations may actually be inhibitive to each other (Rodricks, 1992)

The method for summing potentials for noncarcinogenic effects from multiple chemicals is essentially identical to the carcinogenic approach (EPA, 1989). The following equation is used:

$$\text{Hazard Index (HI)} = E_1/\text{RfD}_1 + E_2/\text{RfD}_2 + \dots + E_i/\text{RfD}_i \quad (28)$$

where: HI = sum of potential for noncarcinogenic effects
 E_i = exposure level (intake) for chemical i
 RfD_i = reference dose for chemical i

This equation assumes that the magnitudes of adverse health effects will be proportional to the sum of ratios of the subthreshold exposures to the acceptable exposures. As mentioned earlier, a hazard index greater than unity is deemed to be a concern. Limitations with this method are: reference doses do not have equal accuracy to slope factors since levels of concern do not increase linearly; combining hazard quotients for substances with varying toxicological effects may be overly conservative, and RfDs include different levels of uncertainty and modifying factors which greatly increase variability in the system. These concerns should not be as important if a few chemicals contribute the most to Hazard Index, but if multiple chemicals contribute equally there may be cause for refinement. This can be done by separating HIs for toxicity effect and possibly exposure pathway if necessary.

Summation of risks across pathways proceeds in the same manner as above for combining different chemicals. Again, there is some potential for overestimation here but currently this is the most scientifically accurate and acceptable method. Uncertainties and variability can propagate quickly when calculating and summing risk estimates so it is important to address them at least qualitatively. The greatest amount of uncertainty in risk estimates typically comes from toxicity information and exposure estimates, but assumptions regarding site or process specific parameters may be significant and should be reviewed also.

Sensitivity and Uncertainty in Modeling

Models of environmental transport mechanisms like those presented above attempt to simplify complicated systems by drawing correlations between the most important parameters which affect those systems. In doing this, the models develop a dependence on those parameters that strongly affect the system; therefore, it is important to use accurate values for these parameters. Sensitivity and uncertainty analyses help to determine which parameters are most important to the model so that effort can be focused on determining accurate estimates for the most important parameters.

There are many ways to conduct sensitivity and uncertainty analyses. A simple and efficient way to perform a sensitivity analysis is to select one input parameter and vary it by a fixed amount (i.e. $\pm 10\%$) while keeping all other parameters fixed. The computed outcomes from each combination of values per parameter can then be compared to determine which parameters have the greatest effect on model outcome. This type of analysis identifies the parameters that can have the greatest effect on the model regardless of variability. Small changes in some parameters may produce large changes in the model outcome, indicating a need to determine the variability associated with those parameters.

An uncertainty analysis is used to indicate the range of uncertainties, or variability, associated with model input parameters. When the sensitivity analysis is complete, the parameters identified as having the greatest effect on computed outcomes can be tested in the model using probability distributions to ascertain the uncertainty of the estimate. These distributions attempt to describe the population of values that would be observed in "real life" through a variety of methods.

Classical statistics presents many ways to represent or infer information about a parameter and its distribution. Some common methods of representing probability distributions are as cumulative distribution functions, or as measures such as fractiles or moments. These classical, or frequentist methods employ an estimator, or function of the observed sample values that is supposed to help describe the true statistic. The estimator is used with the sampling distribution of the statistic to infer the likelihood that the sample was drawn from a particular population with a certain distribution and mean value (Morgan and Henrion, 1990).

An alternative approach to parameter description is the Bayesian, or subjectivist estimation method. In the Bayesian approach, a parameter is interpreted as a random variable that has a probability of lying within a specific range, unlike classical statistics that are concerned with applying a distribution to only a parameter. The application of Baye's rule requires that prior knowledge of a parameter's distribution be known, however, making it more difficult to apply in new situations where little is known about a statistic.

In risk assessments, the classical approach to parameter description is traditionally employed because it requires little previous knowledge about the system. Even though these methods differ in their approaches, the results from each are often similar providing that large populations are sampled in a proper manner (Morgan and Henrion, 1990). Once a particular distribution (normal, lognormal, triangular, etc.) has been assigned to each parameter, a method to propagate these distributions through a model must be employed so that correlations can be drawn for variables whose uncertainty affects the model. The Monte Carlo procedure is an excellent tool for conducting uncertainty analyses of environmental transport models, and has been used by numerous researchers in this role (Fehrenbacher and Hummel, 1996; McKone and Bogen, 1991 & 1992; Morgan and Henrion, 1990).

The Monte Carlo procedure randomly selects input parameter values from probability distributions and calculates results for a specified number of iterations. This simulates model calculations for a given number of possible combinations of input values. The true value to this procedure is not that random samples are taken, but that a uniform distribution of points in the parameter space is represented. To better represent the true population and obtain a more uniform distribution in the parameter space, systematic or stratified sampling techniques can be used. There are many different systematic sampling techniques, but the Latin Hypercube modification of the Monte Carlo Method is agreed upon to work well in these situations (McKay, 1992; Stein, 1987).

In Latin Hypercube sampling, a probability distribution is divided into strata, or intervals of equal probability, and input values are obtained by sampling separately from within each stratum instead of from the distribution as a whole (Decisioneering, Inc, 1993). This allows for a more precise sampling routine because the entire range is

more consistently represented. This probabilistic approach can also be used to generate a distribution of possible model outcomes and contrast a specific modeling goal (i.e. a 90th percent bounding estimate in risk assessment) to a single point estimate. The number of iterations performed in Monte Carlo sampling for this work is 15,000 (based on McKone and Bogen, 1991). This number was chosen to ensure adequate convergence and stabilization of the tails on output distributions, and provides approximately 95 percent confidence that the tails are representative of the "true" distribution (Jackson, 1981 as in Morgan and Henrion, 1990). This is important when a bounding estimate (i.e. upper 90th percentile) of the distribution is desired so that accurate conclusions can be made regarding risk.

A Monte Carlo software package (Crystal Ball®, Decisioneering, Inc.) was used for this work in conjunction with a spreadsheet program (Lotus 1-2-3®) containing the air transport equations outlined earlier. Crystal Ball®, calculates the percentage contribution each parameter makes to overall model variance by computing Spearman rank correlation coefficients between every assumption and model result while the simulation is running.

Spearman rank correlation coefficients differ from traditional linear regressions because ranks are assigned to observations and then substituted for the actual numerical values in the correlation formula. This correlation is nonparametric and has distinct advantages over a simple linear regression. The relationship between variables is no longer assumed to be linear, and no assumptions of normality are made concerning the distributions of the variables as the relationship is nonparametric (Walpole and Myers, 1993). The Sensitivity and Uncertainty of Air Transport Models section covers these concepts as used here in detail.

Section II. Risk Assessment Approach and Analysis

The various disciplines and methodologies outlined in reviewing the literature must be combined to estimate the risks associated with each MHC process. It has been shown that some assumptions regarding the modeled systems are not founded on a strict scientific basis, but are employed with the use of good engineering judgement. This is often necessary in many areas of engineering, especially in risk assessment where so many uncertainties exist regarding the dose and response relationships and widely varying parameter selections.

It is also necessary in risk assessments to pre-determine which exposure scenarios will be quantified for risk in terms of statistical bounding. This is typically dictated by risk management teams to be upper-bound, rather than average estimates of risk. In an upper-bound risk assessment, the upper ranges of distributions for parameters are chosen so as to provide conservative estimates of the potential risks that receptors may encounter. Upper boundary risk assessments are targeted to be approximately in the 90th percentile range. An average estimate of risk would therefore use averages for all parameters. A third risk scenario is known as a "What-If" risk assessment.

"What-if" risk assessments combine aspects of both upper-bound and average assessments in an attempt to provide realistic, but not exceedingly conservative estimates of risk. These risk assessments usually employ upper-end (90th percentile) values for those parameters which have great uncertainty, and use average values for those parameters which have better-quality information, or data. Sensitivity of the results to parameters are often taken into consideration also. This work consists of what-if risk estimates for all quantified pathways in an effort to provide the most realistic results possible with the available data.

Average values of variables are only used for a few parameters where the 90th percentile is judged to provide exceedingly conservative risk estimates. The original value for one parameter (air turnover rate) is also revised to provide a more accurate representation of the 90th percentile air concentration in the process area (see Sensitivity and Uncertainty Analysis of Modeling section).

The steps taken in calculating risk to workers and the population from PWB plants were as follows:

1. Set up generic systems for each alternative MHC process and characterize: bath chemistries, formulations, and liquid agitation method (air sparged); worker exposure durations and scenarios for potential dose rate determination; automation type for transporting wiring boards between baths.
2. Use mass transfer models with generic MHC line bath chemistry data to determine emission rates for each chemical, then estimate corresponding air concentrations in the workplace.
3. Use ISC-LT2 to determine outdoor chemical air concentrations based on estimated (step 2) emission rates from MHC baths.
4. Compile and determine chemical toxicity data for chemicals on MHC lines - RfDs, NOAEL/LOAELs, and cancer SFs for all quantified routes of exposure.
5. Combine exposure and dose information in accordance with RAGs methodology (EPA, 1989a).

With this information, the key chemicals and baths that drive risk can be identified. The elimination or reduction of these components could substantially reduce risk to workers and the environment. Qualitative estimates can also be made about the ecological toxicity of these MHC lines, but calculations regarding non-human receptors are not pursued in this work.

Development of Generic MHC Processes

There are several data sources that were consulted before a representative generic MHC process for each plating alternative could be selected by the CCPCT (1996). These sources included: *Workplace Practices Questionnaire and Performance Demonstration* for the DfE PWB project (CCPCT, 1996); patent information on the proprietary technologies in each alternative; Material Safety and Process Data Sheets supplied by suppliers for each MHC alternative (Shipley, Macdermid, Electrochemicals; Atotech, Solution Technology Systems, Grace Technologies, Learonal, Enthone); various works based on the technology in these processes (Haynes *et al.*, 1989 & 1995; Meyer, 1994; Carano, 1990; Goldman, 1994; Mandich, 1993; Haak *et al.*, 1981); and engineering estimates and judgement.

This information was compiled so that common traits (such as bath dimensions, etc.) within alternatives could be incorporated into a 'generic' process. Figure 1 shows the generic bath types. Once these generic processes were developed, mass transport models were used to predict emissions from chemical baths. In a similar way, generic room characteristics were also determined. These topics are covered below.

The data used are all publicly available, and are reported in conjunction with the Freedom of Information Act, 5 U.S.C. section 552, section 3007(b) of EPA regulations. The Occupational Safety and Health Administration (OSHA) in 29 CFR 1910.1200 requires that industry report all hazardous chemicals that:

- make up at least 1% (0.1% for carcinogens) of the formulation in process baths
- pose a significant hazard to human health

OSHA allows industry to withhold data on chemicals that are reported to be a trade secret, and does not require information on chemicals that only pose ecological hazards.

Bath Chemistries

The first step in determining the characteristics of a generic process is to identify the chemical concentrations in each bath. This was done using the material safety and product data sheets (MSDSs and PDSs) and some patent information. The MHC workplace practices survey (CCPCT, 1996) was not used for bath chemistry data because inconsistencies existed between product lines and baths for different suppliers. The MSDSs identify chemicals that are in the supplier's products, or bath packages. These products are mixed together to form individual baths, and the PDSs provide information on how they are mixed together.

The Workplace Practices Survey contained information on bath sequence and combination of product lines that pertained to each MHC alternative. This allowed for information from each MSDS to be coupled with PDS data for all suppliers to arrive at a chemical concentration in each bath. Since these basic steps were the same for all suppliers, chemical information could be compared between suppliers for the same MHC baths. Chemicals from different suppliers were combined for each bath (as discussed later) to arrive at a generic bath makeup for each MHC alternative.

The PDSs contain information for the bath, product name, and chemicals that appear in that product. This is usually tabulated as the concentration percentages by volume that each supplier's product contributes to the total bath volume. The concentration by mass percentage (weight) of each constituent in a particular supplier product appears in the MSDS sheets, along with various chemical parameter

information, such as specific gravity. This information was used to calculate individual chemical concentrations in the baths as follows:

$$C_b = (Wt)(Vol)(S.G.) / 1000 \quad (2??)$$

where:

- C_b = the concentration of chemical in process bath (g/l)
- Wt = the chemical concentration, by weight, in each product (mg/g)
- Vol = percentage proportion of the product volume to the total bath volume (cm^3/L)
- $S.G.$ = the specific gravity of each product (g/cm^3)
- 1000 = factor for conversion of mg to g

An example calculation for the formaldehyde concentration in the electroless copper bath is shown below for Shipley's C-3000 electroless copper MHC alternative line. The MSDS sheets list the chemicals that are used in this product package (Circuposit 3050A in this instance) on a weight percentage basis. For formaldehyde, this is 7%, or 70 mg of formaldehyde per gram of Circuposit 3050A. The PDS reports the amount of this package that is used in the total bath makeup on a volume percentage basis. For this example this is 4.2%, or 42 cm^3 of Circuposit 3050A per liter of the total bath volume. The remaining volume in the bath is made up of different product packages and non-hazardous materials, such as de-ionized water. The specific gravity of the Circuposit 3050A package is reported in the MSDS as 1.14 g/cm^3 . Combining this information yields the formaldehyde concentration in the electroless bath of Shipley's C-3000 process:

$$\left(\frac{70 \text{ mg}}{g} \right) \left(\frac{42 \text{ cm}^3}{L} \right) \left(\frac{1.14 \text{ g}}{cm^3} \right) \left(\frac{g}{1000 \text{ mg}} \right) = 3.352 \frac{g}{L}$$

In some cases, PDSs reported product packages on a mass per volume basis, and these were directly converted to obtain chemical concentrations in the bath. In other cases chemical concentrations in the bath were derived from patent information or from direct correspondence with product supplier representatives (CCPCT, 1996).

The MSDS and PDS data were combined in the above manner for each supplier's product line. Chemical formulations for alternative processes often have more than one supplier and this means that the bath chemistries will differ from one line to the next. Some suppliers reported chemical concentrations over a range or as being less or

greater than a certain amount. In these cases the largest concentration was used in calculations.

A total chemical list for each alternative MHC process showing chemicals and concentration ranges was compiled from the given information. An example list of information used to develop generic chemical makeups for MHC alternatives is located in Appendix A. All identified chemicals were included in the generic process lists because an intricate knowledge of the chemistry for each MHC alternative would be needed before chemicals could be combined or dropped from these lists based on inferences between supplier makeups. If chemicals unique to only a few suppliers are driving risk then they will be analyzed separately in the risk assessment section. This method is conservative in that all possible chemicals that could be encountered in a MHC process alternative are included.

The average of the estimated concentration ranges for each chemical in a bath was used as the chemical concentration in the exposure assessment. This is consistent with the "what-if" risk assessment approach outlined earlier. The data for this information is considered accurate and the models are not overly sensitive to changes in this parameter.

Certain assumptions were made in determining the generic bath compositions. These assumptions may or may not be valid. Further investigation of the assumptions was beyond the scope of this work, but could be addressed in future work. The most important of these assumptions are:

- chemical reactions do not occur in the baths to alter concentrations and/or bath chemistry
- proprietary supplier chemicals regarded as trade secrets do not provide significant risks to workers and the population
- some alternatives had very few suppliers and manufacturers which provided data for them and their characteristics may not be entirely represented by the available data

Tables 1 - 7 show the generic chemistry formulations used for each process in the exposure assessment. These tables are a compilation of all available chemical information for each MHC process. An average concentration was obtained for

Table 1. Generic Chemistry Formulation: Electroless Copper

CONCENTRATION OF CONSTITUENTS IN BATH (g/l)		VALUES **		AVERAGE
MHC BATH	CHEMICALS in MHC PROCESS*	(1)	(2)	(3)
CLEANER/CONDITIONER	SULFURIC ACID	9.90		
	p-TOLUENE SULFONIC ACID	9.90		
	ISOPROPYL ALCOHOL; 2-PROPANOL	1.65	6.44	3.36
	HYDROXYACETIC ACID	34.65		
	POTASSIUM HYDROXIDE	0.53		
	AMMONIUM CHLORIDE	12.88		
	FORMIC ACID	12.88		
	CATIONIC EMULSIFIER*	6.44		
	TRIETHANOLAMINE	30.30		
	PHOSPHATE ESTER	30.30		
	ETHYLENE GLYCOL	2.44		
	DIMETHYLFORMAMIDE	1.32		
	CONFIDENTIAL INGREDIENTS*	2.00		
	ETHANOLAMINE	16.32		
MICRO-ETCH	POTASSIUM PEROXYMONOSULFATE	25.80		
	POTASSIUM BISULFATE	13.80		
	POTASSIUM SULFATE	19.20		
	MAGNESIUM CARBONATE	1.20		
	POTASSIUM PERSULFATE	9.80		
	SULFURIC ACID	1.84	340.40	121.32
	HYDROGEN PEROXIDE	13.80	35.88	19.91
	SODIUM HYDROXIDE	0.30		
	COPPER SULFATE	0.50		
	ETHYLENE GLYCOL	1.93		
PRE-DIP	SODIUM BISULFATE	2.58	46.60	24.59
	HCL	31.70	181.70	85.64
	SULFURIC ACID	2.58		
CATALYST	HYDROCHLORIC ACID	1.98	158.34	50.94
	STANNOUS CHLORIDE AS TIN (II)	6.32	16.55	10.26
	PALLADIUM(DISSOLVED)	0.36		
	METHANOL	2.52		
	SODIUM BISULFATE	45.20		
	SODIUM SULFATE	12.63		
	SODIUM HYDROXIDE	2.53		
ACCELERATOR	SODIUM CHLORITE	4.52		
	SULFURIC ACID, 66%Be	18.24		
	SODIUM HYPOPHOSPHITE	8.58		
	FLUOBORIC ACID	60.00	60.00	60.00
ELECTROLESS COPPER	FORMALDEHYDE	1.58	5.59	3.68
	COPPER CHLORIDE	5.06	8.32	6.69
	COPPER SULFATE AS COPPER	4.79	11.55	6.98
	HYDROCHLORIC ACID	0.48		
	SODIUM HYDROXIDE	5.78	15.72	10.15
	ETHYLENEDIAMINE-TETRAACETIC ACID TETRASODIUM SALT(EDTA)	34.20	56.21	45.20
	METHANOL	0.04	2.80	1.39
	POTASSIUM CYANIDE	0.22		
	POTASSIUM-SODIUM TARTRATE	31.44		
	SODIUM CARBONATE	0.05		
	TARTARIC ACID	1.03		
	SODIUM CYANIDE	0.23		
	ALKALINE MIXTURE	153.70		
	SULFURIC ACID	1.15		
	SULFURIC ACID	Not Reported		
	DIMETHYLAMINOBORANE	0.72		
	BORIC ACID	5.00		
ACID DIP				
ANTI-TARNISH	METHANOL	0.95	1.25	1.10
	SULFURIC ACID	28.80		
	ISOPROPYL ALCOHOL	2.02		
	POTASSIUM HYDROXIDE	0.30		
	BENZOTRIAZOLE	0.12		
	2-ETHOXYETHANOL	45.90		
	SODIUM m-NITROBENZENESULFONATE	0.12		

* This table does not include Materials listed as "Non-Hazardous"

** Single value reported for chemical concentration in column (1); If more than one process contains chemical, lowest concentration reported is listed in (1) and highest is in (2) - average of all reported values listed in (3)

Table 2. Generic Chemistry Formulation: Tin Palladium

CONCENTRATION OF CONSTITUENTS IN BATH (g/l)		VALUES **		AVERAGE
MHC BATH	CHEMICALS in MHC PROCESS*	(1)	(2)	(3)
CLEANER/CONDITIONER	NONIONIC SURFACTANT	4.50		
	POTASSIUM CARBONATE	6.16		
	MONOETHANOLAMINE; 2-AMINOETHANOL	14.20	25.38	20
	TRIETHANOLAMINE; 2,2',2''-NITRILOTRIS(ETHANOL)	5.1	25.38	15.24
	2-PROPANOL	2.04		
PRE-DIP	SODIUM BISULFATE	46.60		
	SODIUM CHLORIDE	360.00		
	HYDROCHLORIC ACID	1.85	17.10	10.32
CATALYST	SODIUM BISULFATE	42.87		
	SODIUM CHLORIDE	653.00		
	HYDROCHLORIC ACID	9.60	46.00	22.90
	TIN(II) CHLORIDE, STANNOUS CHLORIDE AS TIN	21.10	46.00	31.78
	PALLADIUM (DISSOLVED)	0.96		
	PALLADIUM CHLORIDE	0.50	0.7	0.60
	VANILLIN	1.50		
ACCELERATOR	1,3-BENZENEDIOL	0.73		
	FLUOROBORIC ACID AS FLUORIDE	18.90		
	COPPER AS CU(II)	2.55		
	COPPER SULFATE	0.23	1.38	0.81
	SULFURIC ACID	0.93		
	SODIUM HYDROXIDE	14.38	43.53	28.95
	POTASSIUM CARBONATE	318.00		
	LITHIUM HYDROXIDE	20.30		
	MONOETHANOLAMINE	3.49	20.30	11.90
OTHER (ENHANCER)	SODIUM HYDROXIDE	1.00		
	DIMETHYLAMINE BORANE	1.32		
	SULFIDE COMPOUND*	1.00		
MICRO-ETCH	COPPER SULFATE AS COPPER	13.30		
	SULFURIC ACID	9.20	35.00	20.87
	HYDROGEN PEROXIDE	17.50		
	SODIUM PERSULFATE; DISODIUM PEROXYDISULFATE	134.80	175.00	151.02
OTHER (STABILIZER)	SODIUM HYDROXIDE	6.50		
ACID DIP	SULFURIC ACID	191.40		

* This table does not include Materials listed as "Non-Hazardous"

** Single value reported for chemical concentration in column (1); if more than one process contains chemical, lowest concentration reported is listed in (1) and highest is in (2) - average of all reported values listed in (3)

Table 3. Generic Chemistry Formulation: Organic Palladium

CONCENTRATION OF CONSTITUENTS IN BATH (g/l)		(1)
MHC BATH	CHEMICALS in MHC PROCESS*	
CONDITIONER	TRADE SECRET	5
	AQ SOLUTION, CATIONIC RESIN	NR
	SODIUM CARBONATE	3
	SODIUM BICARBONATE	5
MICRO-ETCH	SODIUM PERSULFATE	75
	SODIUM BISULFATE	75
PRE-DIP	HYDROCHLORIC ACID	3.125
CONDUCTOR	HYDROCHLORIC ACID	3
	TRADE SECRET	3
	SODIUM HYPOPHOSPHITE	3.06
POST-DIP	SODIUM CARBONATE	12.65
	TRISODIUM CITRATE	12.65
	TRADE SECRET	34.5

* This table does not include Materials listed as "Non-Hazardous"

(1) Single value reported for chemical concentration

Table 4. Generic Chemistry Formulation: Non-Formaldehyde Electroless

MHC BATH	CHEMICALS in MHC PROCESS*	CONCENTRATION OF CONSTITUENTS IN BATH (g/l)
		(1)
MICRO-ETCH	POTASSIUM PERSULFATE	9.80
	SULFURIC ACID	20.24
	HYDROGEN PEROXIDE	16.15
	SODIUM HYDROXIDE	0.30
	COPPER SULFATE	0.50
CATALYST	HYDROCHLORIC ACID	2.96
	STANNOUS CHLORIDE	9.48
POST DIP	HYDROCHLORIC ACID	Not Reported
ACCELERATOR	SODIUM CHLORITE	4.52
ELECTROLESS COPPER	COPPER SULFATE	22.43
	SULFURIC ACID	2.56
	SODIUM HYDROXIDE	Not Reported
ANTI-TARNISH	ISOPROPYL ALCOHOL	2.02
	POTASSIUM HYDROXIDE	0.30

* This table does not include Materials listed as "Non-Hazardous"

(1) Single value reported for chemical concentration

Table 5. Generic Chemistry Formulation: Carbon

MHC BATH	CHEMICALS in MHC PROCESS*	CONCENTRATION OF CONSTITUENTS IN BATH (g/l)		AVERAGE (3)
		VALUES ** (1)	(2)	
CLEANER	MONOETHANOLAMINE	11.60		
CONDITIONER	MONOETHANOLAMINE	11.49	11.52	11.50
CARBON	POTASSIUM CARBONATE	62.34		
	SULFURIC ACID	0.04		
	POTASSIUM HYDROXIDE	0.46		
AIR-KNIFE/OVEN				
POST-CLEAN	SODIUM PERSULFATE	150.00	200.00	175.00
ETCH	SULFURIC ACID	1.84		
	COPPER SULFATE PENTA-HYDRATE	5.00		
ANTI-TARNISH	ETHYLENE GLYCOL	3.96		
	BENZOTRIAZOLE	0.32	0.47	0.39

* This table does not include Materials listed as "Non-Hazardous"

** Single value reported for chemical concentration in column (1); if more than one process contains chemical, lowest concentration reported is listed in (1) and highest is in (2) - average of all reported values listed in (3)

Table 6. Generic Chemistry Formulation: Graphite

CONCENTRATION OF CONSTITUENTS IN BATH (g/l)				
MHC BATH	CHEMICALS In MHC PROCESS*	VALUES **		AVERAGE
		(1)	(2)	(3)
CLEANER/CONDITIONER	NON HAZ-INGREDIENTS	437.00		
	SURFACTANT	2.06		
	POTASSIUM CARBONATE	7.39		
	ETHANOLAMINE	19.73		
GRAPHITE	GRAPHITE	29.79	61.20	45.50
	NON HAZ-INGREDIENTS	127.01		
	AMMONIA	1.95		
FIXER(OPTIONAL)	SULFURIC ACID	7.80		
AIR KNIFE/DRY				
MICRO ETCH	SULFURIC ACID	28.00	90.26	59.13
	SODIUM PERSULFATE	23.52	90.26	56.89
	POTASSIUM PEROXYMONOSULFATE	30.09		
	COPPER SULFATE AS COPPER	2.67		
	NON-HAZ INGREDIENTS	15.59		

* This table does not include Materials listed as "Non-Hazardous"

** Single value reported for chemical concentration in column (1); if more than one process contains chemical, lowest concentration reported is listed in (1) and highest is in (2) - average of all reported values listed in (3)

Table 7. Generic Chemistry Formulation: Conductive Polymer

MHC BATH	CHEMICALS In MHC PROCESS*	CONCENTRATION OF CONSTITUENTS IN BATH (g/l)	
		(1)	
MICRO ETCH	POTASSIUM PEROXYMONOSULFATE	100	
	SULFURIC ACID	20	
CLEANER/CONDITIONER	NATRIUM CARBONATE(SODIUM CARBONATE)	7.5	
CATALYST	PHOSPHORIC ACID	2.75	
	ALKALI PERMANGANATE	815	
	SODIUM HYDROXIDE	0.9	
CONDUCTIVE POLYMER	PHOSPHORIC ACID	26.85	
	POTASSIUM HYDROXIDE IN AZOLES	3	

* This table does not include Materials listed as "Non-Hazardous"

(1) Single value reported for chemical concentration

each chemical in a bath that incorporated all supplier's reported concentrations for that chemical. The initial bath makeup was used when calculating this average, and periodic changes in concentration due to depletion and replenishment practices were ignored. It was unfeasible to track all non-steady state chemical concentrations for each bath and supplier; the approach used maintains consistency between suppliers and processes. The actual differences in bath chemistry makeup over the lifetime of a bath are expected to be very small.

The generic process concentrations in Tables 1-7 were developed as mentioned above, using tables of compiled supplier process data combined with correspondence from manufacturers. The supplier and manufacturer process data is contained in an appendix of the CCPCT CTSA (1996), and a sample data sheet for the electroless copper process is given in Appendix A. The data in Tables 1-7 were coupled with exposure duration data and transport mechanism models to calculate intake potential for receptors.

Exposure Scenarios - Workplace Characteristics

The Workplace Practices Survey compiled by the staff at UT's CCPCT and used for the DfE project was the main source of information for determining typical worker and population exposure characteristics (CCPCT, 1996). The first step in any exposure assessment is to characterize the exposure setting and select exposure pathways for quantitative analysis. The CCPCT selected the exposure settings and pathways used in this risk assessment, consisting of: the room size; plant operating parameters; population characteristics such as operations and activities that complete exposure pathways; and average times that workers would spend in the process room.

Table 8 contains information compiled by the CCPCT staff used in characterizing the workplace to calculate exposures and risks in this work. The Workplace Practices Survey (CCPCT, 1996) contains background information used when developing these parameter assumptions.

Table 8. Workplace Characteristics

MHC Process and Room Parameters	Value or Data used	Distribution Conditions relating to collected data
Room Area, ft ²	3,760	Geometric Mean
Room Height, ft	10	Conservative Assumption
Room Volume, m ³	1,065	Product of area and height
Room Ventilation Rate, ft ³ /min	789.8	Revision of original assumption (* see below)
Room Air Turnover Rate, min ⁻¹	0.021	Ventilation rate divided by room volume
Room Air Temperature, ° F	75	Average
# of days MHC process line operates in a year	250	Average
Process Automation: Conveyorized	carbon, graphite, conductive polymer, organic palladium	Majority or all respondents with these processes reported this type of process automation
Process Automation: Non-Conveyorized	electroless copper, non-formaldehyde electroless copper, tin palladium	Majority or all respondents with these processes reported this type of process automation

From CTSA Draft: *Printed Wiring Board Industry MHC Process* (CCPCT, 1996)

*The air turnover rate in the process room is determined by dividing the room ventilation rate by the volume. Initially, the mean room volume and 10th percentile ventilation rate was to be used in calculating the air turnover rate. There was a large amount of variability in the ventilation rate data. The model was later found sensitive to changes in the air turnover rate data in a sensitivity and uncertainty analysis (see Sensitivity and Uncertainty Analysis of Air Transport Models section) as discussed later. This prompted a revision of the air turnover rate that provided a better prediction of the 90th percentile room chemical concentration for several chemicals in MHC processes. This distribution-based air turnover rate is 0.024 room volume air turnovers per minute.

Exposure Scenarios - Worker and Population Characteristics

Worker and population characteristics make up the necessary information for characterizing a typical, or generic MHC worker. The following information was obtained from the CCPCT document (1996) concerning worker exposure parameters.

- Several types of employees may work in the MHC process area each day. These are (in decreasing order of exposure potential from the work area):
 - Line operators: maintain the continuous operation of the MHC plating lines. Potential activities resulting in dermal and inhalation exposure are line operation, bath replacement and replenishment, rack and conveyor cleaning (for conveyorized processes only), and filter replacement
 - Laboratory technicians: sample and analyze the baths periodically to see if adjustments are needed. Potential for dermal and inhalation exposure.
 - Maintenance workers: perform routine maintenance on MHC line. Potential for inhalation exposure.
 - Supervisory personnel: usually spend brief, regular periods of time in process area only. Potential for inhalation exposure.
 - Wastewater treatment operators: treating and removing wastewater from process area. Potential for inhalation and dermal exposure.
 - Other workers (Manufacturing engineer, process representative/specialist): Potential for inhalation exposure.

Table 9 shows the exposure durations used to model workers. The time spent in the process area for line operators was used as a basis to determine all specific exposure duration information; for all processes, the daily inhalation exposure duration for line operators was set equal to the 90th percentile estimate (CCPCT, 1996). For non-conveyorized processes, the time spent in the process area was divided among the the number of baths in an MHC line to determine the dermal contact time per bath for line operators. For line operator exposure to conveyorized MHC processes, a bath-specific exposure duration based on the differing chemical replacement frequency rates for each bath was determined (see Appendix B, Air Transport Models: Exposure Parameters for Conveyorized Processes). Lab technician dermal contact time for conveyorized and non-conveyorized processes was determined from the chemical sampling frequency. Inhalation exposure will also be quantified for residents living near a PWB facility for chemicals released at a rate of 23 kg/year or higher, or for potential carcinogens. This screen is used by EPA to disregard smaller releases of hazardous substances that are insignificant (CCPCT, 1996).

Table 9. Daily Exposure Durations for Dermal and Inhalation Pathways

Parameter	Value used (hrs)	Distribution and Conditions for data rationale
time spent in process area for line operators (<u>all processes</u>) - used as exposure duration for inhalation pathway and as basis for determining line operator dermal exposure duration per bath (see below), hrs/day-bath	8	90th percentile for hours of MHC line operation (rounded up)
Line Operator Dermal Exposure durations per bath, Non-Conveyorized MHC processes	hours/bath -day	Exposure time divided by number of baths in a process
Electroless Copper line op., hrs/bath	0.42	19 baths (8hrs/19 baths = 0.42 hrs/bath)
Non-Electroless Copper line op., hr/bath	0.47	17 baths
Organic Palladium line op., hrs/bath	0.67	12 baths
Tin Palladium line op., hrs/bath	0.57	14 baths
Graphite line op., hrs/bath	0.25	Summation of contact activity durations (CCPCT, 1996)
Carbon line op., hrs/bath	0.22	Summation of contact activity durations (CCPCT, 1996)
Conductive Polymer line op., hrs/bath	0.22	Summation of contact activity durations (CCPCT, 1996)
Laboratory Technician Dermal Exposure durations per bath, Non-Conveyorized MHC processes		Summations of activity durations performed by lab technicians
Electroless Copper lab tech., hrs/bath	0.01	Summation of contact activity durations (CCPCT, 1996)
Non-Electroless Copper lab tech., hrs/bath	0.0007	Summation of contact activity durations (CCPCT, 1996)
Organic Palladium lab tech., hrs/bath	0.002	Summation of contact activity durations (CCPCT, 1996)
Tin Palladium lab tech., hrs/bath	0.0056	Summation of contact activity durations (CCPCT, 1996)
Graphite lab tech., hrs/bath	0.01	Summation of contact activity durations (CCPCT, 1996)
Carbon lab tech., hrs/bath	0.0018	Summation of contact activity durations (CCPCT, 1996)
Conductive Polymer lab tech., hrs/bath	0.0028	Summation of contact activity durations (CCPCT, 1996)

From CTSA Draft: Printed Wiring Board Industry MHC Process (CCPCT, 1996)

These potentials for exposure are rough estimates of the amount of time and typical activities that personnel might encounter each day. This list served as the basis for choosing those personnel exposure scenarios which would be quantified and those which would be evaluated qualitatively.

The workers whose exposure levels were quantified are line operators and laboratory technicians. Inhalation to workers was only quantified for non-conveyorized lines since conveyorized lines are enclosed and have virtually all emissions vented outside (CCPCT, 1996). The dermal activity durations potentially resulting in contact such as line operation, bath sampling and replacement were quantified by dividing the amount of time spent working in the process area by the number of baths in each particular MHC alternative.

Thus, if a line operator spends 8 hours working at the electroless copper line and there are 19 baths in that line, the amount of time available for dermal contact from the chemicals in each particular bath was estimated to be 0.42 hours/day. This approach is conservative but provides a way of determining and comparing upper-bound dermal exposures between processes. If these tend to be risk-driving estimates of exposure, then revisions may be made including allowances for the use of more protective equipment.

These data characterizing the generic workplace and worker characteristics will be used in the next section to quantify exposure from inhalation and dermal contact for line operators, laboratory technicians, and the general populace. Some additional information and assumptions used in the exposure analysis will be presented in tables.

Exposure and Intake Modeling

The equations and relationships regarding exposure estimation have been previously covered in the Literature Review. These mass transfer models used in predicting exposure and intake were developed by Robinson, Cox, Swanson, and Jackson (1997) based on the reviewed literature. Sample calculations for all situations encountered in this work in estimating exposure are located in Appendix C: Sample Modeling and Exposure Calculations. The calculations regarding volatilization and dermal intake of the chemical formaldehyde are shown for the electroless copper non-conveyorized MHC line using all generic parameters identified earlier for that process.

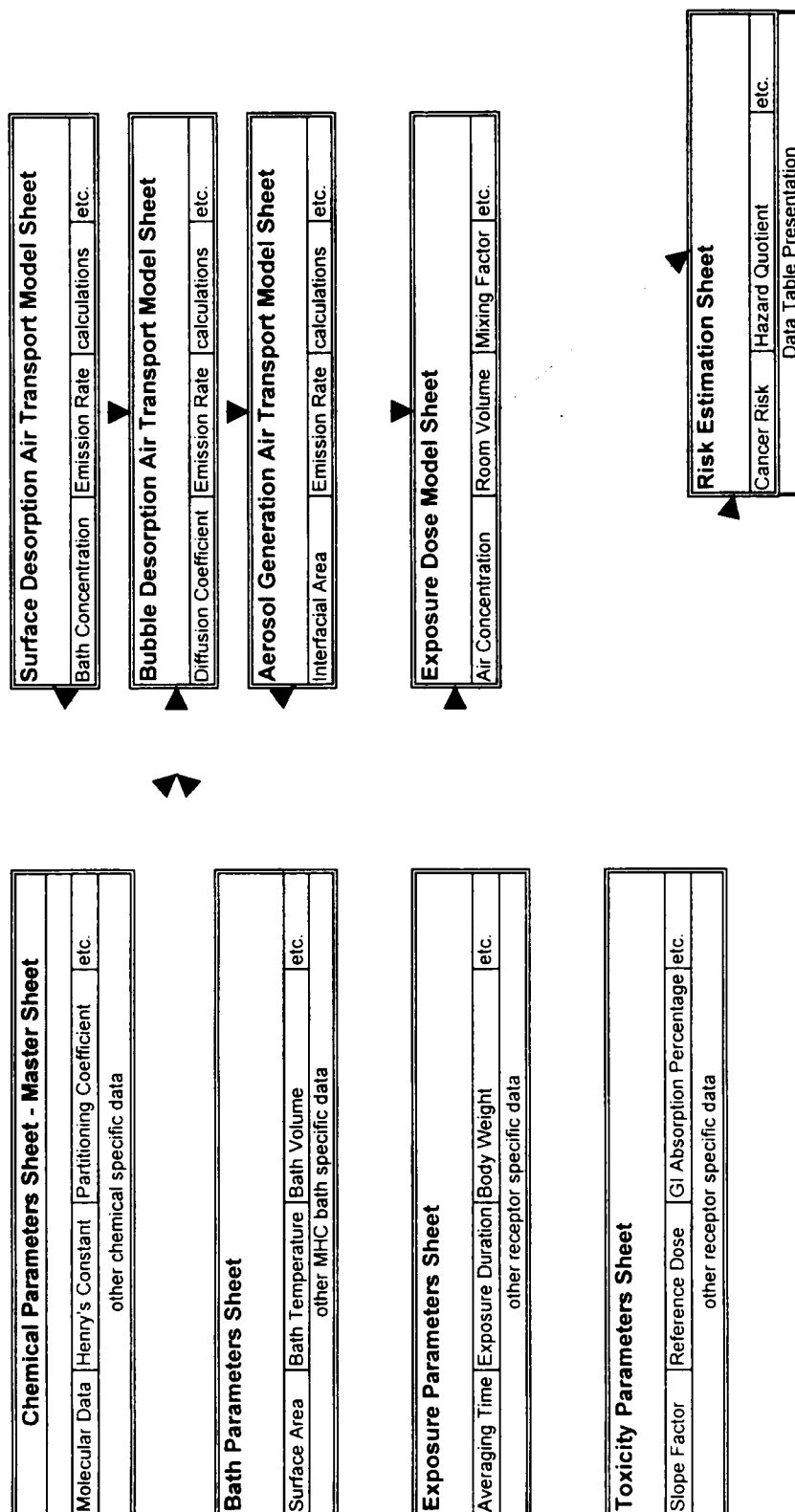
The quantified exposures for line operators and laboratory technicians are covered there, with ambient exposure for the populace being covered in the next section.

The intake and risk calculations involved in this project represented a considerable amount of computing effort, because they were repeated for numerous chemicals in seven different processes with two automation configurations (conveyorized and nonconveyorized). To help alleviate the problems associated with hand calculated or conventional-spreadsheet analyses, Visual Basic® programming in Excel® spreadsheets was used to automate calculations for all MHC alternatives.

This was done by programming all equations for modeling exposure and risk into Visual Basic Macro files in Excel which referred to a master chemical parameters spreadsheet. Each file contained this spreadsheet, but each time the master was updated, it was copied into all the process alternative files. Thus, bath and exposure data were the only information which were entered individually for each MHC alternative. Using a single chemical parameter spreadsheet simplified the quality assurance procedures because only one spreadsheet needed to be checked. The macro files, or functions, referred back to each master sheet and retrieved the necessary information for each operation, then proceeded to the next chemical, bath, and receptor group to complete the calculations. This approach also allowed for later adjustments of parameters or equations in a simplified manner.

A series of checks were implemented throughout the basic functions, to assist in locating data and code mistakes. An identification number was assigned to every chemical and bath in a given MHC process. This number was checked against a master list of chemical and bath names and returned an error signal when there was a mistake; e.g. a chemical's name was misspelled, or a bath name did not exist in the bath parameters sheet. Additionally, the code checked to insure that the gas-side mass transfer resistance controlled (see Literature Review; Diffusional Transport) in the surface desorption model. After checking the code itself and then checking the entered data, it was assured that calculations for exposure and risk were performed properly. Figure 4 shows this calculation process schematically.

Modeling and Visual Basic Spreadsheet Approach for Calculating Risks from MHC Process Tanks



Note:
 Each arrow represents a visual basic macro or calculation performing a series of steps
 Each step performed for all receptors and pathways

Figure 4. Modeling and Visual Basic Spreadsheet Approach for Calculations

Determining outdoor air concentrations using ISCLT2

The Industrial Source Complex Long-Term (ISCLT) air dispersion model, version 2 (USEPA, 1992), was used to predict conservative ambient air concentrations resulting from chemical releases at MHC plants. This model is accepted by EPA and provides adequate accuracy for screening estimates of risk. The following default parameters were used in conjunction with the model as specified by EPA in PPT (1994):

- regulatory default setting for ISCLT
- urban mode (U3)
- standard polar grid, 36 segments with 1 calculation per segment; 1 calculation made at 100 meters radially from center (source) - the highest modeled air concentration regardless of direction was used to determine exposure to population
- single point of release from facility location
- release height of 3 meters for fugitive releases from an area source of 10 meters by 10 meters (100m²)

As mentioned earlier, the location selected for dispersion modeling can have a great effect on predicted air concentration. ISCLT2 requires information on local weather patterns to accurately predict contaminant concentrations at specified distances from a source. Air conditions at the surface and in the upper air are the key data for a given location (USEPA, 1992a). Surface data are comprised of joint frequency distributions of wind speed class, by wind direction sector and by stability category, known as STAR summaries (STability ARray). Upper air data provide information on mixing heights, but there are fewer upper-air stations than surface-air stations, thus making it difficult to evaluate all cities for the same surface-air and upper-air data. It is important to combine surface-air and upper-air data for regions of similar physical geography if data are not available for the same city. Several cities of similar physical and areal geography were used with ISCLT2 to evaluate ambient air concentrations at PWB sites for a fixed source flux.

These cities were chosen to provide high-end modeled air concentrations, and are listed in the Table 10. In the cases where air and surface data were not available for a given city, surrogate city data were used. These cities were selected after randomly testing each location with set emission rates to determine the highest group of outputs. This method, though not exact for a given location, should provide a reasonable comparison of relative risks across MHC alternatives. Each column constitutes one

ISCLT2 run where an air concentration was obtained for the given flux of 1gram per second.

Table 10. ISCLT2 Air Dispersion Modeling Results

Air Data City Location	Oakland	Oakland	Denver	Nashville	Amarillo	Tucson
Surface Data City Location	Fresno	San Francisco	Denver	Knoxville	Amarillo	Phoenix
Resulting Air Concentration ($\mu\text{g}/\text{m}^3$)	103.99	77.64	132.01	88.26	57.07	157.09

Modeled air concentrations are linear with respect to source flux in ISCLT, so a unit approach can be used to relate this fixed source flux to air concentration. This requires only these few ISCLT runs to be made when determining an air concentration relating to a given flux for the various city data. The 3 highest air concentrations, from Tucson/Phoenix, Denver, and Oakland/Fresno, were averaged to estimate an upper-bound air concentration. This average concentration is $131.0 \mu\text{g}/\text{m}^3$, and can be used with the following ratio approach to determine chemical air concentrations that the public might be exposed to:

$$\frac{\text{CONC}_{\text{POPULATION}}}{\text{FLUX}_{\text{POPULATION}}} = \frac{\text{CONC}_{\text{UNIT}}}{\text{FLUX}_{\text{UNIT}}}$$

where:

- CONC = modeled air concentration from ISCLT ($\mu\text{g}/\text{m}^3$)
- FLUX = chemical emission rate from exhaust vent obtained with air transport models (g/s)
- Population = Air concentration modeled at 100 meters outside a PWB facility that the general public could come into contact with
- UNIT = Given flux and corresponding air concentration obtained with ISCLT2 (1 g/s and average concentration of $131.03 \mu\text{g}/\text{m}^3$)

Inserting the unit source flux and averaged high-end air concentration into the ratio above, the following relationship can be obtained for predicting the concentration of each individual chemical from its given flux:

$$\begin{aligned}\text{CONC}_{\text{POP}} &= \frac{\text{CONC}_{\text{UNIT}}}{\text{FLUX}_{\text{UNIT}}} \text{FLUX}_{\text{POP}} = \frac{131.03 \text{ ug} / \text{m}^3}{1 \text{ g} / \text{s}} \text{FLUX}_{\text{POP}} \\ &= 2.18 \times 10^{-3} \frac{\text{ug} / \text{m}^3}{\text{mg} / \text{min}} \text{FLUX}_{\text{POP}}\end{aligned}$$

Inhalation exposure to the general population

The above example will be continued here by determining outdoor formaldehyde concentrations and the corresponding exposures to the general population living around PWB facilities. Some key parameter assumptions for this receptor group are listed in Table 11 (adapted from CCPCT, 1996).

Table 11. Inhalation Exposure Parameters for General Population

Exposure Parameter	Value used in Exp. Assess.	Reference/Comments
Inhalation Rate, m ³ /day	15	EPA, 1995: home inhalation rates for adults based on activity patterns
Exposure Frequency, days/yr	350	EPA, 1991b: typical assumption of 2 week vacation/leisure away from home
Exposure Duration, years	30	EPA, 1990: national 90th percentile residence duration at 1 home
Body Weight, kg	70	EPA, 1991b: average value for adult males
Averaging Time for long term exposure estimates (days)	10950 non-carcinogenic 25550 carcinogenic	30 & 70 years · 365 days/year, based on averaging time assumptions for risk, EPA 1992b
Receptor Home distance from PWB facility, m	100	EPA (1994)

From CTSA Draft: Printed Wiring Board Industry MHC Process (CCPCT, 1996)

To determine inhalation exposure to formaldehyde that the general population may encounter from living near PWB facilities, air concentrations based on formaldehyde releases from PWB plants must first be calculated. This is done using the ratio relationship developed above.

$$\begin{aligned}\text{CONC}_{\text{POP}} &= 2.18 \times 10^{-3} \frac{\text{ug} / \text{m}^3}{\text{mg} / \text{min}} 13.74 \text{ mg} / \text{min} \\ &= 3.00\text{E-}2 \text{ ug} / \text{m}^3 = 3.00\text{E-}5 \text{ mg} / \text{m}^3\end{aligned}$$

This air concentration represents the long-term steady-state formaldehyde concentration that may be encountered at a distance of 100 meters from a typical electroless copper facility. PDRs and LADDs based on inhalation exposure to this air concentration can be calculated as below (see Appendix C. Sample Modeling and Calculations for further examples of dosage calculation):

$$\text{PDR} = \frac{C_Y \cdot \text{IR} \cdot \text{EF} \cdot \text{ED}}{\text{BW} \cdot \text{AT}} \quad (\text{Eq. 20})$$

where:

- C_Y = 6.16E-6 mg/kg·day
- C_Y = 3.0E-5 mg/m³
- IR = 15 m³/day, inhalation rate
- EF = 350 days/yr, exposure frequency
- ED = 30 years, exposure duration
- BW = 70 kg, body weight
- AT = 10950 days (30 years * 365 days/year), averaging time for noncarcinogen effects

$$\text{LADD} = \frac{C_Y \cdot \text{IR} \cdot \text{EF} \cdot \text{ED}}{\text{BW} \cdot \text{AT}} \quad (\text{Eq. 21})$$

where:

- C_Y = 2.64E-6 mg/kg·day
- C_Y = 3.0E-5 mg/m³
- IR, EF, ED, BW = same as above
- AT = 25550 days (70 years * 365 days/year), averaging time for carcinogenic effects

Tables located in Appendix C contain the intermediate calculations outlined above for all MHC process chemicals. Table 12 presents the exposure results for all quantified receptors in non-conveyorized MHC lines. Table 13 presents exposure results for receptors in conveyorized MHC lines.

Table 12. Potential Dose Rates for Non-Conveyorized MHC Alternatives (mg/kg-d)

Receptors	Line Operator	Line Operator	Lab Tech	General Population
Exposure Pathway	Inhalation	Dermal	Dermal	Inhalation
Chemicals In Alternative				
Electroless Copper				
Ammonium Chloride	0.00E+00	8.42E-02	2.07E-03	0.00E+00
Benzotriazole	6.64E-04	2.48E-03	6.10E-05	5.56E-08
Boric Acid	9.15E-04	3.27E-02	8.03E-04	7.65E-08
Copper Chloride (I)	4.05E-04	4.37E-02	1.07E-03	3.39E-08
Copper Sulfate	4.45E-04	4.89E-02	1.20E-03	3.72E-08
Dimethylaminoborane	1.04E-02	3.92E-03	9.63E-05	8.67E-07
Dimethylformamide	7.58E-03	1.13E-03	2.77E-05	6.34E-07
Ethanolamine	5.31E-02	1.01E-02	2.49E-04	4.44E-06
Ethylene Glycol	1.78E-02	2.46E-03	6.05E-05	1.49E-06
Ethylenediamine –Tetraacetic Acid (EDTA)	2.74E-03	1.69E-05	4.15E-07	2.29E-07
Fluoboric Acid	1.18E-02	3.92E-01	9.64E-03	9.84E-07
Formaldehyde, LADD* (Carcinogen)	2.63E-02	1.07E-02	2.64E-04	2.64E-06
Formaldehyde, PDR (Non-Carcinogen)	7.36E-02	3.01E-02	7.39E-04	6.16E-06
Formic Acid	1.88E-01	3.48E-02	8.54E-04	1.57E-05
Hydrochloric Acid	2.91E-05	8.96E-01	2.20E-02	2.43E-09
Hydrogen Peroxide	8.87E-04	1.30E-01	3.20E-03	7.42E-08
Hydroxyacetic Acid	1.68E-04	2.42E-02	5.94E-04	1.41E-08
Isopropyl Alcohol	2.81E+00	3.13E-02	7.68E-04	2.35E-04
Magnesium Carbonate	5.35E-05	7.85E-03	1.93E-04	4.47E-09
Methanol	1.24E+00	1.13E-02	2.78E-04	1.03E-04
P-Toluene Sulfonic Acid	0.00E+00	3.99E-03	9.79E-05	0.00E+00
Palladium	0.00E+00	3.73E-02	9.17E-04	0.00E+00
Potassium Bisulfate	6.15E-04	9.02E-02	2.22E-03	5.15E-08
Potassium Cyanide	1.35E-05	1.46E-03	3.58E-05	1.13E-09
Potassium Hydroxide	1.25E-05	5.44E-03	1.34E-04	1.04E-09
Potassium Persulfate	4.37E-04	6.41E-02	1.57E-03	3.65E-08
Potassium Sulfate	8.56E-04	1.26E-01	3.08E-03	7.16E-08
Potassium-Sodium Tartrate	1.90E-03	2.06E-01	5.05E-03	1.59E-07
Sodium Bisulfate	0.00E+00	4.56E-01	1.12E-02	0.00E+00
Sodium Carbonate	3.03E-06	3.27E-04	8.03E-06	2.53E-10
Sodium Chlorite	0.00E+00	2.95E-02	7.25E-04	0.00E+00
Sodium Cyanide	1.40E-05	1.51E-03	3.71E-05	1.17E-09
Sodium Hydroxide	6.30E-04	8.51E-02	2.09E-03	5.27E-08
Sodium Hypophosphite	0.00E+00	5.61E-02	1.38E-03	0.00E+00
M-Nitrobenzene Sulfonic Acid	4.90E-06	8.78E-07	2.16E-08	4.10E-10
Sodium Sulfate	0.00E+00	8.26E-02	2.03E-03	0.00E+00
Stannous Chloride	0.00E+00	7.30E-01	1.79E-02	0.00E+00
Sulfuric Acid	6.67E-03	1.19E+00	2.92E-02	5.58E-07
Tartaric Acid	6.24E-05	5.74E-05	1.41E-06	5.22E-09
Triethanolamine	0.00E+00	3.45E-03	8.48E-05	0.00E+00
2-Ethoxyethanol	7.79E+00	1.37E-01	3.37E-03	6.52E-04

Tin Palladium	Line Operator - Inhalation	Line Operator - Dermal	Lab Tech - Dermal	General Population - Inhalation
1,3-Benzenediol	0.00E+00	9.72E-03	9.70E-05	0.00E+00
Copper Chloride(I)	0.00E+00	2.26E-02	2.26E-04	0.00E+00
Copper Sulfate	3.95E-04	1.25E-01	1.25E-03	3.31E-08
Ethanolamine	1.07E-01	2.69E-02	2.68E-04	8.94E-06
Fluoboric Acid	9.45E-03	1.68E-01	1.67E-03	7.90E-07
Hydrochloric Acid	0.00E+00	2.95E-01	2.94E-03	0.00E+00
Hydrogen Peroxide	5.20E-04	1.55E-01	1.55E-03	4.35E-08
Isopropyl Alcohol	1.58E+00	1.61E-02	1.61E-04	1.32E-04
Lithium Hydroxide	0.00E+00	1.80E-01	1.80E-03	0.00E+00
Palladium	0.00E+00	8.52E-03	8.50E-05	0.00E+00
Palladium Chloride	0.00E+00	5.32E-03	5.31E-05	0.00E+00
Potassium Carbonate	0.00E+00	2.88E+00	2.87E-02	0.00E+00
Sodium Bisulfate	0.00E+00	7.94E-01	7.92E-03	0.00E+00
Sodium Chloride	0.00E+00	8.99E+00	8.97E-02	0.00E+00
Sodium Hydroxide	0.00E+00	2.57E-01	2.57E-03	0.00E+00
Table 12 (continued)				
Sodium Persulfate	4.49E-03	1.34E+00	1.34E-02	3.75E-07
Stannous Chloride	0.00E+00	2.82E-01	2.81E-03	0.00E+00
Sulfuric Acid	6.21E-04	1.89E+00	1.89E-02	5.19E-08
Triethanolamine	0.00E+00	2.36E-03	2.35E-05	0.00E+00
Vanillin	4.33E-04	2.99E-03	2.99E-05	3.62E-08
Non-Formaldehyde Electroless Copper				
Copper Sulfate	1.47E-03	1.68E-01	2.66E-04	1.23E-07
Hydrochloric Acid	0.00E+00	2.17E-02	3.43E-05	0.00E+00
Hydrogen Peroxide	5.01E-04	1.18E-01	1.87E-04	4.19E-08
Isopropyl Alcohol	3.93E-01	1.31E-02	2.08E-05	3.29E-05
Potassium Hydroxide	7.99E-06	2.20E-03	3.48E-06	6.68E-10
Potassium Persulfate	3.04E-04	7.17E-02	1.14E-04	2.54E-08
Sodium Chlorite	0.00E+00	3.31E-02	5.25E-05	0.00E+00
Sodium Hydroxide	9.31E-06	2.20E-03	3.48E-06	7.79E-10
Stannous Chloride	0.00E+00	6.94E-02	1.10E-04	0.00E+00
Sulfuric Acid	7.94E-04	1.67E-01	2.65E-04	6.64E-08
Organic Palladium				
Hydrochloric Acid	0.00E+00	6.39E-02	2.16E-04	0.00E+00
Sodium Bisulfate	0.00E+00	7.82E-01	2.65E-03	0.00E+00
Sodium Carbonate	0.00E+00	2.29E-01	7.76E-04	0.00E+00
Sodium Hypophosphite	0.00E+00	3.19E-02	1.08E-04	0.00E+00
Sodium Persulfate	0.00E+00	7.82E-01	2.65E-03	0.00E+00
Trisodium Citrate 5.5-Hydrate	0.00E+00	6.70E-03	2.27E-05	0.00E+00

0.00E+00: not available because releases were negligible (e.g. sodium hypophosphate in organic palladium) or there was a lack of chemistry information available (eg. dimethylaminoborane)

* LADD (Lifetime Average Daily Dose) calculated for formaldehyde, the only carcinogen which had an accepted slope factor

Table 13. Potential Dose Rates for Conveyorized MHC Alternatives (mg/kg-d)

Receptors	Line Operator	Laboratory Technician	General Population
Exposure Pathway	Dermal	Dermal	Inhalation
Chemicals In Alternative			
Electroless Copper			
Ammonium Chloride	2.09E-02	2.07E-03	0.00E+00
Benzotriazole	6.30E-04	6.10E-05	5.92E-08
Boric Acid	9.17E-03	8.03E-04	1.16E-07
Copper Chloride(I)	9.80E-03	1.07E-03	1.63E-07
Copper Sulfate	1.11E-02	1.20E-03	1.72E-07
Dimethylaminoborane	1.10E-03	9.63E-05	1.32E-06
Dimethylformamide	2.80E-04	2.77E-05	1.43E-06
Ethanolamine	2.52E-03	2.49E-04	1.00E-05
Ethylene Glycol	6.46E-04	6.05E-05	2.80E-06
Ethylenediamine-Tetraacetic Acid (EDTA)	3.78E-06	4.15E-07	1.10E-06
Fluoboric Acid	9.09E-02	9.64E-03	1.08E-06
Formaldehyde, LADD* (Carcinogen)	2.41E-03	2.64E-04	7.02E-06
Formaldehyde, PDR (Non-Carcinogen)	6.75E-03	7.39E-04	1.64E-05
Formic Acid	8.64E-03	8.54E-04	3.54E-05
Hydrochloric Acid	2.23E-01	2.20E-02	1.17E-08
Table 13 (continued)			
Hydrogen Peroxide	3.65E-02	3.20E-03	8.15E-08
Hydroxyacetic Acid	6.01E-03	5.94E-04	3.17E-08
Isopropyl Alcohol	7.84E-03	7.68E-04	4.65E-04
Magnesium Carbonate	2.20E-03	1.93E-04	4.91E-09
Methanol	2.74E-03	2.78E-04	1.92E-04
P-Toluene Sulfonic Acid	9.91E-04	9.79E-05	0.00E+00
Palladium	9.28E-03	9.17E-04	0.00E+00
Potassium Bisulfate	2.53E-02	2.22E-03	5.65E-08
Potassium Cyanide	3.27E-04	3.58E-05	5.42E-09
Potassium Hydroxide	1.36E-03	1.34E-04	1.14E-09
Potassium Persulfate	1.80E-02	1.57E-03	4.01E-08
Potassium Sulfate	3.52E-02	3.08E-03	7.86E-08
Potassium-Sodium Tartrate	4.60E-02	5.05E-03	7.65E-07
Sodium Bisulfate	1.13E-01	1.12E-02	0.00E+00
Sodium Carbonate	7.32E-05	8.03E-06	1.22E-09
Sodium Chlorite	6.84E-03	7.25E-04	0.00E+00
Sodium Cyanide	3.38E-04	3.71E-05	5.62E-09
Sodium Hydroxide	1.96E-02	2.09E-03	2.49E-07
Sodium Hypophosphite	1.30E-02	1.38E-03	0.00E+00
M-Nitrobenzene Sulfonic Acid	2.23E-07	2.16E-08	4.46E-10
Sodium Sulfate	2.05E-02	2.03E-03	0.00E+00
Stannous Chloride	1.82E-01	1.79E-02	0.00E+00
Sulfuric Acid	3.20E-01	2.92E-02	6.33E-07
Tartaric Acid	1.29E-05	1.41E-06	2.51E-08
Triethanolamine	8.58E-04	8.48E-05	0.00E+00
2-Ethoxyethanol	3.48E-02	3.37E-03	6.95E-04

Tin Palladium	Line Operator - Dermal	Laboratory Technician - Dermal	General Population - Inhalation
1,3-Benzenediol	3.04E-03	9.70E-05	0.00E+00
Copper Chloride(I)	8.13E-03	2.26E-04	0.00E+00
Copper Sulfate	4.87E-02	1.25E-03	1.53E-07
Ethanolamine	1.24E-02	2.68E-04	2.34E-05
Fluoboric Acid	6.02E-02	1.67E-03	5.98E-06
Hydrochloric Acid	1.13E-01	2.94E-03	0.00E+00
Hydrogen Peroxide	6.06E-02	1.55E-03	2.02E-07
Isopropyl Alcohol	8.41E-03	1.61E-04	1.05E-04
Lithium Hydroxide	6.47E-02	1.80E-03	0.00E+00
Palladium	2.67E-03	8.50E-05	0.00E+00
Palladium Chloride	1.67E-03	5.31E-05	0.00E+00
Potassium Carbonate	1.04E+00	2.87E-02	0.00E+00
Sodium Bisulfate	3.42E-01	7.92E-03	0.00E+00
Sodium Chloride	3.54E+00	8.97E-02	0.00E+00
Sodium Hydroxide	9.24E-02	2.57E-03	0.00E+00
Sodium Persulfate	5.23E-01	1.34E-02	1.74E-06
Stannous Chloride	8.83E-02	2.81E-03	0.00E+00
Sulfuric Acid	1.22E+00	1.89E-02	2.41E-07
Triethanolamine	1.23E-03	2.35E-05	0.00E+00
Vanillin	9.37E-04	2.99E-05	1.14E-06
Organic Palladium			
Hydrochloric Acid	1.77E-02	2.16E-04	0.00E+00
Sodium Bisulfate	1.49E-01	2.65E-03	0.00E+00
Sodium Carbonate	4.77E-02	7.76E-04	0.00E+00
Sodium Hypophosphite	6.18E-03	1.08E-04	0.00E+00
Sodium Persulfate	1.49E-01	2.65E-03	0.00E+00
Trisodium Citrate 5.5-Hydrate	1.37E-03	2.27E-05	0.00E+00
Graphite			
Ammonia	4.18E-03	3.32E-04	9.67E-06
Copper Sulfate	1.10E-02	4.54E-04	0.00E+00
Ethanolamine	5.32E-03	3.19E-04	4.32E-06
Graphite	9.76E-02	7.74E-03	0.00E+00
Potassium Carbonate	2.10E-02	1.26E-03	0.00E+00
Peroxymonosulfuric Acid	1.24E-01	5.12E-03	0.00E+00
Sodium Persulfate	2.35E-01	9.68E-03	0.00E+00
Sulfuric Acid	2.44E-01	1.01E-02	0.00E+00
Conductive Polymer			
Sodium Carbonate	2.49E-02	3.29E-04	0.00E+00
Phosphoric Acid	1.00E-01	1.30E-03	0.00E+00
1h-Pyrrole	2.59E-02	3.33E-04	0.00E+00
Peroxymonosulfuric Acid	7.01E-01	8.78E-03	0.00E+00
Sodium Hydroxide	2.73E-03	3.95E-05	0.00E+00
Sulfuric Acid	1.40E-01	1.76E-03	0.00E+00
Carbon			
Copper Sulfate	1.74E-02	1.44E-04	0.00E+00
Ethanolamine	9.59E-03	1.29E-04	1.11E-05

Carbon, continued	Line Operator - Dermal	Laboratory Technician - Dermal	General Population - Inhalation
Potassium Hydroxide	7.32E-02	1.17E-03	0.00E+00
Sodium Persulfate	6.98E-01	5.74E-03	0.00E+00
Sulfuric Acid	6.42E-03	5.28E-05	0.00E+00

Sensitivity and Uncertainty Analyses of Air Transport Models

The three air transport models used in calculating inhalation exposure are complicated and have numerous parameters associated with them. An exhaustive review and revision of each parameter for accuracy is impractical and infeasible. Sensitivity and uncertainty analyses were used to identify those few model parameters having the greatest effect on chemical air concentrations in the workplace. These analysis techniques serve to pinpoint essential parameter assumptions, and allow attention to be focused only on those assumptions that are most important to the modeling outcome.

Sensitivity Analysis

The first step in this analysis was to determine the parameters in the air transport models which had the largest impact on the workplace chemical air concentrations, regardless of variability. This was done by independently varying each parameter in the model by a specific amount and observing the effect on chemical air concentration. The result is a comparison of the importance of each parameter in the model independent of the variability of the other model parameters.

Table 14 lists the parameters that had the greatest effect on workplace air concentrations. Small changes in these parameters caused the model results to vary widely, indicating a need to determine the uncertainty associated with these variables. To ascertain general parameter-dependent variances for all chemicals regarding air modeling outcomes, the effects of changes were observed for several chemicals and transport situations. A list of all parameters used in modeling air transport mechanisms follows.

There were two air-transport scenarios studied in the sensitivity analysis. These dealt with the two main MHC chemicals bath configurations that facilitated mass transport to the atmosphere. Those bath configurations are sparged baths and unsparged baths. As mentioned before, the transport mechanism that applied to all MHC chemicals was surface desorption. In unsparged baths surface desorption was the only transport mechanism, but in sparged baths the bubble desorption and aerosol generation/transport mechanisms applied in addition to surface desorption.

Table 14. Air Transport Model Sensitivity to Changes in Parameters

Parameter (X)	ΔX (%)	1. % Change in Sparged Volatile Modeled Air Conc.	2. % Change in Sparged Non-Volatile Modeled Air Conc.	3. % Change In Non- Sparged Volatile Modeled Air Conc.
Enthalpy (Aqueous or Gas)	10	-23.6	NA	-4.4
Bath Temperature	10	16.2	4.8	19.3
Henry's Constant	10	10.0	NA	10.0
Bath Chemical Concentration	10	10.0	10.0	10.0
Process Room Volume	10	-9.1	-9.1	-9.1
Air Turnover Rate	10	-9.1	-9.1	-9.1
Bath Surface Area	10	5.9	2.3	7.4
Air Sparging Rate	10	2.1	7.7	NA
Air Velocity Across Tank	10	3.7	1.2	4.9
Molecular Weight	10	-2.0	NA	-2.1

The effects of parameter variances on several chemicals were examined in these two MHC bath configurations. The sample chemicals and baths were chosen to represent common and realistic processes. The electroless copper and accelerator baths of the Electroless Copper MHC alternative were selected as the sparged and unsparged sample baths, respectively. These bath configurations were used because the electroless copper process is the most common MHC line, and thus had the most reliable survey data available.

The two groups of chemicals examined were volatiles and non-volatiles (chemicals with a vapor pressure less than 1E-03 torr). Formaldehyde was the main chemical chosen for the sensitivity simulation of volatiles in sparged baths. This was done for several reasons; formaldehyde is one of the risk drivers in MHC processes, and its chemical parameters are known to a high degree of certainty. Copper Chloride (I) was chosen as the sparged non-volatile chemical because it is common to many MHC processes and is also present in the electroless copper bath. Fluoboric acid was selected as another volatile chemical in unsparged and sparged baths, because its chemical properties are known to a high degree of certainty and because it behaves similarly to formaldehyde, which was only present in the sparged electroless copper bath.

A sensitivity analysis was also performed on other chemicals (methanol, isophorone) to verify that different chemicals behaved similarly upon varying of model parameters. This sensitivity analysis was used primarily to eliminate inconsequential parameters for the subsequent Monte Carlo uncertainty analysis, and to serve as a check for the results of that analysis.

Columns 1, 2, and 3 of Table 14 show the percentage change (increase or decrease) in workplace chemical air concentration due to increasing each parameter by 10% (ΔX). Sparged volatiles (vapor pressure > 1E-03 torr) are affected by all three air transport mechanisms mentioned earlier. Sparged non-volatiles are affected only by the aerosol transport mechanisms. Unsparged volatiles are only affected by the surface desorption air transport mechanism. Unsparged non-volatiles are not addressed because their emission rates are negligible.

For example, a 10% increase in bath area has the effect of increasing a sparged volatile's workplace air concentration by 5.9 %, while only increasing a sparged non-volatile's (or salt's) air concentration by 2.3 %. Each parameter listed was also increased by 20% to determine if its relationship to air concentration was highly non-linear, but none exhibited a significant trend in this area. Again, only the parameters exhibiting the greatest effect on workplace air concentrations are in Table 14; all parameters used in modeling workplace air concentrations are listed below. The parameters in this list but not included in Table 14 exhibited negligible effects on computed air concentrations (caused less than 0.01 percent change in sparged chemical workplace air concentration by varying each by 10%).

Chemical Parameters

- Molecular Weight
- Molecular Volume and Molar Solute Area (determined from Molecular Volume)
- Henry's Constant
- Enthalpy (Gaseous and Aqueous)
- Surface Tension Coefficients
- Activity Coefficient
- Density and Viscosity of Water

MHC Bath Parameters

- Chemical Concentration in Bath
- Bath Temperature
- Bath Volume
- Bath Area, Distance across Bath Surface (calculated as square root of bath area), Bath Height (calculated by dividing bath volume by area)
- Air Velocity above Bath Surface

- Sparged Air Flow into Bath (for sparged baths only)
- Sparged Bubble Diameter (for sparged baths only)
- Distance to Tank Rim from Liquid Surface (for sparged baths only)

Process Room Parameters

- Process Room Volume
- Air Turnover Rate (ventilation rate/room volume)
- Dimensionless Mixing Factor, k

Those parameters listed above which exhibited negligible effects on computed air concentrations in the sensitivity analysis are:

- bath volume
- sparged bubble diameter
- surface tension coefficients
- activity coefficient
- molecular volume
- water density and viscosity

Two parameters were arbitrarily fixed and were not considered in the uncertainty analysis:

- distance to the tank rim correction factor: this parameter had no effect on air modeling at the distances encountered in MHC process tanks (from literature)
- dimensionless mixing factor, k: arbitrarily set by EPA to equal 1 for this project (no effect on air modeling), built-in safety factor that sometimes ranges from 0.1 to 0.5

Quantitative Uncertainty Analysis

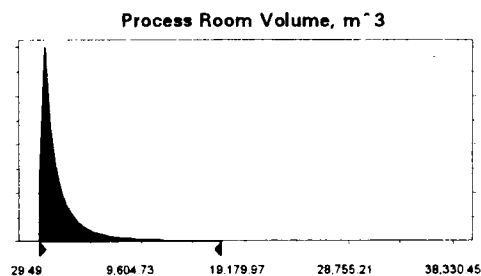
Table 14 only addresses the sensitivity of the air transport models to certain parameters. It is more useful here to examine sensitivity and uncertainty, or variability, on a combined basis. This was done using the Crystal Ball (Decisioneering, Inc.) software package in combination with Lotus 1-2-3®. The air transport equations outlined earlier were used in conjunction with the probability distributions for each parameter to perform a Monte Carlo analysis. These parameter distributions are presented as Figures 5 and 6. The statistical data used to provide these distributions are derived from the original workplace practices survey data and subsequent queries by the CCPCT (1996).

Crystal Ball® was used to produce two independent Monte Carlo simulations with 15,000 iterations each for volatiles in sparged and unsparged baths. The mass flux contribution from non-volatiles in sparged baths is largely negligible in overall

Assumption: Process Room Volume, m³

Lognormal distribution with parameters
Geometric Mean 1,063.16
Geometric Std Dev 3.30

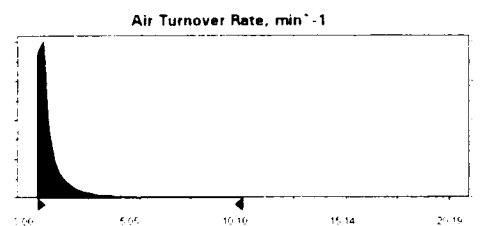
Selected range is from 33.00 to 17,000.00
Mean value in simulation was 1,911.04



Assumption: Air Turnover Rate, min⁻¹

Lognormal distribution with parameters
Mean 0.74
Standard Dev 2.00

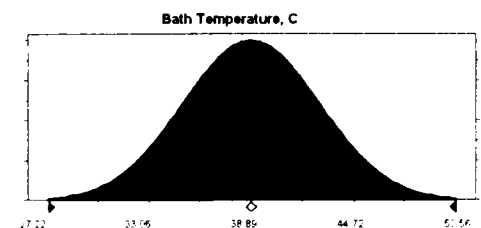
Selected range is from 0.00018 to 10.10
Mean value in simulation was 0.64



Assumption: Bath Temperature, C

Normal distribution with parameters
Mean 38.89
Standard Dev 3.89

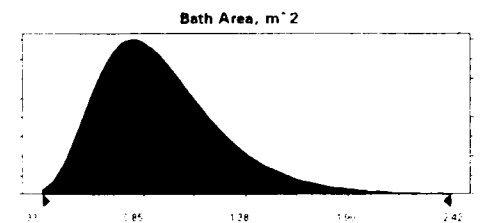
Selected range is from 20.00 to 58.00
Mean value in simulation was 38.89



Assumption: Bath Area, m²

Lognormal distribution with parameters
Log Mean -0.11
Log Std Dev 0.33

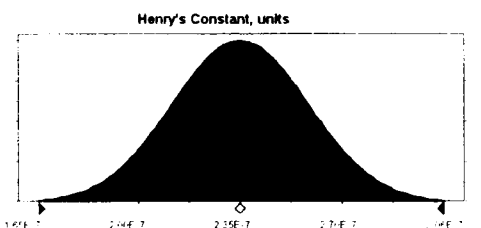
Selected range is from 0.00 to 3.72
Mean value in simulation was 0.94



Assumption: Henry's Constant, unitless

Normal distribution with parameters
Mean 2.35E-07
Standard Dev 2.35E-08

Selected range is from -Infinity to +Infinity
Mean value in simulation was 2.35E-7



Assumption: Chemical Concentration, mg/L

Triangular distribution with parameters
Minimum 1580
Likeliest 3680
Maximum 5600

Selected range is from 1580 to 5600
Mean value in simulation was 3620

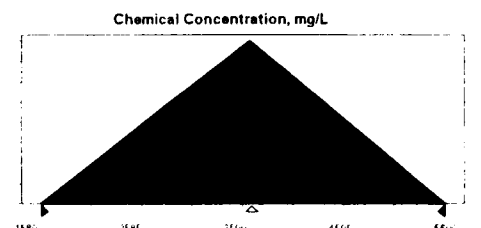
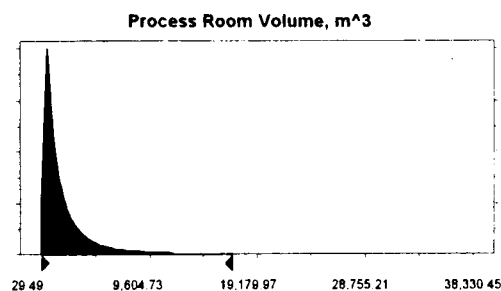


Figure 5. Monte Carlo Parameter Distribution Assumptions - Formaldehyde

Assumption: Process Room Volume, m³

Lognormal distribution with parameters:
Geometric Mean 1,063.16
Geometric Std. Dev. 3.30

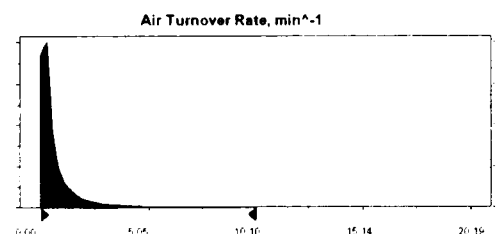
Selected range is from 33.00 to 17,000.00
Mean value in simulation was 1,911.04



Assumption: Air Turnover Rate, min⁻¹

Lognormal distribution with parameters:
Mean 0.74
Standard Dev. 2.00

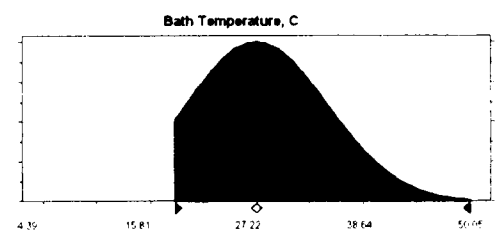
Selected range is from 0.00018 to 10.10
Mean value in simulation was 0.64



Assumption: Bath Temperature, C

Normal distribution with parameters:
Mean 27.22
Standard Dev. 7.61

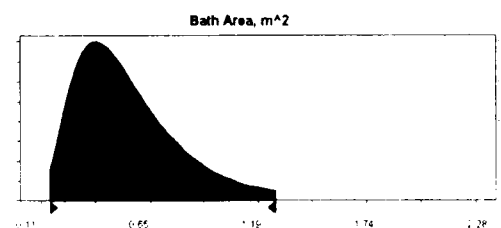
Selected range is from 18.39 to 50.39
Mean value in simulation was 28.95



Assumption: Bath Area, m²

Lognormal distribution with parameters:
Geometric Mean 0.49
Geometric Std. Dev. 1.67

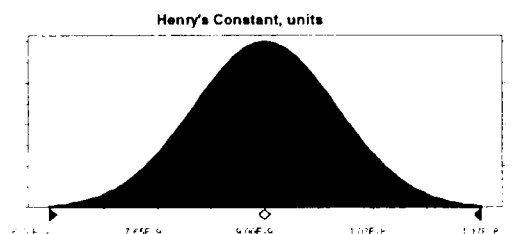
Selected range is from 0.15 to 1.28
Mean value in simulation was 0.53



Assumption: Henry's Constant, unitless

Normal distribution with parameters:
Mean 9.00E-09
Standard Dev. 9.00E-10

Selected range is from 5.40E-9 to 1.26E-8
Mean value in simulation was 9.00E-9



Assumption: Chemical Concentration, mg/L

Triangular distribution with parameters:
Minimum 30000
Likeliest 60000
Maximum 90000

Selected range is from 30000 to 90000
Mean value in simulation was 60000

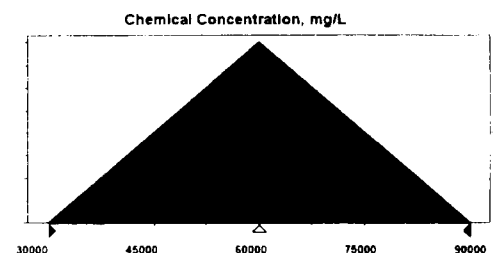


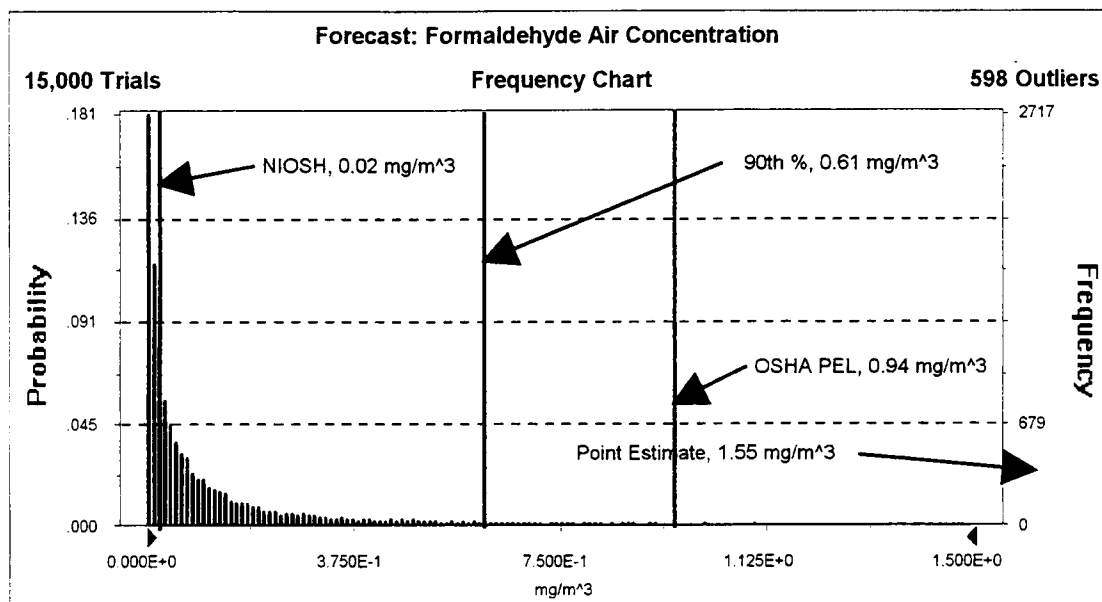
Figure 6. Monte Carlo Parameter Distribution Assumptions - Fluoboric Acid

transport, and was thus not included as a separate Monte Carlo simulation. The chemical and bath configurations/selections used for the Monte Carlo analysis were the same as those in the sensitivity analysis performed earlier. The parameters that had the greatest importance from the sensitivity analysis were examined in this Monte Carlo analysis.

The probabilistic chemical air concentration curves for sparged and unsparged baths are presented as Figures 7 and 8. These figures display the expected log-normal distribution of workplace chemical air concentrations for those simulations. The 90th percentile chemical air concentration from the distribution and the OSHA Permissible Exposure Limit (PEL) for formaldehyde (PEL not established for fluoboric acid), are marked in the figures.

It is evident that the 90th percentile modeled air concentration is less than the OSHA PEL for formaldehyde. The original Point Estimate of air concentration is also shown to illustrate the differences between the use of classic “RME” exposure parameters in a point estimate (90-95th percentile values), and the actual distribution-based (for all parameters), 90th percentile estimate. These charts show that the use of 90-95th percentile parameter values for a point estimate actually results in a chemical air concentration far greater than the 90th percentile. The parameter sensitivity charts were used to more closely assess those parameters which required refinement.

Figure 9 contains the sensitivity charts for the test configurations of sparged and unsparged baths. These identify the parameters that contributed the most to model variance for the three chemical runs used in characterizing uncertainty: formaldehyde in a sparged bath, fluoboric acid in an unsparged bath, and copperchloride in a sparged bath. The similarity between unsparged bath and sparged bath output with respect to parameter uncertainty and sensitivity is expected since most of the chemical flux in sparged baths also comes from the surface desorption mechanism. As mentioned previously, Crystal Ball® calculates this ‘sensitivity’ by computing Spearman rank correlation coefficients between every assumption and model result while the simulation is running, constantly updating the coefficients as more accurate distribution results are obtained.

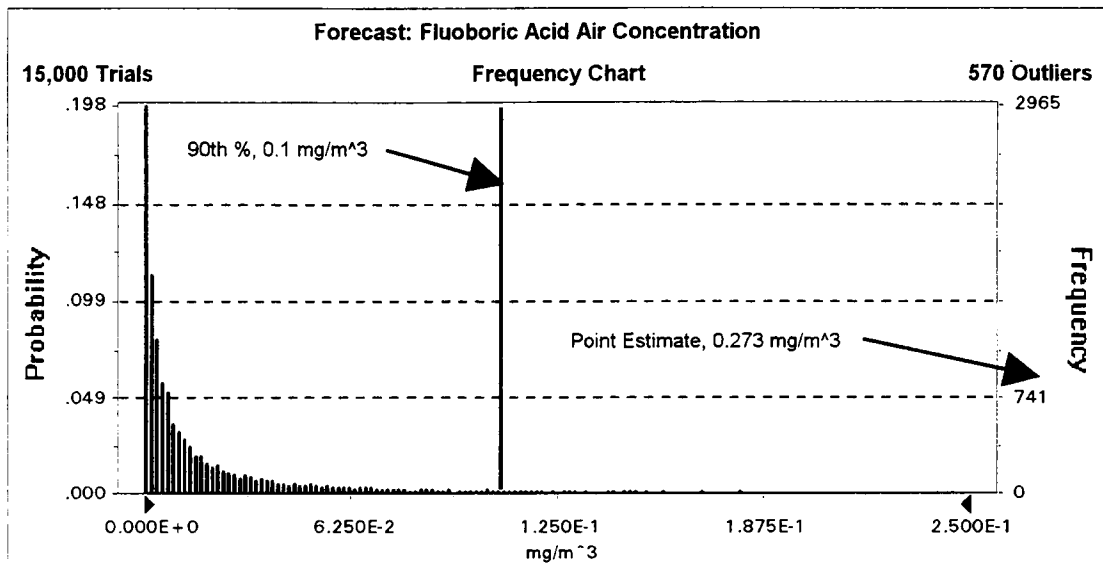


Percentiles:

<u>Percentile</u>	<u>mg/m³</u>
0%	9.569E-05
10%	4.977E-03
20%	1.131E-02
30%	2.026E-02
40%	3.363E-02
50%	5.478E-02
60%	8.814E-02
70%	1.446E-01
80%	2.633E-01
90%	6.107E-01
100%	5.969E+01

After 15,000 Trials, the Mean is 3.209E-1, the Std. Error of the Mean is 1.195E-2

Figure 7. Probabilistic Formaldehyde Air Concentration Curve (Sparged Bath)



Percentiles:

<u>Percentile</u>	<u>mg/m³</u>
0%	1.600E-05
10%	7.568E-04
20%	1.689E-03
30%	3.146E-03
40%	5.288E-03
50%	8.389E-03
60%	1.368E-02
70%	2.294E-02
80%	4.206E-02
90%	1.004E-01
100%	1.265E+01

After 15,000 Trials, the Mean is 5.018E-2, the Std. Error of the Mean is 1.787E-3

Figure 8. Probabilistic Fluoboric Acid Air Concentration Curve (Unsparged)

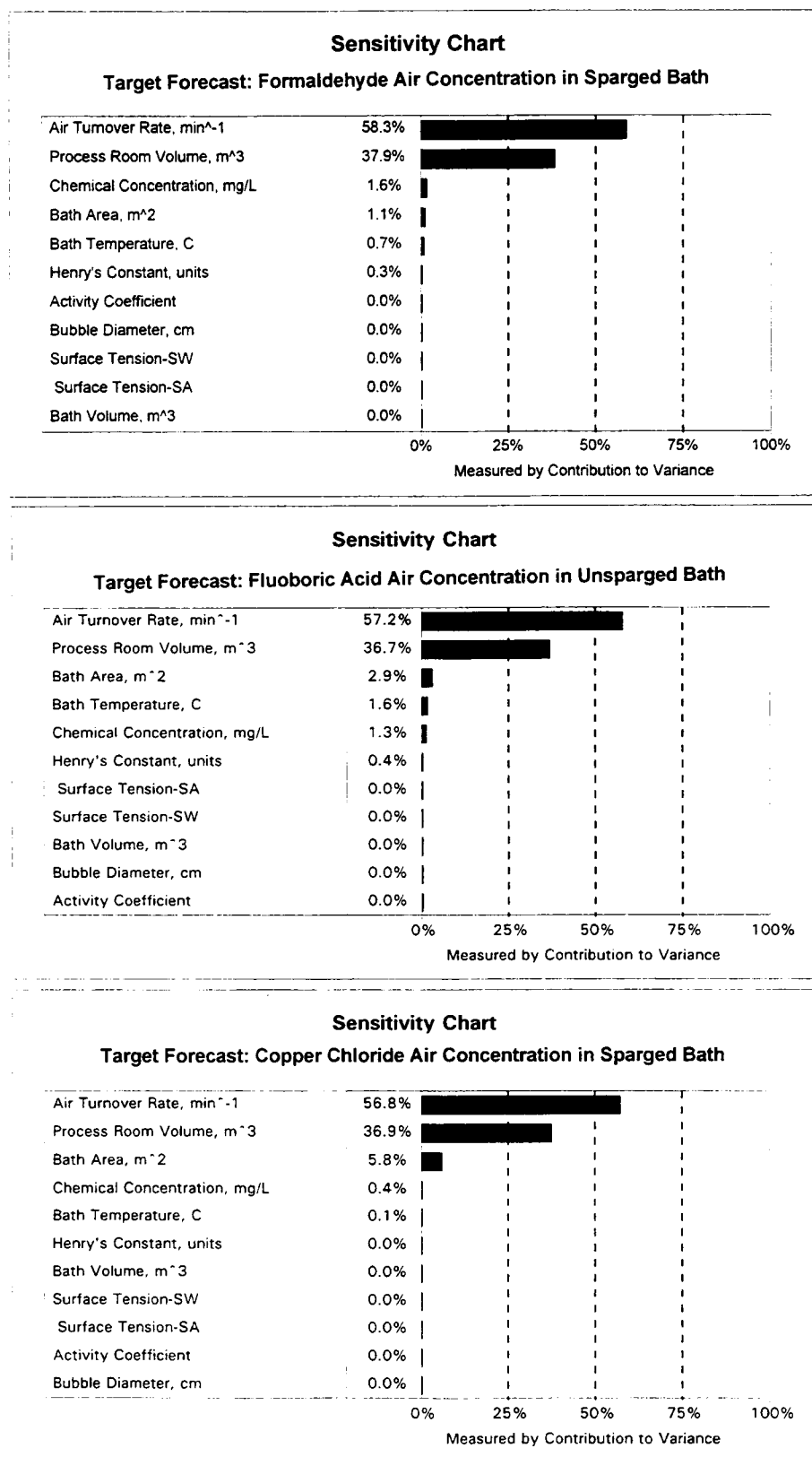


Figure 9. Sensitivity Charts for Sparged and Unsparged Bath Analyses

The parameter contributing the most to model variance for both bath types is air turnover rate in the process room, as seen from the charts in Figure 9. This stems from the high variation of the reported ventilation rates in the practices survey (CCPCT, 1996). Although the model is equally sensitive to air turnover rate and room volume, the latter parameter is less important because the survey data contained less variability.

Sensitivity analysis for other parameters, including chemical concentration in the bath, bath temperature, and Henry's constant were conducted. Chemical concentration in the bath, bath area, and bath temperature exhibited some influence on model variance as seen from Figure 9, although they were much less important than air turnover rate. These parameters had little variability, and the point estimate models already used averages of their collected distributions for reasons mentioned before. Bath area was the only other parameter that contributed more than 1% to total model variance in all simulations. It was evident from the analysis results, however, that the values used to represent the parameter distributions in modeling needed no further refinement.

There are several important reasons for this conclusion. Bath temperature is important because it is used to correct Henry's constant for temperature by an exponential relationship, and consequently has multiple correlations to the models. Bath temperature, however, has very little variability and thus contributed little to the variability of the predictions.

Henry's constant (H_V) can have a great effect on the outcome of the model, depending on the variability of that data, but this parameter's importance was far outweighed when considering the variability in air turnover rate and room volume. Mackay (1991) has observed that a great deal of variation occurs with H_V when hydrophobic chemicals associate at the air-water interface and electrolytes or sorbents affect solubility in water. These variations are very difficult to characterize unless H_V is measured under the bath conditions in question, which is beyond the scope of this study.

Bath concentration also needed no further refinement for the same reasons: its survey data contained little variability, and the approach used for developing generic bath concentrations (adding all chemicals from different processes and taking averages of reported concentrations) was conservative enough to allow for the small variances in

the uncertainty output when compared with the large contribution of variance from air turnover rate.

Development of the 90th percentile Air Turnover Rate

The sensitivity analysis demonstrated that the air turnover rate needed to be refined in order to achieve more realistic, 90th percentile point estimates of workplace air concentrations. It is developed by dividing ventilation rate by the room volume. The room volume obtained in the CCPCT (1996) survey had some variability, but the ventilation rate data was highly variable. The high level of uncertainty associated with the resulting air turnover rate caused this parameter to contribute the most to model variance as calculated by Spearman rank correlation coefficients. It was apparent from the results that the air turnover rate estimate needed to be revised to reduce uncertainty in the output, and to more accurately assess worker health exposure and risk.

Originally, the 10th percentile air turnover rate from the CCPCT (1996) survey had been used to model inhalation exposure. This value (inversely related to air concentration) was consistent with the other assumptions used in the model to provide high-end ("what-if") estimates of exposure. In this "what-if" screening-level risk scenario, the 90th percentile assumption was used for parameters which had high variability; averages of other parameters were used when variability was small. However, as seen from the previous section, the use of the 10th percentile air turnover rate actually caused the resulting air concentrations to be greater than the 90th percentile level calculated from the Monte Carlo runs. Thus, by revising the air turnover rate an arbitrary "correction factor" was introduced that provided the desired upper-boundary estimates of air concentration while maintaining realism with collected survey data.

The 90th percentile workplace air concentration of formaldehyde from the Monte Carlo run (frequency distribution) for sparged volatiles is 0.61 mg/m³, compared to a 1.55 mg/m³ point estimate for "high-end" exposure. These points can be seen on Figure 7. The point estimate of exposure is the value used in the actual exposure assessment, and is calculated with the 10th percentile air turnover rate.

Because of this, it was decided to calculate a Monte Carlo distribution-based air turnover rate that would provide the actual 90th percentile air concentration. This was done using point estimates for all parameters and setting the air concentration equal to

the 90th percentile probability frequency distribution calculated with Crystal Ball. The distribution-based air turnover rate used in exposure modeling was obtained as follows:

$$R_v = \frac{F_{Y,T}}{(\text{Conc} \cdot V_R \cdot k)} \quad (\text{Eq. 17})$$

$$= 0.0211 \text{ min}^{-1}$$

where: $F_{Y,T}$ = 10.37 + 3.36 + 0.0117 = 13.74 mg/min, total emission rate of formaldehyde from all mechanisms (surface + bubble desorption + aerosol transfer)
 V_R = 1,065 m³, room volume
 Conc. = 0.61 mg/m³, formaldehyde air concentration from Monte Carlo Runs simulating Sparged Volatiles
 k = 1, dimensionless air mixing factor

It is useful here to compare the corrected (calculated above) air turnover rate to the original 10th percentile assumption of 0.0083 min⁻¹. The dependence of this distribution-based air turnover rate on chemical and bath type was then tested with several other runs. The resulting air turnover rates that provided the 90th percentile air concentration were: 0.02056 min⁻¹ for fluoboric acid in an unsparged bath, and 0.021 min⁻¹ for copper chloride in a sparged bath. Air turnover rate is inversely proportional to exposure, so the lowest value from these runs; 0.021 min⁻¹ (rounded) was used for all MHC processes in the exposure assessment. There is virtually no difference between estimated air turnover rates for different chemicals; therefore, no further comparison Monte Carlo runs were made. Any other variations in computed data are small when compared to variation in the actual compiled data: 10.8 min⁻¹ maximum and 1.8E-4 min⁻¹ minimum (CCPCT, 1996).

This approach is consistent across alternatives, while providing a conservative but realistic estimate of exposure. The results of this sensitivity and uncertainty analyses are consistent with those obtained by Fehrenbacher and Hummel (1996) in their analysis of the surface desorption model. They suggest default ventilation rates for use with this model of 14 m³/min and 85 m³/min for bounding (maximum) and “what if” (average) estimates of exposure, respectively. The air turnover rate calculated above from the Monte Carlo Analysis (0.021 min⁻¹) is equal to 22.3 m³/min when multiplied by the mean room volume of 1,065 m³ (for MHC facilities).

The results of this study indicated that values for a few parameters are the keys to successfully modeling flux from PWB baths. These important parameters are:

- Air Turnover Rate (ventilation rate combined with room volume - highly variable information from survey)
- Bath Temperature (accurate information from survey)
- Chemical Concentration in Bath (accurate information from survey)
- Henry's Law Constant (could be somewhat variable, but information from analysis indicated that adjustment of this parameter is unnecessary)

Because of this study, additional scrutiny was placed on estimates for all these parameters in an effort to maximize accuracy. The results for the models were largely indifferent to changes in the other parameters when compared with these four. In addition, the density and viscosity values for water in model calculations were kept at 25°C for simplicity, since the variance to these parameters due to temperature adjustments in the bath accounted for less than 1% of overall variance.

Design Ventilation Rate Comparison

A comparison of traditional ventilation guidelines and design practices was made to check and validate the selected (Monte-Carlo probability distribution-based) air turnover rate. Several sources were surveyed regarding these guidelines: Industrial Ventilation: A Manual of Recommended Practice (ASHRAE, 1974); Heating, Ventilating, and Air-Conditioning Applications (ASHRAE, 1991); A Study of Local Exhaust Ventilation in Industrial Premises (Olander et al., 1995); OSHA General Industry Ventilation Standards - 1910.94 and 1910.106 (OSHA, 1985).

There are two common and accepted methods for handling hazardous fume exhaust from indoor chemical and industrial applications: dilution or local ventilation. Local ventilation consists of a dedicated air inlet and outlet (hood, piping, and centrifugal or axial flow fans) for a particular area of the room where a process or open tank exists. Dilution ventilation is a general ventilation system where contaminated air is flushed and diluted with uncontaminated air from outside. Local ventilation is the preferred method and is employed in some of the conveyorized MHC alternatives (see Workplace Characteristics), but it is not typically used for some alternatives in most of the smaller, established plating shops. In these cases, dilution ventilation is typically the only means of reducing indoor chemical concentrations, even though many of these buildings may not have been designed with industrial applications in mind. As mentioned earlier,

indoor chemical emissions from those MHC alternatives which have enclosed, local ventilation systems are considered to be negligible.

The design of a dilution ventilation system is based on four limiting factors (ASHRAE, 1974): the quantity of contaminant generated must not be too great or air volume necessary for dilution will be impractical; workers must be far enough away from contaminant evolution so that they will not be exposed to concentrations in excess of established permissible exposure limits (PELs, or TLVs); the toxicity of contaminant must be reasonably low; and evolution of contaminants must be reasonably uniform. Keeping these factors in mind, the following steps are then taken to determine an acceptable ventilation rate:

- determine an acceptable level of exposure to chemical(s) of interest
- determine the generation rate of contaminant(s)
- determine a mixing factor K which depends on: toxicity of contaminant, effectiveness of ventilation system and location of exhaust, geometry of work area, and contaminant concentration in replacement air

The required ventilation volume per mass of solvent generated, at normal temperature and pressure, is given by (ASHRAE, 1991):

$$Q_M = \left(\frac{3.87 \times 10^8 \cdot SG \cdot K}{M \cdot TLV} \right) \quad (22)$$

where:

Q_M	= dilution volume req'd for solvents, based on ft ³ /lb solvent evaporated
SG	= specific gravity of mixture in air
M	= molecular weight of solvent
TLV	= threshold limit value or permissible exposure limit, ppm
K	= mixing factor

When several hazardous materials are present, their effects for dilution purposes are considered as additive (ASHRAE, 1991). This requires calculating the dilution rate of each component and using the sum of the rates as the total dilution rate for the mixtures. Four chemicals were used to represent a typical MHC process when computing a dilution rate for comparison purposes: formaldehyde, ethanolamine, isopropyl alcohol, and methanol. Formaldehyde and ethanolamine are very toxic and have relatively low emission rates, while the other two are moderately toxic and have high emission rates.

The TLV values used in eq. 22 were OSHA PELs, and the mixing factor K was based on a worst-case distribution condition and the chemical's corresponding toxicity rating (high or moderate). The required room dilution volume for ventilation was then computed as ft³ of air per pound of solvent generated. An air turnover rate was computed as follows:

$$R_V = \frac{Q_M \text{ (ft}^3 \text{ / lb)} \cdot \text{emission rate (lb / min)}}{\text{room volume (ft}^3\text{)}} \quad (\text{Eq. 17})$$

where: R_V = air turnover rate, min⁻¹
 Q_M = dilution ventilation rate calculated above, ft³/lb
 emission rate = $F_{Y, \text{TOTAL}}$ from air mass transport models for each chemical
 room volume = 1,065 m³, from CCPCT, 1996

By normalizing the ventilation rates by the same room volume used in the exposure assessment, a similar comparison can be made between accepted design standards and the workplace practices (CCPCT, 1996) ventilation rate data. Table 15 compares the data below.

Table 15. Comparison of Dilution Ventilation Design Standards with Distribution-Based Ventilation Rate

Parameter Design Basis	Air Turnover Rates (min ⁻¹)
Monte Carlo - 90th % Corrected based on distribution of data from Sensitivity/Uncertainty Analysis	0.021
1. Formaldehyde (Dilution-based)	0.15
2. Ethanolamine (Dilution-based)	0.013
3. Isopropyl Alcohol (Dilution-based)	0.0039
4. Methanol (Dilution-Based)	0.0064
Total of 1-4 (Dilution-Based)	0.174

It can be seen from Table 15 that the revised Monte-Carlo based air turnover rate is actually more conservative (from a calculated risk perspective) than an air turnover rate designed to dilute the concentrations of only four chemicals. Recall that air turnover rate is inversely related to contaminant air concentration; larger dilution-based air turnover rates lessen the concentration of contaminants in the air, while the Monte Carlo distribution-based rate causes the air concentrations to be an order of magnitude higher. The Monte Carlo distribution-based 90th percentile rate is actually not high enough by design ventilation standards, but air concentrations and the ensuing

exposures and risks modeled with it are thus more conservative. This again supports the corrected choice of 0.021 min^{-1} , an air turnover rate that is larger than the 10th percentile of the collected data (and more closely approximates the 90th percentile air concentrations). This rate, though lower than the median air turnover rate reported in the workplace practices survey, provides a conservative value for use in estimating screening-level risks to humans from MHC alternatives.

In most MHC plating shops where localized ventilation is not employed, the ventilation rate would probably be much higher, again resulting in lower chemical air concentrations. This is further supported by OSHA Ventilation Standard 1910.106 (h) (3) (iii) which states that: "enclosed processing buildings shall be ventilated at a rate of not less than 1 cubic foot per minute per square foot of solid floor area." This is roughly equivalent to an air turnover rate of 0.1 min^{-1} when normalized to the generic room volume used in this work. A summary of the comparison dilution-rate calculations in spreadsheet form is located in Appendix D.

It is important to recall here that the range of reported ventilation rates collected in the workplace practices survey was very large. Errors in this information could have been due to incorrectly answered questions (facilities reporting both local and general ventilation rates, etc.), or a lack of knowledge about the actual ventilation rates in buildings. Because of this high variability, the 10th percentile rate was originally chosen, but was deemed to be too conservative to represent the majority of actual MHC plating shops. The mean value of air turnover rates (ventilation rates combined with each facility's reported process room area and a 10 ft height assumption) for all processes was 0.1728 min^{-1} . Thus, the air turnover rate chosen from the Monte Carlo analysis may be slightly less than the minimum ventilation rates for some processes according to good design practice, but is more realistic than the original 10th percentile assumption taken from the survey data.

Risk Characterization

This section will present examples for calculating risks from MHC lines. The statistical significance of risk comparisons between processes will also be addressed. A qualitative discussion of uncertainty in this risk estimate will follow, outlining important assumptions made during the risk assessment.

Appendix E contains all toxicology values obtained and used in this risk assessment. The lowest values for NOELs/LOELs were used when several were noted, and RfCs for inhalation exposure were converted to RfDs per EPA standard methods (1991b) assuming an inhalation rate of 20 m³/day and a 70 kg body weight. Some dermal RfDs and NOELs/LOELs were also converted from oral toxicity measures as covered earlier.

Very few dermal RfDs or NOELs for MHC chemicals were found in the literature, so oral toxicity measures were converted to dermal ones using gastrointestinal tract absorption percentages, as outlined earlier. These were usually available, but in some cases a conservative assumption of 0.2 was used for organics to facilitate high-end risk estimates (EPA, 1991b). These assumptions add additional uncertainty, but facilitate a comparison for this important pathway between MHC alternatives.

Formaldehyde was the only probable carcinogen (B1) with a reported unit risk concentration (in air): 1.3E-5 (μg/m³)⁻¹. This was converted to a slope factor of 0.0455 mg/kg-day per EPA (1991b). At the time of this work, several chemicals are under review for a change in carcinogen status. This may necessitate a reevaluation of cancer risk potential from MHC lines when this new information becomes available.

The health risks from the formaldehyde example earlier can now be estimated. The non-carcinogen toxic effect hazard quotient (HQ) from formaldehyde inhalation exposure can not be calculated because there is no established inhalation RfD or RfC. The dermal HQ from formaldehyde exposure to line operators is determined as follows:

$$\begin{aligned} \text{HQ}_{\text{DER, LINE OPERATOR}} &= \text{Dose Rate} / \text{RfD} & \text{(Eq. 24)} \\ &= 15.05 \end{aligned}$$

where: Dose Rate = 3.01E-2 mg/kg·d
 RfD = 2.0E-3 mg/kg·d, reference dose (RfD_{DER})

A number greater than one represents a high probability for toxic effect occurrence. This is an exposure route that is a major concern for this receptor group, and will be addressed in the conclusions. To estimate the HQ_{DER} for lab technicians in the previous formaldehyde example, the same equation is utilized.

$$\text{HQ}_{\text{DER, LAB TECHNICIAN}} = \text{Dose Rate} / \text{RfD} \quad \text{(Eq. 24)}$$

$$= 0.369$$

where: Dose Rate = $7.39\text{E-}4$ mg/kg-d
 RfD = $2.0\text{E-}3$ mg/kg-d, reference dose (RfD_{DER})

The dermal RfD is calculated as:

$$\begin{aligned}\text{RfD}_{\text{DER}} &= \text{RfD}_{\text{ORAL}} \cdot \text{absorption factor} \\ &= 2\text{E-}3 \text{ mg/kg-d}\end{aligned}$$

where: $\text{RfD}_{\text{ORAL}} = 0.2$
 absorption factor = 0.01, equivalent to 1% absorption efficiency

As stated previously, this dermal absorbed dose must be converted from the orally administered dose because it is more conservative. The actual dose that causes adverse health effects in an organism may be much lower than the administered dose because it is not absorbed readily. This means that only a small portion of a dosage X applied to a species actually enters the bloodstream and causes an effect. The dermal HQs calculated above are combined with HQs from other chemicals for both dermal and inhalation pathways to arrive at Hazard Indexes (HIs) for receptors.

Different adverse effects on target organs, etc. in the body are assumed equal in health hazard potential here. The threshold theory of noncarcinogenic biological response to chemicals actually states that hazard quotients should only be added for those chemicals which exhibit similar toxic effects (liver weight, sensitization, etc.), but this practice is commonly accepted and is consistent across MHC alternatives. HQs are summed to determine total hazard potential (HI) as follows:

$$\text{HI}_{\text{ALL PATHWAYS}} = \text{HQ}_{\text{DER}, i} + \text{HQ}_{\text{INH}, i} + \dots + \text{HQ}_{\text{DER}, n} + \text{HQ}_{\text{INH}, n} \text{ (Eq. 27)}$$

where: HI = total hazard index for a particular receptor from all pathways and chemicals in alternative
 $\text{HQ}_{\text{DER OR INH}, i}$ = hazard quotient for chemical i from dermal or inhalation pathways, respectively
 $\text{HQ}_{\text{DER OR INH}, n}$ = hazard quotient for chemical n from dermal or inhalation pathways, respectively

The margin of exposure (MOE) for line operator inhalation exposure to formaldehyde is calculated as follows:

$$\begin{aligned}\text{MOE} &= \text{NOAEL or LOAEL} / \text{Dose} && \text{(Eq. 25)} \\ &= 0.48\end{aligned}$$

where: Dose Rate = 7.42E-2 mg/kg-d, exposure level
NOAEL/LOAEL = 0.0356 mg/kg-d, lowest observed adverse effect
level, lowest dose in study at which effects were
observed

A number less than 1,000 or 100 represents a concern level of exposure that is potentially harmful to health (for LOAELs and NOAELs, respectively). Again, this measure of toxic potential is not as accurate or acknowledged as hazard quotients using EPA-endorsed reference doses, but it serves here to compare and contrast MHC alternatives where RfDs are scarce for chemicals. MOEs are only calculated for chemicals when RfDs are not available for that contact route. The generalizations made using MOEs will only be relative concerning noncarcinogenic risk, and should not be taken as precise estimates. This caveat applies to both HIs and MOEs. To estimate the MOE from the general public's inhalation of formaldehyde, the same equation is used:

$$\begin{aligned}\text{MOE} &= \text{LOAEL} / \text{Dose} && \text{(Eq. 25)} \\ &= 5.79\text{E}+03\end{aligned}$$

where: Dose Rate = 6.16E-6 mg/kg-d, exposure level
LOAEL = 0.0356 mg/kg-d, lowest observed adverse effect
level, lowest dose in study at which effects were
observed

This MOE obviously does not represent a concern level for the general population, and this chemical's non-carcinogen inhalation risk to the public can be considered negligible here. The final type of risk measure is to estimate the probability of excess lifetime cancer development. Information on the carcinogen potential of most chemicals is often difficult to locate and insufficient for EPA to develop slope factors to apply in risk calculations. Formaldehyde is the only chemical in all MHC alternatives that has a defined slope factor, and thus presents the only carcinogenic risk to workers. It is not surprising that only one chemical in MHC lines has an accepted slope factor, however, because the majority of accepted SFs exist for those chemicals that are commonly used in many industries. To estimate the line operator's ELCR from formaldehyde inhalation in the workplace, the following equation applies:

$$\begin{aligned}\text{Risk} &= \text{Dose Rate} \cdot \text{SF} && \text{(Eq. 23)} \\ &= 1.19\text{E}-3\end{aligned}$$

where: Dose Rate = 2.63E-2 mg/kg-d, chronic daily intake averaged over 70 years
SF = 0.0455 (mg/kg-d)⁻¹

This risk roughly equates to one out of every 1,000 people developing cancer that are exposed to this dosage. EPA usually targets ELCRs of 1E-06 to 1E-04 as health-protective goals depending on the situation, but does not typically regulate risk to workers. OSHA is the regulatory agency that sets risk and health-protective levels of exposure; one form of which is the permissible exposure limit (PEL). The estimated formaldehyde air concentration in the workplace is actually less than half of the OSHA PEL for formaldehyde, but PELs and TLVs are set independent of EPA and are not necessarily derived on a risk basis. This ELCR for workers is high enough to warrant attention as a risk driver for process chemicals, however, and will be addressed in the conclusions. The cancer risk from inhalation of formaldehyde to the general populace is:

$$\begin{aligned} \text{Risk} &= \text{Dose Rate} \cdot \text{SF} \\ &= 2.52\text{E-}10 \end{aligned} \quad (\text{Eq. 23})$$

where: Dose Rate = 5.54E-9 mg/kg-d, chronic daily intake averaged over 70 years, calculated above
SF = 0.0455 (mg/kg-d)⁻¹

This cancer risk (general population) is negligible and may be ignored with regard to other hazard comparisons between processes. The generalization that inhalation exposure to the population will be negligible for almost all chemicals can also be drawn from this example and the assessment results.

The example equations in the risk characterization outline how every risk/hazard potential was calculated for the MHC alternatives. Table 16 below presents Hazard Quotients for chemicals in MHC alternatives which had reference doses, and Table 17 presents the Margin of Exposure for all processes. Table 18 summarizes total risks to receptors by pathway for all processes. Hazard Indices are summed across chemicals and pathways, and the total Margin of Exposure is calculated by summing the reciprocals across pathways and chemicals.

Table 16. Hazard Quotients (all Receptors) for Chemicals in Non-Conveyorized MHC Lines

Receptors	Line Operator	Line Operator	General Population	Laboratory Technician
Exposure Pathway	Inhalation	Dermal	Inhalation	Dermal
Chemicals In Alternative				
Electroless Copper				
Dimethylformamide	8.85E-01	NA	7.39E-05	NA
Ethylene Glycol	NA	1.23E-03	NA	3.02E-05
Formaldehyde	NA	1.50E+01	NA	3.69E-01
Hydrochloric Acid	1.45E-02	NA	1.22E-06	NA
Methanol	NA	2.26E-02	NA	5.55E-04
Potassium Cyanide	NA	5.83E-01	NA	1.43E-02
Sodium Cyanide	NA	7.55E-01	NA	1.86E-02
Stannous Chloride	NA	3.93E+01	NA	9.65E-01
2-Ethoxyethanol	1.36E+02	3.42E-01	1.14E-02	8.41E-03
Tin Palladium				
Stannous Chloride	NA	1.52E+01	NA	1.51E-01
Organic Palladium	No HQ Data for Process			
Non-Formaldehyde				
Electroless Copper				
Stannous Chloride	NA	3.73E+00	NA	5.91E-03

Hazard Quotients (all Receptors) for Chemicals in Conveyorized MHC Lines

Receptors	Line Operator	General Population	Laboratory Technician
Exposure Pathway	Dermal	Inhalation	Dermal
Chemicals In Alternative			
Electroless Copper			
Dimethylformamide	NA	1.67E-04	NA
Ethylene Glycol	3.23E-04	NA	3.02E-05
Formaldehyde	3.37E+00	NA	3.69E-01
Hydrochloric Acid	NA	5.84E-06	NA
Methanol	5.49E-03	NA	5.55E-04
Potassium Cyanide	1.31E-01	NA	1.43E-02
Sodium Cyanide	1.69E-01	NA	1.86E-02
Stannous Chloride	9.76E+00	NA	9.65E-01
2-Ethoxyethanol	8.70E-02	1.22E-02	8.41E-03
Tin Palladium			
Stannous Chloride	4.75E+00	NA	1.51E-01
Organic Palladium	No HQ Data for Process		
Conductive Polymer	No HQ Data for Process		
Graphite			
Ammonia	NA	9.67E-06	NA

NA: No quantified result for exposure pathway due to lack of available information, or negligible results (conveyorized line operator inhalation not shown because emissions to indoor air negligible)

Table 17. Margin of Exposure (all Receptors) for Chemicals in Non-Conveyorized MHC Lines

Receptors	Line Operator	Line Operator	General Population	Laboratory Technician
Exposure Pathway	Inhalation	Dermal	Inhalation	Dermal
Chemicals In Alternative Electroless Copper				
Ammonium Chloride	NA	1.95E+04	NA	7.93E+05
Benzotriazole	NA	8.78E+03	NA	3.57E+05
Boric Acid	NA	1.72E+03	NA	7.00E+04
Copper Chloride(I)	4.23E+02	9.60E-01	5.06E+06	3.91E+01
Dimethylformamide	NA	2.22E+04	NA	9.03E+05
Ethanolamine	6.83E+01	6.32E+03	8.17E+05	2.57E+05
Ethylene Glycol	4.97E+02	NA	5.94E+06	NA
Fluoboric Acid	NA	1.96E+00	NA	7.99E+01
Formaldehyde	4.84E-01	NA	5.79E+03	NA
Formic Acid	8.99E+02	NA	1.08E+06	NA
Hydrogen Peroxide	2.54E+04	2.42E+02	3.04E+08	9.85E+03
Hydroxyacetic Acid	NA	2.07E+03	NA	8.42E+04
Isopropyl Alcohol, 2-Propanol	9.98E+01	6.40E+02	1.19E+06	2.60E+04
Methanol	3.69E+02	NA	4.41E+06	NA
Palladium	NA	1.27E+00	NA	5.18E+01
Potassium Hydroxide	1.63E+05	NA	1.94E+09	NA
Potassium Sulfate	5.01E+03	NA	5.98E+07	NA
Sodium Carbonate	9.44E+05	NA	1.13E+10	NA
Sodium Chlorite	NA	1.69E+01	NA	6.89E+02
Sodium Hydroxide	9.06E+02	NA	1.08E+07	NA
Sodium Sulfate	NA	5.09E+03	NA	2.07E+05
Sulfuric Acid	2.83E+00	NA	3.38E+04	NA
Tartaric Acid	NA	3.03E+04	NA	1.23E+06
Triethanolamine	NA	9.27E+03	NA	3.77E+05
Tin Palladium				
1,3-Benzenediol	NA	1.03E+04	NA	1.03E+06
Copper Chloride(I)	NA	1.86E+00	NA	1.86E+02
Ethanolamine	3.39E+01	2.38E+03	4.06E+05	2.39E+05
Fluoboric Acid	NA	4.59E+00	NA	4.60E+02
Hydrogen Peroxide	4.34E+04	2.03E+02	5.19E+08	2.03E+04
Isopropyl Alcohol, 2-Propanol	1.18E+02	1.24E+03	2.12E+06	1.25E+05
Palladium	NA	5.58E+00	NA	5.59E+02
Palladium Chloride	NA	8.92E+00	NA	8.94E+02
Sulfuric Acid	3.04E+01	NA	3.63E+05	NA
Triethanolamine	NA	1.36E+04	NA	1.36E+06
Vanillin	NA	1.28E+03	NA	1.29E+05
Organic Palladium	No Margin of Exposure Data for Process			
Non-Formaldehyde Electroless Copper				
Hydrogen Peroxide	4.50E+04	2.67E+02	5.38E+08	1.68E+05
Isopropyl Alcohol, 2-Propanol	7.13E+02	1.52E+03	8.52E+06	9.60E+05

Non-Formaldehyde Electroless Copper	Line Operator - Inhalation	Line Operator - Dermal	General Population - Inhalation	Laboratory Technician - Dermal
Potassium Hydroxide	2.54E+05	NA	3.04E+09	NA
Sodium Chlorite	NA	1.51E+01	NA	9.53E+03
Sodium Hydroxide	6.14E+04	NA	7.34E+08	NA
Stannous Chloride	NA	NA	NA	NA
Sulfuric Acid	2.38E+01	NA	2.84E+05	NA

Margin of Exposure (all Receptors) for Chemicals in Conveyorized MHC Lines

Receptors	Line Operator	General Population	Laboratory Technician
Exposure Pathway	Dermal	Inhalation	Dermal
Chemicals in Alternative Electroless Copper			
Ammonium Chloride	7.84E+04	NA	7.93E+05
Benzotriazole	3.46E+04	NA	3.57E+05
Boric Acid	6.13E+03	NA	7.00E+04
Copper Chloride(I)	4.29E+00	1.05E+06	3.91E+01
Dimethylformamide	8.93E+04	NA	9.03E+05
Ethanolamine	2.54E+04	3.69E+05	2.57E+05
Ethylene Glycol	NA	3.17E+06	NA
Fluoboric Acid	8.47E+00	NA	7.99E+01
Formaldehyde	NA	2.18E+03	NA
Formic Acid	NA	4.78E+05	NA
Hydrogen Peroxide	8.63E+02	2.77E+08	9.85E+03
Hydroxyacetic Acid	8.32E+03	NA	8.42E+04
Isopropyl Alcohol	2.55E+03	6.02E+05	2.60E+04
Methanol	NA	2.38E+06	NA
Palladium	5.12E+00	NA	5.18E+01
Potassium Hydroxide	NA	1.79E+09	NA
Potassium Sulfate	NA	5.46E+07	NA
Sodium Carbonate	NA	2.35E+09	NA
Sodium Chlorite	7.31E+01	NA	6.89E+02
Sodium Hydroxide	NA	2.29E+06	NA
Sodium Sulfate	2.05E+04	NA	2.07E+05
Sulfuric Acid	NA	2.98E+04	NA
Tartaric Acid	1.35E+05	NA	1.23E+06
Triethanolamine	3.73E+04	NA	3.77E+05
Tin Palladium			
1,3-Benzenediol	3.29E+04	NA	1.03E+06
Copper Chloride(I)	5.17E+00	NA	1.86E+02
Ethanolamine	5.16E+03	1.55E+05	2.39E+05
Fluoboric Acid	1.28E+01	NA	4.60E+02
Hydrochloric Acid	NA	NA	NA
Hydrogen Peroxide	5.19E+02	1.12E+08	2.03E+04
Isopropyl Alcohol	2.38E+03	2.67E+06	1.25E+05
Lithium Hydroxide	NA	NA	NA
Palladium	1.78E+01	NA	5.59E+02

Tin Palladium, continued	Line Operator - Dermal	General Population - Inhalation	Laboratory Technician - Dermal
Palladium Chloride	2.85E+01	NA	8.94E+02
Sulfuric Acid	NA	7.83E+04	NA
Triethanolamine	2.60E+04	NA	1.36E+06
Vanillin	4.10E+03	NA	1.29E+05
Organic Palladium	No Margin of Exposure Data for Process		
Conductive Polymer	No Margin of Exposure Data for Process		
Graphite			
Ethanolamine	1.20E+04	8.39E+05	2.01E+05
Carbon			
Ethanolamine	6.68E+03	3.26E+05	4.98E+05

NA: No quantified result for exposure pathway due to lack of available information, or negligible results (conveyorized line operator inhalation not shown because emissions to indoor air negligible)

Table 18. Non-Carcinogen Receptor Risks Summarized by Pathway and Process

Process and Receptor	Hazard Index		Margin of Exposure	
	Inhalation	Dermal	Inhalation	Dermal
Non-Conveyorized Processes				
Electroless Copper - Line Operator	1.37E+02	5.6E+01	4.06E-01	4.16E-01
Electroless Copper - Lab Technician	NC	1.37E+00	NC	1.69E+01
Electroless Copper – General Public	1.15E-02	NC	5.79E+03	NC
Tin Palladium - Line Operator	NA	1.52E+01	1.47E+01	9.48E-01
Tin Palladium - Lab Technician	NC	1.51E-01	NC	9.50E+01
Tin Palladium - General Public	NA	NC	1.76E+05	NC
Non-Formaldehyde Electroless Copper - Line Operator	NA	3.73E+00	2.29E+01	1.42E+01
Non-Formaldehyde Electroless Copper - Lab Technician	NC	5.91E-03	NC	8.94E+03
Non-Formaldehyde Electroless Copper - General Public	NA	NC	2.74E+05	NC
Organic Palladium	No Risks to Receptors were Estimated			
Conveyorized Processes				
Electroless Copper - Line Operator	NC	1.35E+01	NC	1.78E+00
Electroless Copper - Lab Technician	NC	1.38E+00	NC	1.69E+01
Electroless Copper – General Public	1.23E-02	NC	1.99E+03	NC
Tin Palladium - Line Operator	NC	4.75E+00	NC	2.73E+00
Tin Palladium - Lab Technician	NC	1.51E-01	NC	9.50E+01
Tin Palladium - General Public	NA	NC	5.10E+04	NC
Organic Palladium	No Risks to Receptors were Estimated			
Carbon - Line Operator	NC	NA	NC	6.68E+03
Carbon – Lab Technician	NC	NA	NC	4.98E+05
Carbon – General Public	NA	NC	3.26E+05	NC

Conveyorized Process Non-Carcinogen Risks	Hazard Index		Margin of Exposure	
	Inhalation	Dermal	Inhalation	Dermal
Graphite - Line Operator	NC	NA	NC	1.20E+04
Graphite - Lab Technician	NC	NA	NC	2.01E+05
Graphite - General Public	3.38E-04	NC	8.39E+05	NC
Conductive Polymer	No Risks to Receptors were Estimated			

NA: Not quantified for exposure pathway due to lack of available chemical information, or negligible results.

NC: Not calculated because exposure pathway incomplete, or because non-conveyorized line operator inhalation exposure more conservative than lab technicians' due to longer exposure duration (unnecessary to quantify lab technician risk for inhalation).

Other Worker Risks

Risk results from line operators and lab technicians can also be applied to other workers exposure through a ratio approach. The time spent in the process area and the resulting risk estimate for a particular worker type are proportional to another worker's time and corresponding risk since all hazard and risk equations are linear. Two very important assumptions must be stated here.

The first is that risks are only proportional if both worker types have the same exposure characteristics (i.e. they both don't wear gloves, and the ratio of their expected activities during the work period are similar: that is, a line operator will be dermally exposed approximately 1/3 of his shift and a laboratory technician will also). The second assumption is that airborne concentrations of chemicals in the workplace are similar throughout the day. That means a worker spending time from 8:00 a.m. to 11:00 a.m. can expect the same contaminant emissions that one at 10:00 p.m. can. This is probably not the case, but the assumption simplifies differences between process operating characteristics a great deal.

The average line operator spends 1,900 hours per year in the process area. If the line operator's cancer risk due to formaldehyde inhalation is to be compared with a contract worker who only spends 62 hours/yr in the workplace, the following equation applies:

$$\begin{aligned}\text{Contract Worker Inhalation Risk} &= \frac{62 \text{ hr/yr}}{1900 \text{ hr/yr}} \cdot 1.05 \text{ E} - 03 \\ &= 3.43\text{E}-05\end{aligned}$$

This conversion of risk will also work for hazard quotients, but with MOEs the inverse ratio must be multiplied to obtain other workers' risks. The following list contains the average exposure times for MHC line workers on an annual basis (CCPCT, 1996):

- Laboratory Technician - 62 hours per year
- Maintenance worker - 930 hours per year
- Supervisor - 1,150 hours per year
- Wastewater treatment operator - 1,140 hours per year
- Other - 1,030 hours per year

Conversions between worker types and their respective risks should only be used for relational comparisons, as there is much uncertainty associated with this approach. It is also important to understand that only exposure estimates are being adjusted here, because non-carcinogen dose-response theory is not necessarily linear. Results for laboratory technicians are shown in Table 12.

Uncertainties in Risk

The most difficult task in any comprehensive risk assessment is the reduction of errors and uncertainties. The processes or sites being studied are complicated environmental systems which do not usually lend themselves to simple models. The advantages gained by approximating the real system with complex models can easily be lost if large uncertainties exist for parameters. Therefore, it is important to identify assumptions and situations which provide uncertainty and variability in risk assessments, and then improve these assumptions if possible. If this cannot be done, then these uncertainties must be addressed qualitatively for better understanding of the results. This area of risk assessment is often neglected, even though it may be the most important with regard to final decision making and risk management.

Uncertainties can propagate through calculations made early in the exposure assessment and distort end results because of sensitivity in the models. This was addressed earlier in the Sensitivity and Uncertainty Analyses of the air transport models, and prompted a revision of the process room air turnover rate assumption. The largest amount of uncertainty in risk assessment arises from the toxicology data, however, and it is difficult and beyond the scope of this work to revise or improve these numbers.

Some of the factors providing uncertainty include:

- Estimation of Exposure Point Concentrations: The use of conservative models to estimate air transport and dispersion, and all the inherent assumptions associated

with those models covered previously such as: location of worker in relation to process tank, duration of dermal contact with tank, the use of protective gloves in the process area, etc. In addition, most of the chemical parameters used in these models add uncertainty due to their empirically-derived nature; however, this factor is lessened somewhat because of the Uncertainty Analysis performed earlier.

- Estimation of Exposure Dose: Uncertainties exist in assumptions regarding inhalation rates, frequencies and duration of exposure, and absorption and bioavailability of compounds into the body for a particular situation. Two important assumptions regarding exposure deal with inhalation and dermal exposure to workers. Conveyorized processes are assumed to vent all airborne contaminants to outside air, and workers are assumed not to wear gloves or protective clothing other than eye protection while in the process area.
- Extrapolation of laboratory animal data and results to humans: the assumption that human bodies behave (absorb, distribute, metabolize and excrete substances introduced to the body) similarly to animals prompts the use of large (i.e. 10,000) uncertainty and modifying factors in toxicity reference measures that introduce uncertainty. When toxicity uncertainty levels are this high, the variation in exposure modeling is insignificant by comparison.
- Extrapolation of high dose-response data to low dose-response situations: toxicology studies are performed at high doses which will provide statistically significant results concerning adverse effect relationships; however, the doses actually encountered in the environment are much lower (several orders of magnitude) than these, and the assumption that the relationship is linear between the two dose ranges may not be valid and is unproven.
- The use of administered dose data for absorbed dose risk estimates: when dermal dose information is not available and oral dose and gastrointestinal tract absorption percentages are used to derive dermal toxicity references which have not been verified in laboratory studies, uncertainty is inherent. It is not completely realistic to assume that the outer skin layers, which are designed to repel foreign materials, are as absorbent as the interior of the GI tract, which is designed to absorb as many nutrients as possible. In the absence of more detailed information, however, this estimate provides a comparison between chemicals.
- Discrepancies in distribution of test animal or human populations - there are often chemicals which affect sensitive sub-populations much more than the general population of a species; if these questions cannot be addressed then variability is introduced to any estimates of risk which might involve sensitive sub-populations since protective reference information on toxicity is typically based on the most sensitive receptors from literature.
- Chemical speciation and effects of mixtures: this is one of the most significant areas of research in toxicology because very little is understood about toxic relationships between multiple chemicals. When estimates of risk and hazard potential from several chemicals and exposure routes are combined, the assumption is made that

their target organs and adverse effects are additive and equal in importance, but this is not proven. Some chemical mixtures may be antagonistic and thus lessen toxicity, while others may heighten toxicity to receptors. Some may affect entirely different portions of the body while not actually reaching a threshold for adverse effects. Additionally, the chemical speciation in the process bath might be different than the speciation used in toxicity tests. This might have an effect on their relative toxicity, and could even prevent them from being absorbed.

- The use of provisional RfCs and RfDs: some of the hazard information was still under review at the time of this study and had not been fully accepted by EPA. These may be subject to future change, as well as the currently accepted theory of carcinogen dose-response.

Some uncertainties are inherent to assumptions made regarding the particular process or site being studied in a risk assessment. For this work, uncertainties stemming from assumptions and generalizations about the processes include the following:

- The absence of chemical data from processes: OSHA does not require manufacturers to report chemicals which are below 1% (0.1% for carcinogens) of the bath formulation. Chemicals not listed on MSDS sheets, etc. could provide additional health hazards not quantified.
- Proprietary chemical data: OSHA also allows for trade secret information regarding certain chemicals in processes to be withheld from public documentation. These trade-secret chemicals could also provide additional risks, adding uncertainty to risk comparisons between processes.
- Indirect risks to the general population: Risks from consumption of food-chain biota (fish, etc.) which have bioaccumulated chemicals released from process facilities.
- Uneven mixing of air in the process room (especially non-conveyorized processes): Concentrations of chemicals in indoor air could be elevated/decreased for certain receptors depending on air flow currents, localized eddies, and time spent in a particular location in the process area.
 - If uneven mixing in the process area were incorporated into the emission source for ISCLT2 (k from Literature Review: Diffusional Transport), the emission source used to determine ambient air concentrations would be greater (more concentrated after averaging between air exchange events).

Toxicity data is also scarce, and this makes it difficult to quantitatively compare results with large data gaps. If one alternative has higher risks than another, it may be because there was less toxicity data available for chemicals in that other process. It is difficult to quantitatively compare risk between any two MHC alternatives when discrepancies exist regarding available chemical information. Table 19 shows the

Table 19. Toxicity Datagaps for chemicals in MHC processes

Chemical data gaps by process	RfD Inhale	RfD Oral	NOAEL/ LOAEL Inhale	NOAEL/ LOAEL Oral
All MHC Lines - Total chemicals in list: 65				
Chemicals in list with no established value for toxicity measure	59	60	51	47
Percentage of total chemicals in list	90.8%	92.3%	78.5%	72.3%
Electroless Copper - Total chemicals in process: 39				
Chemicals in process with no established value for toxicity measure	37	33	26	25
Percentage of total chemicals in process	94.9%	84.6%	66.7%	64.1%
Tin Palladium - Total chemicals in process: 20				
Chemicals in process with no established value for toxicity measure	19	19	15	12
Percentage of total chemicals in process	95.0%	95.0%	75.0%	60.0%
Non-Formaldehyde Electroless - Total chemicals in process: 10				
Chemicals in process with no established value for toxicity measure	9	9	5	7
Percentage of total chemicals in process	90.0%	90.0%	50.0%	70.0%
Organic Palladium - Total chemicals in process: 6				
Chemicals in process with no established value for toxicity measure	5	6	5	6
Percentage of total chemicals in process	83.3%	100.0%	83.3%	100.0%
Graphite - Total chemicals in process: 8				
Chemicals in process with no established value for toxicity measure	7	8	3	7
Percentage of total chemicals in process	87.5%	100.0%	50.0%	87.5%
Conductive Polymer - Total chemicals in process: 6				
Chemicals in process with no established value for toxicity measure	6	6	5	6
Percentage of total chemicals in process	100.0%	100.0%	83.3%	100.0%
Carbon - Total chemicals in process: 5				
Chemicals in process with no established value for toxicity measure	5	5	2	4
Percentage of total chemicals in process	100.0%	100.0%	40.0%	80.0%

amount of missing data for alternatives, and Figure 10 illustrates the same information graphically. The percentages of toxic-effect reference measures (RfDs, NOAEL & LOAELs) reported for chemicals in each process are listed in the table below. There is some variation in percentages of reported information among each alternative (e.g. all, or 100% of the chemicals in the carbon process have no inhalation RfD, while only 83% of the chemicals in the organic palladium process have no reported inhalation RfDs) but little variation for a process versus all the chemicals reported for MHC process lines.

The variation shown above prevents the use of risk results for definitive safety decisions between process alternatives. The processes with fewer hazardous chemicals (i.e. conductive polymer, graphite, etc.) appear to have a higher percentage of toxicity information in one area (i.e. inhalation NOAELs/LOAELs) than others, but this may be misleading when considering how few hazardous chemicals these processes actually have reported compared with others. For instance, the percentage of chemicals in the graphite line with no established inhalation NOAEL/LOAEL is 50%, while 66.7% of the hazardous chemicals in the electroless copper process are without an inhalation NOAEL/LOAEL. It would seem that chemicals in the electroless copper process have less toxicity information available for the inhalation pathway and that carbon is better characterized, until one considers that there are 13 chemicals (out of 39) with an inhalation NOAEL/LOAEL in the electroless copper process versus 5 in graphite (out of 8). It is difficult to make any conclusions about toxicity here without acknowledging that electroless copper simply has more reported chemicals in the MHC line than graphite.

Parameter assumptions for exposure duration can also be very important with regard to uncertainty. Uncertainty in risk assessment is intrinsically bound to the types of scenarios being modeled, (i.e. reasonable maximum exposure, "what-if") and it is important to understand what the goal of the RA is before reviewing and interpreting the results. The differences in expected outcomes for an RME risk assessment are very different from those of an average, or "what-if" assessment. When decisions are made regarding risk, these differences should be taken into account.

In this "what-if" case, the goal is to get screening level descriptions of relative risks between processes. This is why parameters like air turnover rate were modified so risks would be more accurate, and easily comparable. The goal here is not to determine

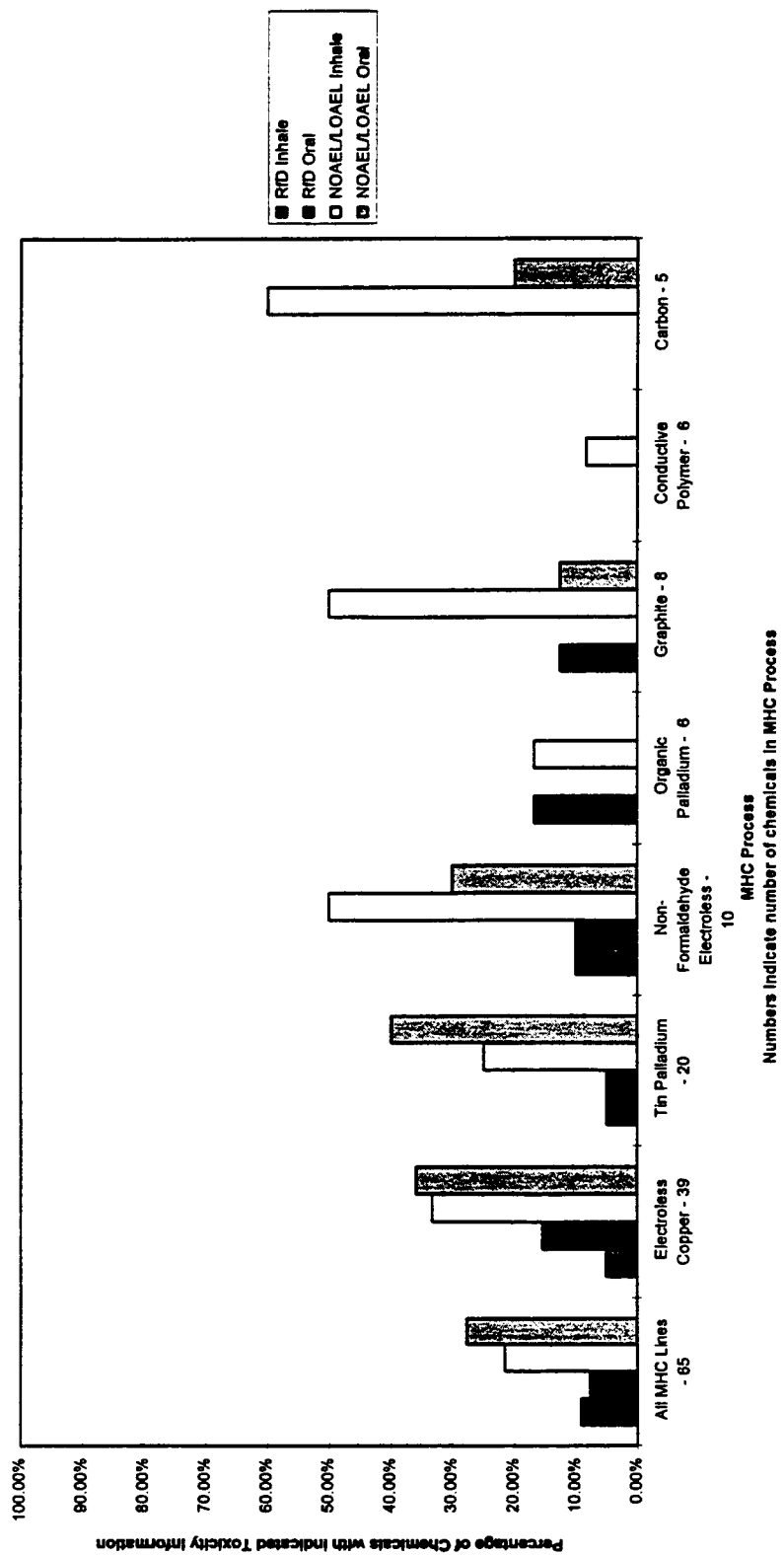


Figure 10. Data Gaps for Chemicals in MHC Processes

the absolute number and magnitude of risks from MHC processes, but to make an informed decision on which are relatively safe when compared with others.

Finally, there is uncertainty in the composition of the process alternative baths. Most baths contain a group of core chemicals common to all suppliers, but the generic bath makeups developed to represent these processes include all chemicals reported by all suppliers in them. This again introduces uncertainty with regard to total process risk, but will not affect identification of the larger hazard contributors.

Section III. Results and Discussion

Representative bath chemical compositions have been developed for MHC process tanks based on data collected from MSDS and supplier process sheets, and in a survey performed by the CCPCT (1996). The bath compositions were coupled through spreadsheets and visual basic programs with emission models developed elsewhere and with exposure data obtained from various sources to arrive at potential dose rates and risks for receptors. An uncertainty analysis was performed on the emission models. A number of observations can be made from this information.

The uncertainty and sensitivity analysis results indicated that one parameter: air turnover rate, had a significant effect on air concentrations based on its variability and the models' sensitivity to changes in it. The value used for air turnover rate in modeling emission rates was revised based on these results and compared with standard ventilation design practices. A more accurate description of emission rates from MHC process baths was obtained. Other parameters which had some effect on model outcomes were bath temperature and chemical concentration in the bath. Bath temperature data had little variability, but the models' were extremely sensitive to changes in its value. Chemical concentration in the bath had a some variability and changes in its value directly affected the air modeling outcomes. Monte Carlo simulations were used to determine the influence of various parameters on model predictions. The measure of each parameter's variance and influence on air modeling was computed by spearman rank correlation coefficients while the Monte Carlo simulation was running. The most significant contributions to variance of the overall air concentration outcomes ranged from approximately 80-93 percent for air turnover rate, 2-15 percent for bath temperature, and 3-6 percent for chemical bath concentration.

Three processes had significant risks associated with them when compared with commonly-accepted risk-target levels (Cancer Risk > 1E-06 or HI > 1). These three MHC alternatives are: Electroless Copper, Non-formaldehyde Electroless Copper, and Tin Palladium. Risks from other processes were below accepted target levels, but the overall chemical toxicity data was insufficient to definitively conclude that these other processes were without significant risks to worker health. Inhalation risks to the general population living near a MHC process facility were deemed negligible from the chemical information available. This conclusion most likely applies to any other chemicals emitted

from a PWB facility that do not currently have toxicity information due to the large rate of dispersion when compared with the very small MHC tank emissions. Possible risks to the public from contaminant releases to land and water were beyond the scope of this study.

Interestingly, dermal exposure to MHC baths had a larger overall impact than expected. Most of the significant health risks for alternatives were associated with the dermal pathway. This finding, however, is directly related to the conservative assumption for contact time used in dermal modeling; a worker was assumed to have his/her hands in a bath for the total amount of time spent in the process area. Other contributing factors to the dermal pathway dominance were the assumption that workers did not wear gloves or other protective gear, and the conversion of oral reference doses to dermal ones with gastrointestinal absorption percentages.

The inhalation pathway also had significant risks, but overall was less important than the dermal pathway. One assumption that strongly affected the inhalation pathway involved conveyORIZED process lines; all emissions from these lines were assumed to be vented to outside air. This assumption is relatively accurate, however, as conveyORIZED lines are typically completely enclosed and pressurized, and correspondence with MHC manufacturers validated this assumption. The elimination of the inhalation pathway through the use of conveyORIZED lines also significantly reduced risks for some processes that only come configured with enclosed hood systems. These processes were the conductive polymer and graphite systems.

A few chemicals drive risk for most MHC processes that had significant exposures. Formaldehyde in the electroless copper process (non-conveyORIZED) had significant inhalation and dermal risks, and was the only chemical classified as a carcinogen (B1) in all MHC lines. The estimated formaldehyde cancer risk to line operators (Electroless Copper) was $1.19\text{E-}03$. This is much greater than typically accepted cancer risk targets by EPA ($\sim 1\text{E-}6$ to $1\text{E-}4$) and may warrant further consideration. The hazard quotients for dermal formaldehyde exposure were also high: line operators on the non-conveyORIZED electroless copper line had an HQ of 15 for formaldehyde, while those on the conveyORIZED line had a dermal HQ of 3.4 from formaldehyde exposure. The formaldehyde inhalation MOE for the non-conveyORIZED

line operators was also worthy of attention: 0.48. Overall, formaldehyde had the highest associated risks, but was only present in the electroless copper line.

Stannous Chloride also contributed large dermal hazard quotients in several lines. It caused line operators on the non-conveyorized electroless copper line to have a dermal HQ of 39, and lab technicians on the same line to have an HQ of 0.97. The conveyorized electroless copper line operator had a dermal HQ of 9.7 also. On the Tin Palladium line (non-conveyorized) line operator dermal HQ was 15, and for conveyorized Tin Palladium it was 4.7. On the Non-Formaldehyde Electroless Copper line, the line operator dermal HQ was 3.7. Stannous chloride is particularly significant as a risk driver because it was present in so many MHC lines. There is uncertainty associated with these results on stannous chloride, however, because its RfD is based on Tin (Sn^{2+}), and the actual MHC bath toxicity characteristics may not be the same due to chemical speciation, and the formation of metal complexes in baths.

2-ethoxyethanol had a high inhalation HQ of 136. This chemical was only present in the electroless copper line. Copper Chloride also had low (high-hazard) MOEs for dermal contact in several processes: 0.96 and 4.3 for line operators in non-conveyorized and conveyorized electroless copper, respectively; 1.9 and 5.2 for line operators in non-conveyorized and conveyorized tin palladium, respectively. The certainty of MOEs as human health-protective risk estimates is lower than that associated with hazard quotients, however. This is because RfD values used in calculating HQs have inherent uncertainty factors, while MOEs are calculated with NOAELs and LOAELs that are unadjusted for protection of human health.

Other chemicals which exhibited potentially harmful MOEs for line operators in several MHC lines were: Ethanolamine for inhalation (68 in non-conveyorized electroless copper, 33.9 in non-conveyorized tin palladium); Palladium for dermal contact (1.3 and 5.1 in non- and conveyorized electroless copper, 5.6 and 17.8 in non- and conveyorized tin palladium); Palladium Chloride for dermal contact (8.9 and 28.5 in non- and conveyorized tin palladium); and Sulfuric Acid for inhalation (2.8 non-conveyorized electroless copper, 30.3 in non-conveyorized tin palladium, 23.8 in non-formaldehyde electroless copper). The chemicals listed for MHC processes in the conclusion section represent the risk drivers for all receptors, and reduction or

elimination of these drivers would increase safety of MHC lines to workers or the environment (see Areas for Further Research).

Conclusions

The risks obtained in this work for MHC process alternatives are only screening level estimates. This means that those processes which appear to have significant risks associated with them should not be viewed as unsafe or life-threatening, only as less safe than the other processes which showed lower risks. The approach and assumptions used to characterize processes were geared toward relative consistencies in those areas of high uncertainty, and not absolute measurements per process or across the industry.

The following conclusions are based on the findings of this work:

- The air turnover rate in the MHC process room (determined by dividing process room ventilation rate by process room volume) had the greatest effect on the air modeling variance with respect to sensitivity and uncertainty. The point estimate for this parameter was revised from the original 10th percentile assumption to more accurately reflect the majority of industry practices and be less conservative. The revised air turnover rate which provided the approximate 90th percentile indoor chemical air concentrations was found to be 0.021 room volume turnovers/min⁻¹.
- Inhalation risks to the general population from MHC facility emissions are below standard target risks (1×10^{-6} ELCR and 1.0 HI) despite very conservative characterizing assumptions (upper-boundary air dispersion modeling conditions and conservative exposure durations).
- Conveyorized MHC processes provide less overall risk to workers than Non-Conveyorized processes.
- The steadfast use of proper protective equipment in MHC process areas, such as breathing filters, eye protection, gloves, and coats, would substantially reduce or possibly eliminate risks to workers. The combination of diligent protective equipment use with a conveyorized MHC process could be the best solution to reducing worker risk.
- Three MHC processes posed risks above standard levels of concern to workers (again, these risks are to be viewed as comparative levels among MHC process

alternatives). These are electroless copper, non-formaldehyde electroless copper, and tin palladium. The risk indicators for these processes [summation across chemical and pathway for HI and MOE (reciprocal summation)] are as follows (all numbers for non-conveyorized process configuration):

Electroless Copper – 1.3×10^{-3} ELCR, 1.27×10^2 HI, 0.205 MOE

Non-Formaldehyde Electroless Copper – 3.73×10^0 HI, 8.76 MOE

Tin Palladium – 1.5×10^1 HI, 0.89 MOE

- The other processes showed substantially lower, or negligible risks to workers. Organic Palladium and Conductive Polymer showed no risks to workers based on the available toxicity information at the time of this study.

A more complete work on this subject can be found in the CTSA report developed by the CCPCT (1996).

Areas for Further Research

- Additional toxicity information can be gathered for chemicals where none currently exists, and for those mixtures and groups of chemicals which are believed to be more toxic when combined.
- Comparisons of predicted emissions and chemical concentrations should be made with measured data from PWB facilities. This would also help to discern differences between various ventilation systems. To accurately assess whether workers are exposed to unacceptable chemical levels in the workplace, actual measurements would have to be taken from the work area of each MHC process alternative and then compared to risk indicators (RfDs, CSFs).
- The development of alternatives for the accelerator and catalyst baths (typically the risk drivers across processes) that do not use hazardous substances. The use and advancement of conveyor techniques and operator-free maintenance should also be explored as this might be the only true way to maintain a balance between economic and technological feasibility versus worker health safety.

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Appendices

Appendix A. Generic Chemistry MHC Makeup Example

Appendix B. Air transport modeling, exposure intake, and risk calculation
spreadsheets

Appendix C. Sample Calculations for Exposure and Risk Estimates

Appendix D. Dilution Ventilation Rate Comparison Calculations

Appendix E. Toxicity Table

Appendix A: Generic Chemistry Makeup Example

APPENDIX A

EXAMPLE BATH CHEMISTRY MAKEUP INFORMATION: ELECTROLESS COPPER

PROCESS: C-3000ELECTROLESS

SUPPLIER: SUPPLY

BATH		PRODUCT NAME		MSDS DATA				PRODUCT DATA				NOTES
CONDITIONER	CONDITIONER 3320	CHEMICALS	WT. %	CONC. USED	S.G.	CONC. IN BATH (G/L)	BATH INGREDIENTS	CONC. % BY V	BY VOL. USED			
MICRO-ETCH	PREPOSET ETCH 748	SULFURIC ACID	6	6	1.100	9,900	DI WATER	63	15	83	ALL BY VOL. % ARE GIVEN IN TERMS OF 100 gm TANK TOTALS	
		P-TOLUENE SULFONIC ACID	1	1	1.100	9,900	COND. 3320	15		16	100-120 F	
		ISOPROPYL ALCOHOL	21	21	1.100	1,650					75-83 F	
		HYDROXYACETIC ACID	52	52	1.100	34,650					S.G. OF ACID IS 1.04	
		WATER	14	14	1.100	83,900					ADD DI WATER TO BRING VOL. TO 100%	
PRE-ZIP "CONTAINS CHLORIDES (H2O2)"	CATA-PREP 404L	NON-HAZ MATERIALS	43	43	1.250	23,800	DI WATER	50	100	100		
		POTASSIUM PEROXYMONOSULFATE	23	23	1.250	19,200	SULFURIC ACID	1		1		
		POTASSIUM BISULFATE	32	32	1.250	19,200	ETCH 748	50 LBS		4.8		
		MAGNESIUM CARBONATE	2	2	1.250	1,200						
		SULFURIC ACID(105-MARTIN BAYES)	1.0	1.0	1.840	1,840						
PALLADIUM CATALYST	CATA-POSIT 44 CATALYST	SODIUM BISULFATE	4	4	1.165	48,800	CATA-PREP 404(L)	100		100		
		NON-HAZ MATERIALS	96	96	1.165	1118,400					75-100 F	
		HYDROCHLORIC ACID	10	10	1.200	3,600						
		STANNOUS CHLORIDE AS TIN	22	22	1.200	7,920	CATA-PREP 404(L)	87		87		
		WATER	65.6	65.6	1.200	23,580	CATA-POSIT 44	3		3	100-120 F	
ELECTROLESS COPPER	CIRCUPOSIT 3350A	PALLADIUM(DISSOLVED)	<1	1	1.200	0.360						
		NON-HAZ MATERIALS	2.5	2.5	1.200	0.900						
		SODIUM BISULFATE	4	4	1.165	43,702						
		TIN CHLORIDE(105-MARTIN BAYES)	7	7	1.140	3,352	DI WATER	73.8		73.8		
		FORMALDEHYDE	10	10	1.140	4,768	CIRCUPOSIT 3350M	12		12	115 F	
CIRCUPOSIT 3350B	CIRCUPOSIT 3350C	COPPER SULFATE AS COPPER	61	61.0	1.140	39,763	CIRCUPOSIT 3350A	4.2		4.2		
		HYDROCHLORIC ACID	1	1.0	1.140	0.476	CIRCUPOSIT 3350B	10		10		
		NON-HAZ MATERIALS	<1	1.0	1.140	0.476						
		SODIUM HYDROXIDE	5	5	1.200	8,000						
		WATER	76	75	1.200	90,000						
CIRCUPOSIT 3350M	CIRCUPOSIT 3350R RPLNISHR	NON-HAZ MATERIALS	20	20	1.300	24,000	DI WATER	94.5		94.5		
		SODIUM HYDROXIDE	67	67	1.300	REPLENISHMENT	CIRCUPOSIT 3350M	3		3		
		WATER	10	10	1.300	REPLENISHMENT	CIRCUPOSIT 3350B	2.5		2.5		
		ETHYLENEDIAMINE-TETRAACETIC ACID	25	25	1.140	34,200						
		TETRASODIUM BALT(EDTA)	70	70	1.140	95,760						
ANTI-TARNISH	ANTI-TARNISH 7130	NON-HAZ MATERIALS	5	5	1.140	8,940	DI WATER	94.5		94.5		
		ETHYLENEDIAMINE-TETRAACETIC ACID	22	22	1.140	REPLENISHMENT	SULFURIC ACID(98%)	3		3		
		SODIUM HYDROXIDE	<3	3	1.140	REPLENISHMENT	ANTI-TARN 7130	2.5		2.5		
		WATER	75	75	1.140	REPLENISHMENT						
		NON-HAZ MATERIALS	<3	3	1.140	REPLENISHMENT						
CIRCUPOSIT 3350M	CIRCUPOSIT 3350R RPLNISHR	METHANOL	5	5.0	1.000	1,250	DI WATER	94.5		94.5		
		WATER	80	80.0	1.000	22,500	SULFURIC ACID(98%)	3		3		
		NON-HAZ MATERIALS	5	5.0	1.000	1,250	ANTI-TARN 7130	2.5		2.5		
		SULFURIC ACID	95	95.0	1.000	28,800						

FOOTNOTES: 1) WEIGHT % AS REPORTED ON MSDS
2) WEIGHT % USED IN CONCENTRATION CALCULATIONS IF A RANGE OF VALUES GIVEN AN AVG. WAS TAKEN, IGNORED <> SIGNS
3) SPECIFIC GRAVITY OF PRODUCT AS REPORTED ON MSDS
4) CONCENTRATION OF CHEMICAL CONSTITUENTS IN FINAL BATH MAKE-UP

**Appendix B: Air transport modeling, exposure intake, and risk calculation
spreadsheets**

BATH PARAMETERS SHEET - NON CONVEYORIZED PROCESSES

ELECTROLESS COPPER

BATHS	temp		Volume m ³ V	Tank Surface Characteristics			air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z			air flow L/min Q ₀	dia bubble cm d _b
CONDITIONER/CLEANER	58.33	331.4833	0.450	85.867	0.524552	0.724	0.508	1		
MICROETCH	35.00	308.15	0.560	106.825	0.524389	0.724	0.508	1	53.8	0.2
PRE-DIP	26.11	299.2611	0.443	89.992	0.492092	0.701	0.508	1		
CATALYST	36.67	309.8167	0.450	89.359	0.504054	0.710	0.508	1		
ACCELERATOR	27.22	300.3722	0.466	93.747	0.496608	0.705	0.508	1		
ELECTROLESSCOPPER	38.89	312.0389	0.867	112.360	0.771415	0.878	0.508	1	53.8	0.2
ACID DIP	24.44	297.5944	0.397	83.657	0.475067	0.689	0.508	1		
ANTI-TARNISH	28.89	302.0389	0.413	80.502	0.51249	0.716	0.508	1	53.8	0.2

NON-FORMALDEHYDE ELECTROLESS COPPER

BATHS	temp		Volume m ³ V	Tank Surface Characteristics			air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z			air flow L/min Q ₀	dia bubble cm d _b
CONDITIONER/CLEANER	51.11	324.26	0.151	61.115	0.248	0.498	0.508	1		
MICROETCH	39.44	312.59	0.151	61.115	0.248	0.498	0.508	1	53.8	0.2
PRE-DIP	25	298.15	0.151	61.115	0.248	0.498	0.508	1		
CATALYST	37.78	310.93	0.151	61.115	0.248	0.498	0.508	1		
POSTDIP	25	298.15	0.151	61.115	0.248	0.498	0.508	1		
ACCELERATOR	51.11	324.26	0.151	61.115	0.248	0.498	0.508	1		
ELECTROLESSCOPPER	72.78	345.93	0.235	71.046	0.330	0.575	0.508	1	53.8	0.2
ANTI-TARNISH	25	298.15	0.151	61.115	0.248	0.498	0.508	1	53.8	0.2

TIN PALLADIUM

BATHS	temp		Volume m ³ V	Tank Surface Characteristics			air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z			air flow L/min Q ₀	dia bubble cm d _b
CLEANER/CONDITIONER	73.33	346.4833	0.246	71.219	0.345449	0.588	0.508	1		
PRE-DIP	23.89	297.0389	0.201	66.688	0.300811	0.548	0.508	1		
CATALYST	43.89	317.0389	0.212	61.022	0.347349	0.589	0.508	1		
ACCELERATOR	56.67	329.8167	0.254	66.441	0.381683	0.618	0.508	1		
OTHER(ENHANCER)	24.44	297.5944	0.223	74.119	0.301294	0.549	0.508	1		
MICROETCH	24.44	297.5944	0.242	77.096	0.314206	0.561	0.508	1	53.8	0.2
OTHER(STABILIZER)	22.78	295.9278	0.193	66.976	0.288213	0.537	0.508	1		
ACID DIP	24.44	297.59	0.223	65.015	0.343	0.586	0.508	1		

ORGANIC PALLADIUM

BATHS	temp		Volume m ³ V	Tank Surface Characteristics			air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z			air flow L/min Q ₀	dia bubble cm d _b
CONDITIONER	40.56	313.7056	1.037	127.571	0.813	0.902	0.508	1		
MICROETCH	25.56	298.7056	0.780	127.881	0.610	0.781	0.508	1		
PRE-DIP	21.11	294.2611	1.037	127.571	0.813	0.902	0.508	1		
CONDUCTOR	45.00	318.15	0.780	127.881	0.610	0.781	0.508	1		
POST-DIP	23.33	296.4833	0.780	127.881	0.610	0.781	0.508	1		

BATH PARAMETERS SHEET - CONVEYORIZED PROCESSES

ELECTROLESS COPPER

BATHS	temp		Volume m ³ V	Tank Surface Characteristics				air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z				air flow L/min Q _G	dia bubble cm d _b
CONDITIONER/CLEANER	54.40	327.55	0.303	16.308	1.858	1.363		0.508	1		
MICROETCH	36.67	309.82	0.204	34.694	0.588	0.767		0.508	1	53.8	0.2
PRE-DIP	26.11	299.26	0.129	43.878	0.294	0.542		0.508	1		
CATALYST	46.67	319.82	0.140	31.180	0.449	0.670		0.508	1		
ACCELERATOR	27.22	300.37	0.466	82.624	0.564	0.751		0.508	1		
ELECTROLESS COPPER	32.78	305.93	0.700	13.514	5.18	2.276		0.508	1	53.8	0.2
ACID DIP	35.56	308.71	0.700	155.902	0.449	0.670		0.508	1		
ANTI-TARNISH	28.89	302.04	0.413	70.598	0.585	0.765		0.508	1	53.8	0.2

TIN PALLADIUM

BATHS	temp		Volume m ³ V	Tank Surface Characteristics				air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z				air flow L/min Q _G	dia bubble cm d _b
CLEANER/CONDITIONER	45.56	318.71	0.371	40.769	0.91	0.954		0.508	1		
PRE-DIP	81.00	354.15	0.220	43.738	0.503	0.709		0.508	1		
CATALYST	117.00	390.15	0.655	37.027	1.769	1.330		0.508	1		
ACCELERATOR	103.00	376.15	0.303	35.029	0.865	0.930		0.508	1		
MICROETCH	92.00	365.15	0.220	42.065	0.523	0.723		0.508	1	53.8	0.2
ACID DIP	94.00	367.15	0.201	39.960	0.503	0.709		0.508	1		

ORGANIC PALLADIUM

BATHS	temp		Volume m ³ V	Tank Surface Characteristics				air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z				air flow L/min Q _G	dia bubble cm d _b
CONDITIONER	37.78	310.93	0.280	14.760	1.897	1.377		0.508	1		
MICROETCH	23.89	297.04	0.140	17.722	0.790	0.889		0.508	1		
PRE-DIP	26.10	299.25	0.091	24.011	0.379	0.616		0.508	1		
CONDUCTOR	46.11	319.26	0.409	13.202	3.098	1.760		0.508	1		
POST-DIP	25.00	298.15	0.170	20.681	0.822	0.907		0.508	1		

GRAPHITE

BATHS	temp		Volume m ³ V	Tank Surface Characteristics				air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z				air flow L/min Q _G	dia bubble cm d _b
CLEANER/CONDITIONER	51.67	324.8167	0.163	30.285	0.537	0.733		0.508	1		
GRAPHITE	27.78	300.9278	0.140	26.059	0.537	0.733		0.508	1		
FIXER(OPTIONAL)	23.89	297.0389	0.110	31.980	0.343	0.586		0.508	1		
MICRO ETCH	31.11	304.2611	0.208	34.400	0.605	0.778		0.508	1		

CARBON

BATHS	temp		Volume m ³ V	Tank Surface Characteristics				air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z				air flow L/min Q _G	dia bubble cm d _b
CLEANER	53.89	327.0389	0.182	14.546	1.249	1.118		0.508	1		
CONDITIONER	27.22	300.3722	0.178	14.243	1.249	1.118		0.508	1		
CARBON BLACK 1	30.56	303.7056	0.484	34.830	1.391	1.179		0.508	1		
CARBON BLACK 2	30.56	303.7056	0.484	34.830	1.391	1.179		0.508	1		
MICROETCH	46.67	319.8167	0.379	24.923	1.519	1.232		0.508	1		

CONDUCTIVE POLYMER

BATHS	temp		Volume m ³ V	Tank Surface Characteristics				air velocity m/s V _z	dist. from tank rim m for F _D	Sparged Baths Only	
	C t	K t		Height cm h	Area m ² A	dist. across m z				air flow L/min Q _G	dia bubble cm d _b
MICRO ETCH 1	22.22	295.3722	0.310	84.399	0.368	0.606		0.508	1		
MICRO ETCH 2	22.22	295.3722	0.310	84.399	0.368	0.606		0.508	1		
CLEANER/CONDITIONER	70.00	343.15	0.310	72.890	0.426	0.653		0.508	1		
CATALYST	92.22	365.3722	0.651	70.075	0.929	0.964		0.508	1		
CONDUCTIVE POLYMER	5.00	278.15	0.098	21.186	0.465	0.682		0.508	1		

AIR TRANSPORT MODELS - NON-CONVEYORIZED ELECTROLESS COPPER

OPEN TANK VOLATILIZATION - SURFACE DESORPTION

BATHS	CHEMICALS	mg/L Chem conc in bath	temp corrected				mg/min Fy,O	Resistance Check		VERIFY OK ?	1 400E+01	
			atm m3/mol HY	unitless HY	cm/sec kg			Liquid Side s/cm HY/kL	Gas Side s/cm 1/kg		Line Operator mg/day Dermal exposure	Lab Tech mg/day
CONDITIONER/CLEANER	SULFURIC ACID	9900	SALT	SALT	2.924E-01	0	SALT	3.420358416	SALT		5 405E+00	1 328E-01
CONDITIONER/CLEANER	p-TOLUENE SULFONIC ACID	9900	SALT	SALT	2.596E-01	0	SALT	3.851516756	SALT		3 328E-01	8 178E-03
CONDITIONER/CLEANER	ISOPROPYL ALCOHOL, 2-PROPANOL	3363	3 1732E-05	0.001167	3.278E-01	404.7994	1.944251904	3.05021677	NOT OK		1.633E+00	4.011E-02
CONDITIONER/CLEANER	HYDROXYACETIC ACID	34650	2.52971E-10	9.3E-09	3.098E-01	0.031422	1.54998E-05	3.227692782	OK		2 018E+00	4.958E-02
CONDITIONER/CLEANER	POTASSIUM HYDROXIDE	530	SALT	SALT	3.335E-01	0	SALT	2.998759201	SALT		2 894E-01	7 110E-03
CONDITIONER/CLEANER	AMMONIUM CHLORIDE	12875	SALT	SALT	3.375E-01	0	SALT	2.963045783	SALT		7 030E+00	1 727E-01
CONDITIONER/CLEANER	FORMIC ACID	12875	6.7164E-07	2.47E-05	3.508E-01	35.10078	0.0411521	2.850451196	OK		2 903E+00	7 133E-02
CONDITIONER/CLEANER	TRIETHANOLAMINE, OR 2,2,2-NITRILOTR	30300	SALT	SALT	2.673E-01	0	SALT	3.740814552	SALT		2 882E-01	7 081E-03
CONDITIONER/CLEANER	ETHYLENE GLYCOL	2438	2.41308E-07	8.87E-06	3.252E-01	2.213479	0.014785186	3.074589359	OK		1 148E-01	2 821E-03
CONDITIONER/CLEANER	DIMETHYLFORMAMIDE	1316	2.97291E-07	1.09E-05	3.127E-01	1.415881	0.018215349	3.197718893	OK		9 410E-02	2 312E-03
CONDITIONER/CLEANER	ETHANOLAMINE	16320	1.60872E-07	5.81E-06	3.265E-01	9.919067	0.00985879	3.062499539	OK		8 457E-01	2 078E-02
MICROETCH	PEROXYMONOSULFURIC ACID, OR POT	25800	SALT	SALT	2.963E-01	0	SALT	3.755746777	SALT		1 409E+01	3 461E-01
MICROETCH	POTASSIUM BISULFATE	13800	SALT	SALT	2.725E-01	0	SALT	3.670390962	SALT		7 535E+00	1 851E-01
MICROETCH	POTASSIUM SULFATE	19200	SALT	SALT	2.590E-01	0	SALT	3.86042742	SALT		1 048E+01	2 576E-01
MICROETCH	MAGNESIUM CARBONATE	1200	SALT	SALT	3.025E-01	0	SALT	3.305579998	SALT		6.522E-01	1 610E-02
MICROETCH	POTASSIUM PERSULFATE	9800	SALT	SALT	2.378E-01	0	SALT	4.204814416	SALT		5.351E+00	1 315E-01
MICROETCH	SULFURIC ACID	121320	SALT	SALT	2.924E-01	0	SALT	3.420092961	SALT		6.624E+01	1 628E+00
MICROETCH	HYDROGEN PEROXIDE	19910	SALT	SALT	3.808E-01	0	SALT	2.626343102	SALT		1 087E+01	2 671E-01
MICROETCH	SODIUM HYDROXIDE	302	SALT	SALT	3.641E-01	0	SALT	2.746143733	SALT		1 646E-01	4 045E-03
MICROETCH	COPPER SULFATE, OR CUPRIC SULFAT	500	SALT	SALT	2.637E-01	0	SALT	3.79249091	SALT		2 730E-01	6 708E-03
MICROETCH	ETHYLENE GLYCOL	1925	9.40172E-08	3.72E-06	3.253E-01	0.732481	0.006196728	3.074350739	OK		9 066E-02	2 228E-03
PRE-DIP	SODIUM BISULFATE	24590	SALT	SALT	2.843E-01	0	SALT	3.517767852	SALT		1 343E-01	3 298E-01
PRE-DIP	HYDROCHLORIC ACID	85640	SALT	SALT	3.795E-01	0	SALT	2.635174213	SALT		4 678E+01	1 149E+00
PRE-DIP	SULFURIC ACID	2575	SALT	SALT	2.971E-01	0	SALT	3.368169687	SALT		1 406E+00	3 455E-02
CATALYST	HYDROCHLORIC ACID	50940	SALT	SALT	3.772E-01	0	SALT	2.651044287	SALT		2 781E+01	6 834E-01
CATALYST	STANNOUS CHLORIDE	111700	SALT	SALT	2.572E-01	0	SALT	3.68733506	SALT		6 098E-01	1 499E+00
CATALYST	PALLADIUM	5710	SALT	SALT	2.900E-01	0	SALT	3.447729437	SALT		3 118E+00	7 660E-02
CATALYST	METHANOL	2518	7.66219E-06	0.000301	3.911E-01	89.7425	0.502302275	2.556912267	NOT OK		4 743E-01	1 165E-02
CATALYST	SODIUM BISULFATE	45202	SALT	SALT	2.826E-01	0	SALT	3.538953257	SALT		2 468E+01	6 064E-01
CATALYST	SODIUM SULFATE	12625	SALT	SALT	2.727E-01	0	SALT	3.686440873	SALT		6.893E+00	1 694E-01
CATALYST	SODIUM HYDROXIDE	2525	SALT	SALT	3.678E-01	0	SALT	2.719123977	SALT		1 379E+00	3 387E-02
ACCELERATOR	SODIUM CHLORITE	4515	SALT	SALT	3.018E-01	0	SALT	3.313249951	SALT		2 465E+00	6 057E-02
ACCELERATOR	SULFURIC ACID	18240	SALT	SALT	2.964E-01	0	SALT	3.373865535	SALT		9 959E+00	2 447E-01
ACCELERATOR	SODIUM HYPOPHOSPHITE	8580	SALT	SALT	3.037E-01	0	SALT	3.29246688	SALT		4 685E+00	1 151E-01
ACCELERATOR	FLUOBORIC ACID	80000	9.97038E-09	4.05E-07	3.038E-01	2.197263	0.000674168	3.291191523	OK		3 276E+01	8 050E-01
ELECTROLESSCOPPER	FORMALDEHYDE	3680	4.35114E-07	1.7E-05	3.582E-01	10.38746	0.02832118	2.791753736	OK		2 511E+00	6 170E-02
ELECTROLESSCOPPER	COPPER CHLORIDE(I)	6690	SALT	SALT	2.649E-01	0	SALT	3.774298363	SALT		3 653E+00	8 975E-02
ELECTROLESSCOPPER	COPPER SULFATE, OR CUPRIC SULFAT	6980	SALT	SALT	2.394E-01	0	SALT	4.176897909	SALT		3 811E+00	9 364E-02
ELECTROLESSCOPPER	HYDROCHLORIC ACID	480	SALT	SALT	3.391E-01	0	SALT	2.948626432	SALT		2 621E-01	6 440E-03
ELECTROLESSCOPPER	SODIUM HYDROXIDE	10190	SALT	SALT	3.306E-01	0	SALT	3.024348129	SALT		5.564E+00	1 367E-01
ELECTROLESSCOPPER	ETHYLENEDIAMINE-TETRAACETIC ACID	45200	SALT	SALT	2.128E-01	0	SALT	4.699433864	SALT		1 409E-03	3 461E-05
ELECTROLESSCOPPER	METHANOL	1390	8.42454E-06	0.000329	3.516E-01	74.42888	0.54834625	2.843928007	NOT OK		2 619E-01	6 434E-03
ELECTROLESSCOPPER	POTASSIUM CYANIDE	223	SALT	SALT	2.919E-01	0	SALT	3.425426783	SALT		1 218E-01	2 992E-03
ELECTROLESSCOPPER	POTASSIUM-SODIUM TARTRATE	31440	SALT	SALT	2.268E-01	0	SALT	4.412106404	SALT		1 717E+01	4 218E-01
ELECTROLESSCOPPER	SODIUM CARBONATE	50	SALT	SALT	2.610E-01	0	SALT	3.831583822	SALT		2 730E-02	6 708E-04
ELECTROLESSCOPPER	TARTARIC ACID	1031	SALT	SALT	2.424E-01	0	SALT	4.124563405	SALT		4 792E-03	1 177E-04
ELECTROLESSCOPPER	SODIUM CYANIDE	231	SALT	SALT	3.133E-01	0	SALT	3.191739645	SALT		1 261E-01	3 099E-03
ELECTROLESSCOPPER	SULFURIC ACID	1150	SALT	SALT	2.655E-01	0	SALT	3.766573331	SALT		6 279E-01	1 543E-02
ELECTROLESSCOPPER												
ELECTROLESSCOPPER												
ELECTROLESSCOPPER												
ELECTROLESSCOPPER												
ELECTROLESSCOPPER												
ACID DIP	SULFURIC ACID										0.000E+00	0.000E+00
ACID DIP	DIMETHYLAMINOBORANE	720	6.82146E-07	2.79E-05	3.377E-01	1.935796	0.046555355	2.961421697	OK		3 273E-01	8 043E-03
ACID DIP	BORIC ACID	5000	8.77045E-09	3.59E-07	3.337E-01	0.170808	0.000598569	2.996637554	OK		2 730E+00	6 708E-02
ANTI-TARNISH	METHANOL	1100	5.43753E-06	0.000219	3.895E-01	28.90136	0.365641682	2.567544261	NOT OK		2 702E-01	5 092E-03
ANTI-TARNISH	SULFURIC ACID	28800	SALT	SALT	2.941E-01	0	SALT	3.400523402	SALT		1 572E+01	3 864E-01
ANTI-TARNISH	ISOPROPYL ALCOHOL, 2-PROPANOL	2016	9.42903E-06	0.00038	3.298E-01	77.7669	0.634046784	3.032528245	NOT OK		9 787E-01	2 405E-02
ANTI-TARNISH	POTASSIUM HYDROXIDE	302	SALT	SALT	3.354E-01	0	SALT	2.981369084	SALT		1 651E-01	4 057E-03
ANTI-TARNISH	BENZOTRIAZOLE	119	1.75674E-07	7.09E-06	2.819E-01	0.07295	0.011813039	3.547766241	OK		2 072E-01	5 092E-03
ANTI-TARNISH	M-NITROBENZENE SULFONIC ACID	119	SALT	SALT	2.477E-01	0	SALT	4.037069665	SALT		7 332E-05	1 802E-06
ANTI-TARNISH	2-ETHOXYETHANOL	45900	5.36494E-06	0.000217	2.997E-01	919.0141	0.362105806	3.336674171	NOT OK		1 144E+01	2 810E-01

SPARGED TANK VOLATILIZATION - BUBBLE DESORPTION

BATHS	CHEMICALS	cm/s KOL_O2	temp corrected				mg/min Fy, S
			cm2/s Dy	cm/min KOL_y	min tb	cm2/cm3 a	
MICROETCH	POTASSIUM BISULFATE	0.011293315	SALT	SALT	0.0073112	0.021065	0
MICROETCH	PEROXYMONOSULFURIC ACID, OR POT	0.011293315	SALT	SALT	0.0073112	0.021065	0
MICROETCH	POTASSIUM SULFATE	0.011293315	SALT	SALT	0.0073112	0.021065	0
MICROETCH	MAGNESIUM CARBONATE	0.011293315	SALT	SALT	0.0073112	0.021065	0
MICROETCH	POTASSIUM PERSULFATE	0.011293315	SALT	SALT	0.0073112	0.021065	0
MICROETCH	SULFURIC ACID	0.011293315	SALT	SALT	0.0073112	0.021065	0
MICROETCH	HYDROGEN PEROXIDE	0.011293315	SALT	SALT	0.0073112	0.021065	0
MICROETCH	SODIUM HYDROXIDE	0.011293315	SALT	SALT	0.0073112	0.021065	0
MICROETCH	COPPER SULFATE, OR CUPRIC SULFAT	0.011293315	SALT	SALT	0.0073112	0.021065	0
MICROETCH	ETHYLENE GLYCOL	0.011293315	1.41859E-05	0.58023	0.0073112	0.021065	0.38505849
ELECTROLESSCOPPER	FORMALDEHYDE	0.011293315	1.8098E-05	0.811781	0.00769	0.01432	3.364284293
ELECTROLESSCOPPER	COPPER CHLORIDE(I)	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	COPPER SULFATE, OR CUPRIC SULFAT	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	HYDROCHLORIC ACID	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	SODIUM HYDROXIDE	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	ETHYLENEDIAMINE-TETRAACETIC ACID	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	METHANOL	0.011293315	1.71228E-05	0.768037	0.00769	0.01432	24.60385755
ELECTROLESSCOPPER	POTASSIUM CYANIDE	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	POTASSIUM-SODIUM TARTRATE	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	SODIUM CARBONATE	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	TARTARIC ACID	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	SODIUM CYANIDE	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER	SULFURIC ACID	0.011293315	SALT	SALT	0.00769	0.01432	0
ELECTROLESSCOPPER							
ELECTROLESSCOPPER							
ELECTROLESSCOPPER							
ELECTROLESSCOPPER							
ELECTROLESSCOPPER							
ANTI-TARNISH	METHANOL	0.011293315	1.71228E-05	0.605874	0.0055096	0.021554	12.98320483
ANTI-TARNISH	SULFURIC ACID	0.011293315	SALT	SALT	0.0055096	0.021554	0
ANTI-TARNISH	ISOPROPYL ALCOHOL, 2-PROPANOL	0.011293315	1.17657E-05	0.41632	0.0055096	0.021554	41.26153287
ANTI-TARNISH	POTASSIUM HYDROXIDE	0.011293315	SALT	SALT	0.0055096	0.021554	0
ANTI-TARNISH	BENZOTRIAZOLE	0.011293315	1.06295E-05	0.376117	0.0055096	0.021554	0.045282332
ANTI-TARNISH	M-NITROBENZENE SULFONIC ACID	0.011293315	SALT	SALT	0.0055096	0.021554	0
ANTI-TARNISH	2-ETHOXYETHANOL	0.011293315	1.02461E-05	0.362551	0.0055096	0.021554	536.5147917

AEROSOLS FROM SPARGED TANK - AEROSOL GENERATION AND TRANSPORT

BATHS	CHEMICALS	FT	FA	FD	m/min/m2		cm KLW	M/Mb	r/E	mg/min FY, A
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AIR TRANSPORT MODELS - CONVEYORIZED ELECTROLESS COPPER

OPEN TANK VOLATILIZATION - SURFACE DESORPTION

OPEN TANK VOLATILIZATION - SURFACE DESORPTION										Resistance Check				Line Operator	Lab Tech
BATHS	CHEMICALS	mg/L	temp corrected	unitless	cm/sec	mg/min	Liquid Side s/cm HY/L	Gas Side s/cm 1/kg	VERIFY OK ?	mg/day Dermal exposure	mg/day				
		Chem conc In bath	atm m3/mol HY	HY	kg	Fy,O									
CONDITIONER/CLEANER	SULFURIC ACID	9900	SALT	SALT	2.131E-01	0	SALT	4.6923011	SALT	1.344	0.133				
CONDITIONER/CLEANER	p-TOLUENE SULFONIC ACID	9900	SALT	SALT	1.893E-01	0	SALT	5.2837981	SALT	0.083	0.008				
CONDITIONER/CLEANER	ISOPROPYL ALCOHOL, 2-PROPANOL	3363	2.73261E-05	0.001017	2.390E-01	910.8499	1.69440294	4.1845134	NOT OK	0.406	0.040				
CONDITIONER/CLEANER	HYDROXYACETIC ACID	34650	2.17847E-10	8.1E-09	2.258E-01	0.070703	1.3508E-05	4.4279881	OK	0.502	0.050				
CONDITIONER/CLEANER	POTASSIUM HYDROXIDE	530	SALT	SALT	2.431E-01	0	SALT	4.1139201	SALT	0.072	0.007				
CONDITIONER/CLEANER	AMMONIUM CHLORIDE	12875	SALT	SALT	2.460E-01	0	SALT	4.0649257	SALT	1.747	0.173				
CONDITIONER/CLEANER	FORMIC ACID	12875	5.78384E-07	2.15E-05	2.557E-01	78.9812	0.03586379	3.9104601	OK	0.721	0.071				
CONDITIONER/CLEANER	TRIMETHANOLAMINE; OR 2,2,2-NITRIL	30300	SALT	SALT	1.949E-01	0	SALT	5.1319266	SALT	0.072	0.007				
CONDITIONER/CLEANER	ETHYLENE GLYCOL	2438	2.07803E-07	7.73E-06	2.371E-01	4.980608	0.01288519	4.2179495	OK	0.029	0.003				
CONDITIONER/CLEANER	DIMETHYLFORMAMIDE	1316	2.56013E-07	9.52E-06	2.280E-01	3.185912	0.01587458	4.3868677	OK	0.023	0.002				
CONDITIONER/CLEANER	ETHANOLAMINE	18320	1.38535E-07	5.15E-06	2.380E-01	22.31918	0.00859013	4.2013838	OK	0.210	0.021				
MICROETCH	PEROXYMONOSULFURIC ACID, OR PO	25800	SALT	SALT	2.587E-01	0	SALT	3.8648013	SALT	3.951	0.346				
MICROETCH	POTASSIUM BISULFATE	13800	SALT	SALT	2.648E-01	0	SALT	3.776967	SALT	2.113	0.185				
MICROETCH	POTASSIUM SULFATE	18200	SALT	SALT	2.517E-01	0	SALT	3.9725215	SALT	2.940	0.258				
MICROETCH	MAGNESIUM CARBONATE	1200	SALT	SALT	2.940E-01	0	SALT	3.4015631	SALT	0.184	0.018				
MICROETCH	POTASSIUM PERSULFATE	9800	SALT	SALT	2.311E-01	0	SALT	4.3269084	SALT	1.501	0.131				
MICROETCH	SULFURIC ACID	121320	SALT	SALT	2.841E-01	0	SALT	3.5194012	SALT	18.580	1.628				
MICROETCH	HYDROGEN PEROXIDE	19910	SALT	SALT	3.700E-01	0	SALT	2.7026035	SALT	3.049	0.287				
MICROETCH	SODIUM HYDROXIDE	302	SALT	SALT	3.539E-01	0	SALT	2.8258627	SALT	0.046	0.004				
MICROETCH	COPPER SULFATE; OR CUPRIC SULFA	500	SALT	SALT	2.562E-01	0	SALT	3.9026123	SALT	0.077	0.007				
MICROETCH	ETHYLENE GLYCOL	1925	1.01054E-07	3.97E-06	3.161E-01	0.853275	0.00682464	3.1636198	OK	0.025	0.002				
PRE-DIP	SODIUM BISULFATE	24590	SALT	SALT	3.233E-01	0	SALT	3.0927331	SALT	3.337	0.330				
PRE-DIP	HYDROCHLORIC ACID	85640	SALT	SALT	4.316E-01	0	SALT	2.316779	SALT	11.622	1.149				
PRE-DIP	SULFURIC ACID	2575	SALT	SALT	3.379E-01	0	SALT	2.9594518	SALT	0.349	0.035				
CATALYST	HYDROCHLORIC ACID	50940	SALT	SALT	3.883E-01	0	SALT	2.575487	SALT	6.913	0.683				
CATALYST	STANNOUS CHLORIDE	111700	SALT	SALT	2.648E-01	0	SALT	3.7765423	SALT	15.159	1.499				
CATALYST	PALLADIUM	5710	SALT	SALT	2.988E-01	0	SALT	3.3494858	SALT	0.775	0.077				
CATALYST	METHANOL	2518	1.16218E-05	0.000443	4.026E-01	120.9055	0.73805056	2.4840378	NOT OK	0.118	0.012				
CATALYST	SODIUM BISULFATE	45202	SALT	SALT	2.909E-01	0	SALT	3.4308097	SALT	6.134	0.606				
CATALYST	SODIUM SULFATE	12625	SALT	SALT	2.807E-01	0	SALT	3.5819525	SALT	1.713	0.169				
CATALYST	SODIUM HYDROXIDE	2525	SALT	SALT	3.786E-01	0	SALT	2.6416263	SALT	0.343	0.034				
ACCELERATOR	SODIUM CHLORITE	4515	SALT	SALT	2.924E-01	0	SALT	3.4203508	SALT	0.571	0.061				
ACCELERATOR	SULFURIC ACID	18240	SALT	SALT	2.871E-01	0	SALT	3.4829258	SALT	2.308	0.245				
ACCELERATOR	SODIUM HYPOPHOSPHITE	8580	SALT	SALT	2.942E-01	0	SALT	3.3988959	SALT	1.086	0.115				
ACCELERATOR	FLUOBORIC ACID	60000	9.96934E-09	4.04E-07	2.943E-01	2.417077	0.0006741	3.3975793	OK	7.591	0.805				
ELECTROLESSCOPPER	FORMALDEHYDE	3680	3.34136E-07	1.33E-05	2.225E-01	33.87353	0.02218288	4.4940465	OK	0.562	0.062				
ELECTROLESSCOPPER	COPPER CHLORIDE(I)	6890	SALT	SALT	1.646E-01	0	SALT	6.0757051	SALT	0.818	0.090				
ELECTROLESSCOPPER	COPPER SULFATE; OR CUPRIC SULFA	6980	SALT	SALT	1.487E-01	0	SALT	6.7234708	SALT	0.854	0.094				
ELECTROLESSCOPPER	HYDROCHLORIC ACID	480	SALT	SALT	2.107E-01	0	SALT	4.7465735	SALT	0.059	0.006				
ELECTROLESSCOPPER	SODIUM HYDROXIDE	10190	SALT	SALT	2.054E-01	0	SALT	4.8684671	SALT	1.246	0.137				
ELECTROLESSCOPPER	ETHYLENEDIAMINE-TETRAACETIC ACI	45200	SALT	SALT	1.322E-01	0	SALT	7.5649489	SALT	0.000	0.000				
ELECTROLESSCOPPER	METHANOL	1390	6.46943E-06	0.000258	2.184E-01	243.1809	0.4294983	4.5780344	OK	0.059	0.006				
ELECTROLESSCOPPER	POTASSIUM CYANIDE	223	SALT	SALT	1.814E-01	0	SALT	5.5141065	SALT	0.027	0.003				
ELECTROLESSCOPPER	POTASSIUM-SODIUM TARTRATE	31440	SALT	SALT	1.408E-01	0	SALT	7.1024214	SALT	3.845	0.422				
ELECTROLESSCOPPER	SODIUM CARBONATE	50	SALT	SALT	1.621E-01	0	SALT	6.1679208	SALT	0.006	0.001				
ELECTROLESSCOPPER	TARTARIC ACID	1031	SALT	SALT	1.506E-01	0	SALT	6.6395469	SALT	0.001	0.000				
ELECTROLESSCOPPER	SODIUM CYANIDE	231	SALT	SALT	1.946E-01	0	SALT	5.1379268	SALT	0.028	0.003				
ELECTROLESSCOPPER	SULFURIC ACID	1150	SALT	SALT	1.649E-01	0	SALT	6.0632697	SALT	0.141	0.015				
ELECTROLESSCOPPER															
ELECTROLESSCOPPER															
ELECTROLESSCOPPER															
ELECTROLESSCOPPER															
ELECTROLESSCOPPER															
ACID DIP	SULFURIC ACID									0.000	0.000				
ACID DIP	DIMETHYLAMINOBORANE	720	1.12384E-06	4.44E-05	3.425E-01	2.948989	0.07393843	2.919934	OK	0.092	0.008				
ACID DIP	BORIC ACID	5000	1.44493E-08	5.7E-07	3.384E-01	0.280032	0.00095064	2.9546585	OK	0.766	0.067				
ANTI-TARNISH	METHANOL	1100	5.4378E-06	0.000219	3.768E-01	31.91842	0.36565871	2.6539063	NOT OK	0.053	0.005				
ANTI-TARNISH	SULFURIC ACID	28800	SALT	SALT	2.845E-01	0	SALT	3.5149035	SALT	3.993	0.386				
ANTI-TARNISH	ISOPROPYL ALCOHOL, 2-PROPANOL	2018	9.4295E-06	0.00038	3.190E-01	85.88512	0.63407632	3.1345305	NOT OK	0.249	0.024				
ANTI-TARNISH	POTASSIUM HYDROXIDE	302	SALT	SALT	3.245E-01	0	SALT	3.0816505	SALT	0.042	0.004				
ANTI-TARNISH	BENZOTRIAZOLE	119	1.75683E-07	7.08E-06	2.727E-01	0.080566	0.01181359	3.8870991	OK	0.053	0.005				
ANTI-TARNISH	M-NITROBENZENE SULFONIC ACID	119	SALT	SALT	2.396E-01	0	SALT	4.1728607	SALT	0.000	0.000				
ANTI-TARNISH	2-ETHOXYETHANOL	45900	5.38521E-06	0.000217	2.899E-01	1014.952	0.36212287	3.4489067	NOT OK	2.904	0.281				

SPARGED TANK VOLATILIZATION - BUBBLE DESORPTION

BATHS	CHEMICALS	cm/s KOL,O2	temp corrected					mg/min Fy, S
			cm2/s Dy	cm/min KOL,y	min tb	cm2/cm3 a	cm Fy, S	
MICROETCH	POTASSIUM BISULFATE	0.011293315	SALT	SALT	0.00237448	0.018786	0	
MICROETCH	PEROXYMONOSULFURIC ACID, OR PO	0.011293315	SALT	SALT	0.00237448	0.018786	0	
MICROETCH	POTASSIUM SULFATE	0.011293315	SALT	SALT	0.00237448	0.018786	0	
MICROETCH	MAGNESIUM CARBONATE	0.011293315	SALT	SALT	0.00237448	0.018786	0	
MICROETCH	POTASSIUM PERSULFATE	0.011293315	SALT	SALT	0.00237448	0.018786	0	
MICROETCH	SULFURIC ACID	0.011293315	SALT	SALT	0.00237448	0.018786	0	
MICROETCH	HYDROGEN PEROXIDE	0.011293315	SALT	SALT	0.00237448	0.018786	0	
MICROETCH	SODIUM HYDROXIDE	0.011293315	SALT	SALT	0.00237448	0.018786	0	
MICROETCH	COPPER SULFATE; OR CUPRIC SULFA	0.011293315	SALT	SALT	0.00237448	0.018786	0	
MICROETCH	ETHYLENE GLYCOL	0.011293315	1.41856E-05	0.603672	0.00237448	0.018786	0.41164877	
ELECTROLESSCOPPER	FORMALDEHYDE	0.011293315	1.8098E-05	0.702292	0.00092488	0.002132	2.63511307	
ELECTROLESSCOPPER	COPPER CHLORIDE(I)	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	COPPER SULFATE; OR CUPRIC SULFA	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	HYDROCHLORIC ACID	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	SODIUM HYDROXIDE	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	ETHYLENEDIAMINE-TETRAACETIC ACI	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	METHANOL	0.011293315	1.71228E-05	0.664448	0.00092488	0.002132	19.2712449	
ELECTROLESSCOPPER	POTASSIUM CYANIDE	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	POTASSIUM-SODIUM TARTRATE	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	SODIUM CARBONATE	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	TARTARIC ACID	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	SODIUM CYANIDE	0.011293315	SALT	SALT	0.00092488	0.002132	0	
ELECTROLESSCOPPER	SULFURIC ACID	0.011293315	SALT	SALT	0.00092488	0.002132	0	
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ANTI-TARNISH	METHANOL	0.011293315	1.71228E-05	0.60589	0.0048318	0.018883	12.9838096	
ANTI-TARNISH	SULFURIC ACID	0.011293315	SALT	SALT	0.0048318	0.018883	0	
ANTI-TARNISH	ISOPROPYL ALCOHOL, 2-PROPANOL	0.011293315	1.17857E-05	0.416331	0.0048318	0.018883	41.2634548	
ANTI-TARNISH	POTASSIUM HYDROXIDE	0.011293315	SALT	SALT	0.0048318	0.018883	0	
ANTI-TARNISH	BENZOTRIAZOLE	0.011293315	1.06295E-05	0.376127	0.0048318	0.018883	0.04528444	
ANTI-TARNISH	M-NITROBENZENE SULFONIC ACID	0.011293315	SALT	SALT	0.0048318	0.018883	0	
ANTI-TARNISH	2-ETHOXYETHANOL	0.011293315	1.02461E-05	0.362561	0.0048318	0.018883	536.539783	

AEROSOLS FROM SPARGED TANK - AEROSOL GENERATION AND TRANSPORT

BATHS	CHEMICALS	FT	FA	FD	m/min/m2 RA	cm KLW	M/MB	fIE	mg/min F.Y. A
MICROETCH	POTASSIUM BISULFATE	0.91273715	1.13208	1	0.01553276	SALT	SALT	0.0113176	0.126039
MICROETCH	PEROXYMONOSULFURIC ACID, OR PO	0.91273715	1.13208	1	0.01553276	SALT	SALT	0.0113176	0.235638
MICROETCH	POTASSIUM SULFATE	0.91273715	1.13208	1	0.01553276	SALT	SALT	0.0113176	0.175359
MICROETCH	MAGNESIUM CARBONATE	0.91273715	1.13208	1	0.01553276	SALT	SALT	0.0113176	0.01096
MICROETCH	POTASSIUM PERSULFATE	0.91273715	1.13208	1	0.01553276	SALT	SALT	0.0113176	0.089506
MICROETCH	SULFURIC ACID	0.91273715	1.13208	1	0.01553276	SALT	SALT	0.0113176	1.108048
MICROETCH	HYDROGEN PEROXIDE	0.91273715	1.13208	1	0.01553276	SALT	SALT	0.0113176	0.181843
MICROETCH	SODIUM HYDROXIDE	0.91273715	1.13208	1	0.01553276	SALT	SALT	0.0113176	0.002754
MICROETCH	COPPER SULFATE; OR CUPRIC SULFA	0.91273715	1.13208	1	0.01553276	SALT	SALT	0.0113176	0.004567
MICROETCH	ETHYLENE GLYCOL	0.91273715	1.13208	1	0.01553276	8.17E-10	0.00616779	0.0113176	2.87E-05
ELECTROLESSCOPPER	FORMALDEHYDE	0.875679845	1.13208	1	0.01047968	1.42E-07	0.3196596	0.0672674	0.056662
ELECTROLESSCOPPER	COPPER CHLORIDE(I)	0.875679845	1.13208	1	0.01047968	SALT	SALT	0.0672674	0.363165
ELECTROLESSCOPPER	COPPER SULFATE; OR CUPRIC SULFA	0.875679845	1.13208	1	0.01047968	SALT	SALT	0.0672674	0.378908
ELECTROLESSCOPPER	HYDROCHLORIC ACID	0.875679845	1.13208	1	0.01047968	SALT	SALT	0.0672674	0.026057
ELECTROLESSCOPPER	SODIUM HYDROXIDE	0.875679845	1.13208	1	0.01047968	SALT	SALT	0.0672674	0.553162
ELECTROLESSCOPPER	ETHYLENEDIAMINE-TETRAACETIC ACI	0.875679845	1.13208	1	0.01047968	6.30E-05	SALT	0.0672674	2.453671
ELECTROLESSCOPPER	METHANOL	0.875679845	1.13208	1	0.01047968	5.83E-08	0.00678623	0.0672674	0.008797
ELECTROLESSCOPPER	POTASSIUM CYANIDE	0.875679845	1.13208	1	0.01047968	SALT	SALT	0.0672674	0.012106
ELECTROLESSCOPPER	POTASSIUM-SODIUM TARTRATE	0.875679845	1.13208	1	0.01047968	SALT	SALT	0.0672674	1.706713
ELECTROLESSCOPPER	SODIUM CARBONATE	0.875679845	1.13208	1	0.01047968	SALT	SALT	0.0672674	0.002714
ELECTROLESSCOPPER	TARTARIC ACID	0.875679845	1.13208	1	0.01047968	1.00E-06	SALT	0.0672674	0.05594
ELECTROLESSCOPPER	SODIUM CYANIDE	0.875679845	1.13208	1	0.01047968	SALT	SALT	0.0672674	0.01254
ELECTROLESSCOPPER	SULFURIC ACID	0.875679845	1.13208	1	0.01047968	SALT	SALT	0.0672674	0.062427
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ELECTROLESSCOPPER									
ELECTROLE									

AIR TRANSPORT MODELS: NON-CONVEYORIZED NON-FORMALDEHYDE ELECTROLESS COPPER

OPEN TANK VOLATILIZATION - SURFACE DESORPTION

BATHS	CHEMICALS	temp corrected				Resistance Check			Lab Tech mg/day mg/day Dermal exposure
		mg/L m conc In	atm m3/mol HY	unilless HY	cm/sec kg	mg/min Fy.O	Liquid Side s/cm HV/KL	Gas Side s/cm 1/kg	
MICROETCH	POTASSIUM PERSULFATE	9800	SALT	SALT	2.860E-01	0	SALT	3.48609937	5.9878 0.00949543
MICROETCH	SULFURIC ACID	20240	SALT	SALT	3.527E-01	0	SALT	2.83550777	12.36664 0.019610971
MICROETCH	HYDROGEN PEROXIDE	16150	SALT	SALT	4.593E-01	0	SALT	2.17743095	9.86765 0.015648082
MICROETCH	SODIUM HYDROXIDE	300	SALT	SALT	4.392E-01	0	SALT	2.27675445	0.1833 0.000290676
MICROETCH	COPPER SULFATE, OR CUPRIC SULF	500	SALT	SALT	3.180E-01	0	SALT	3.14425296	0.3055 0.000484461
CATALYST	HYDROCHLORIC ACID	2980	SALT	SALT	4.508E-01	0	SALT	2.21975053	1.80856 0.002868008
CATALYST	STANNOUS CHLORIDE	9480	SALT	SALT	3.072E-01	0	SALT	3.25491132	5.79228 0.009185376
POSTDIP	HYDROCHLORIC ACID								
ACCELERATOR	SODIUM CHLORIDE	4520	SALT	SALT	3.591E-01	0	SALT	2.78456443	2.76172 0.004379525
ELECTROLESCOPPER	COPPER SULFATE, OR CUPRIC SULF	22400	SALT	SALT	2.960E-01	0	SALT	3.37871969	13.6864 0.021703841
ELECTROLESCOPPER	SULFURIC ACID	2560	SALT	SALT	3.282E-01	0	SALT	3.04695139	1.56416 0.002480439
ELECTROLESCOPPER	SODIUM HYDROXIDE								
ANTI-TARNISH	ISOPROPYL ALCOHOL, 2-PROPANOL	2020	7.89E-06	0.0003225	3.955E-01	38.295607	0.5374764	2.52865703	1.097345987 0.001740167
ANTI-TARNISH	POTASSIUM HYDROXIDE	300	SALT	SALT	4.023E-01	0	SALT	2.48598824	0.1833 0.000290676

SPARGED TANK VOLATILIZATION - BUBBLE DESORPTION

BATHS	CHEMICALS	temp corrected									
		cm/s	cm2/s	Dy	cm/min	min	lb	cm2/cm3	mg/min	Fy.S	
MICROETCH	POTASSIUM PERSULFATE	1.129E-02	SALT	SALT	4.183E-03	4.459E-02	0				
MICROETCH	SULFURIC ACID	1.129E-02	SALT	SALT	4.183E-03	4.459E-02	0				
MICROETCH	HYDROGEN PEROXIDE	1.129E-02	SALT	SALT	4.183E-03	4.459E-02	0				
MICROETCH	SODIUM HYDROXIDE	1.129E-02	SALT	SALT	4.183E-03	4.459E-02	0				
MICROETCH	COPPER SULFATE, OR CUPRIC SULF	1.129E-02	SALT	SALT	4.183E-03	4.459E-02	0				
MICROETCH	COPPER SULFATE, OR CUPRIC SULF	1.129E-02	SALT	SALT	4.862E-03	3.344E-02	0				
ELECTROLESCOPPER	SULFURIC ACID	1.129E-02	SALT	SALT	4.862E-03	3.344E-02	0				
ELECTROLESCOPPER	SODIUM HYDROXIDE										
ELECTROLESCOPPER	ISOPROPYL ALCOHOL, 2-PROPANOL	1.129E-02	1.177E-05	3.796E-01	4.183E-03	4.459E-02	35.046473				
ANTI-TARNISH	POTASSIUM HYDROXIDE	1.129E-02	SALT	SALT	4.183E-03	4.459E-02	0				
ANTI-TARNISH											

AEROSOLS FROM SPARGED TANK - AEROSOL GENERATION AND TRANSPORT

BATHS	CHEMICALS	mg/min									
		FT	FA	FD	RA	cm	MUMB	fie	mg/min	FY.A	
MICROETCH	POTASSIUM PERSULFATE	9.418E-01	1.132E+00	1.000E+00	2.340E-02	SALT	SALT	7.183E-03	0.066804		
MICROETCH	SULFURIC ACID	9.418E-01	1.132E+00	1.000E+00	2.340E-02	SALT	SALT	7.183E-03	0.117318		
MICROETCH	HYDROGEN PEROXIDE	9.418E-01	1.132E+00	1.000E+00	2.340E-02	SALT	SALT	7.183E-03	0.093611		
MICROETCH	SODIUM HYDROXIDE	9.418E-01	1.132E+00	1.000E+00	2.340E-02	SALT	SALT	7.183E-03	0.001739		
MICROETCH	COPPER SULFATE, OR CUPRIC SULF	9.418E-01	1.132E+00	1.000E+00	2.340E-02	SALT	SALT	7.183E-03	0.002898		
ELECTROLESCOPPER	COPPER SULFATE, OR CUPRIC SULF	1.706E+00	1.132E+00	1.000E+00	3.662E-02	SALT	SALT	1.499E-02	0.270948		
ELECTROLESCOPPER	SULFURIC ACID	1.706E+00	1.132E+00	1.000E+00	3.662E-02	SALT	SALT	1.499E-02	0.030966		
ELECTROLESCOPPER	SODIUM HYDROXIDE										
ELECTROLESCOPPER	ISOPROPYL ALCOHOL, 2-PROPANOL	8.081E-01	1.132E+00	1.000E+00	2.007E-02	1.139E-06	1.060E-01	6.163E-03	0.022895		
ANTI-TARNISH	POTASSIUM HYDROXIDE	8.081E-01	1.132E+00	1.000E+00	2.007E-02	SALT	SALT	6.163E-03	0.001492		

AIR TRANSPORT MODELS - NON-CONVEYORIZED TIN PALLADIUM

OPEN TANK VOLATILIZATION - SURFACE DESORPTION

BATHS	CHEMICALS	mg/L	Chem conc in bath	temp corrected air m3/mol	unlless HY	cm/sec	mg/min Fy.O	Liquid Sid s/cm	Gas Side s/cm	Resistance Check 1kg	VERIFY OK ?
CLEANER/CONDITIONER	POTASSIUM CARBONATE	6160	SALT	2.75758E-07	9.6997E-06	3.015E-01	0	SALT	3.31692475	SALT	OK
CLEANER/CONDITIONER	ETHANOLAMINE	20000	SALT	2.75758E-07	3.628E-01	14.57316	0.016164	0.016164	2.7582944	OK	OK
CLEANER/CONDITIONER	TRIETHANOLAMINE, OR 2,2,2-NIT	15250	SALT	SALT	2.967E-01	0	SALT	3.3688436	SALT	0.002	0.014
CLEANER/CONDITIONER	ISOPROPYL ALCOHOL, 2-PROPA	2040	SALT	5.43932E-05	0.00191307	3.639E-01	294.3855	3.188447	2.7477646	NOT OK	0.013
CLEANER/CONDITIONER											
CLEANER/CONDITIONER											
CLEANER/CONDITIONER											
CLEANER/CONDITIONER											
CLEANER/CONDITIONER											
PRE DIP	SODIUM BISULFATE	46500	SALT	SALT	SALT	3.215E-01	0	SALT	3.11049189	SALT	0.344
PRE DIP	SODIUM CHLORIDE	360000	SALT	SALT	SALT	3.793E-01	0	SALT	2.63625207	SALT	2.660
PRE DIP	HYDROCHLORIC ACID	10300	SALT	SALT	SALT	4.292E-01	0	SALT	2.33008213	SALT	0.076
CATALYST	SODIUM BISULFATE	42870	SALT	SALT	SALT	3.101E-01	0	SALT	3.22438708	SALT	0.317
CATALYST	SODIUM CHLORIDE	653000	SALT	SALT	SALT	3.658E-01	0	SALT	2.73782228	SALT	4.828
CATALYST	HYDROCHLORIC ACID	22900	SALT	SALT	SALT	4.140E-01	0	SALT	2.41540218	SALT	0.169
CATALYST	STANNOUS CHLORIDE	31800	SALT	SALT	SALT	2.823E-01	0	SALT	3.54160234	SALT	0.235
CATALYST	PALLADIUM	980	SALT	SALT	SALT	3.183E-01	0	SALT	3.14127185	SALT	0.087
CATALYST	PALLADIUM CHLORIDE	600	SALT	SALT	SALT	2.861E-01	0	SALT	3.49477107	SALT	0.045
CATALYST	VANILIN	1500	SALT	SALT	SALT	2.952E-01	0.000894	0.001461	3.38810482	OK	0.002
CATALYST	1,3-BENZENEDIOL	730	SALT	SALT	SALT	3.168E-01	0	SALT	3.16481211	SALT	0.008
ACCELERATOR	FLUOBORIC ACID	18900	SALT	SALT	SALT	3.249E-01	1.763922	0.002093	3.0615931	OK	0.140
ACCELERATOR	COPPER SULFATE; OR CUPRIC S	810	SALT	SALT	SALT	2.859E-01	0	SALT	3.5029733	SALT	0.006
ACCELERATOR	COPPER CHLORIDE(I)	2350	SALT	SALT	SALT	3.159E-01	0	SALT	3.16548304	SALT	0.019
ACCELERATOR	SULFURIC ACID	930	SALT	SALT	SALT	3.168E-01	0	SALT	3.15900409	SALT	0.007
ACCELERATOR	SODIUM HYDROXIDE	29000	SALT	SALT	SALT	3.942E-01	0	SALT	2.53650395	SALT	0.214
ACCELERATOR	POTASSIUM CARBONATE	316000	SALT	SALT	SALT	2.941E-01	0	SALT	3.40067689	SALT	2.350
ACCELERATOR	ETHANOLAMINE	11900	SALT	1.51064E-07	5.9816E-06	3.535E-01	5.37778	0.009303	2.8248971	OK	0.008
ACCELERATOR	LITHIUM HYDROXIDE	20300	SALT	SALT	SALT	3.892E-01	0	SALT	2.56913498	SALT	15.042
ACCELERATOR	SODIUM GLUCONATE	1173	SALT	SALT	SALT	2.972E-01	0	SALT	3.42020616	SALT	0.009
MICROETCH	COPPER SULFATE; OR CUPRIC S	13300	SALT	SALT	SALT	2.997E-01	0	SALT	3.33668131	SALT	0.098
MICROETCH	SULFURIC ACID	20900	SALT	SALT	SALT	3.323E-01	0	SALT	3.00904131	SALT	0.154
MICROETCH	HYDROGEN PEROXIDE	17500	SALT	SALT	SALT	4.328E-01	0	SALT	2.31069008	SALT	12.968
MICROETCH	SODIUM PERSULFATE	151000	SALT	SALT	SALT	2.768E-01	0	SALT	3.61109365	SALT	1.116
ACID DIP	SULFURIC ACID	191400	SALT	SALT	SALT	3.251E-01	0	SALT	3.07572835	SALT	141.827

Line Operator	mg/day	Lab Tech	mg/day
Dermal exposure	4.565	Dermal exposure	0.046
			0.014
			0.002
			0.013

34.531	266.760	7.632	31.767	483.873	16.969	23.564	0.711	0.445	0.250	0.812	14.005	0.600	1.890	0.689	21.489	235.638	0.837	15.042	0.009	9.855	15.487	12.968	111.891	141.827
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SPARGED TANK VOLATILIZATION - BUBBLE DESORPTION

BATHS	CHEMICALS	cm/s	KOL.02	cm2/s	Dy	temp corrected cm/min	KOL.V	lb	cm2/cm3	mg/min Fy.S
MICROETCH	COPPER SULFATE; OR CUPRIC S	1.129E-02	SALT	SALT	0.052765	0.035156	0			0
MICROETCH	SULFURIC ACID	1.129E-02	SALT	SALT	0.052765	0.035156	0			0
MICROETCH	HYDROGEN PEROXIDE	1.129E-02	SALT	SALT	0.052765	0.035156	0			0
MICROETCH	SODIUM PERSULFATE	1.129E-02	SALT	SALT	0.052765	0.035156	0			0

AEROSOLS FROM SPARGED TANK - AEROSOL GENERATION AND TRANSPORT

BATHS	CHEMICALS	FT	FA	FD	RA	cm	ml/min/m2	mg/min Fy.A
MICROETCH	COPPER SULFATE; OR CUPRIC S	8.034E-01	1.132E+00	1.000E+00	1.766E-02	SALT	6.876E-03	0.073797
MICROETCH	SULFURIC ACID	8.034E-01	1.132E+00	1.000E+00	1.766E-02	SALT	6.876E-03	0.115967
MICROETCH	HYDROGEN PEROXIDE	8.034E-01	1.132E+00	1.000E+00	1.766E-02	SALT	6.876E-03	0.097102
MICROETCH	SODIUM PERSULFATE	8.034E-01	1.132E+00	1.000E+00	1.766E-02	SALT	6.876E-03	0.837849

AIR TRANSPORT MODELS - CONVEYORIZED TIN PALLADIUM

OPEN TANK VOLATILIZATION - SURFACE DESORPTION

BATHS	CHEMICALS	Chem conc in bath	temp corrected	unilless	cm/sec	mg/min	Liquid Side	Resistance Check	Line Operator	Lab Tech
CLEANER/CONDITIONER	POTASSIUM CARBONATE	6160	SALT	HY	2.36E-01	0	SALT	4.2237128	mg/day	mg/day
CLEANER/CONDITIONER	ETHANOLAMINE	20000	9.76E-08	3.7349E-06	2.84E-01	11.60416	0.0062249	3.5147077	0.734	0.014
CLEANER/CONDITIONER	TRIETHANOLAMINE OR 2,2,2-NIT	15250	SALT	SALT	2.32E-01	0	SALT	4.2931925	0.103	0.002
CLEANER/CONDITIONER	ISOPROPYL ALCOHOL, 2-PROPA	2040	1.927E-05	0.00073671	2.857E-01	234.4101	1.2278525	3.5006112	0.702	0.013
CLEANER/CONDITIONER										
CLEANER/CONDITIONER										
CLEANER/CONDITIONER										
CLEANER/CONDITIONER										
PRE-DIP	SODIUM BISULFATE	46600	SALT	SALT	2.827E-01	0	SALT	3.5371022	18.611	0.344
PRE-DIP	SODIUM CHLORIDE	360000	SALT	SALT	3.336E-01	0	SALT	2.9978195	143.773	2.660
PRE-DIP	HYDROCHLORIC ACID	10300	SALT	SALT	3.774E-01	0	SALT	2.6466577	4.113	0.076
CATALYST	SODIUM BISULFATE	42870	SALT	SALT	2.064E-01	0	SALT	4.8438153	9.943	0.317
CATALYST	SODIUM CHLORIDE	653000	SALT	SALT	2.436E-01	0	SALT	4.1083051	151.460	4.826
CATALYST	HYDROCHLORIC ACID	22300	SALT	SALT	2.756E-01	0	SALT	3.8285218	5.311	0.169
CATALYST	STANNOUS CHLORIDE	31600	SALT	SALT	1.879E-01	0	SALT	5.3286504	7.375	0.235
CATALYST	PALLADIUM	960	SALT	SALT	2.119E-01	0	SALT	4.7188956	0.223	0.007
CATALYST	PALLADIUM CHLORIDE	600	SALT	SALT	1.905E-01	0	SALT	5.2495979	0.139	0.004
CATALYST	VANILIN	1300	2.6143E-07	8.1696E-06	1.905E-01	2.554247	0.0136094	5.0697593	0.078	0.002
CATALYST	1,3-BENZENEDIOL	730	SALT	SALT	2.103E-01	0	SALT	4.7543192	0.294	0.008
ACCELERATOR	FLUOBORIC ACID	18900	1.5872E-07	5.1421E-06	2.645E-01	13.34041	0.0085702	3.7809755	5.028	0.140
ACCELERATOR	COPPER SULFATE; OR CUPRIC S	810	SALT	SALT	2.372E-01	0	SALT	4.2979871	0.216	0.006
ACCELERATOR	COPPER CHLORIDE(I)	2350	SALT	SALT	2.575E-01	0	SALT	3.8839021	0.678	0.019
ACCELERATOR	SULFURIC ACID	930	SALT	SALT	2.580E-01	0	SALT	3.8759527	0.247	0.007
ACCELERATOR	SODIUM HYDROXIDE	29000	SALT	SALT	3.213E-01	0	SALT	3.1121737	7.716	0.214
ACCELERATOR	POTASSIUM CARBONATE	316000	SALT	SALT	2.397E-01	0	SALT	4.1724741	84.605	2.350
ACCELERATOR	ETHANOLAMINE	11900	7.0543E-07	2.284E-05	2.881E-01	40.67174	0.0380899	3.4704268	0.300	0.008
ACCELERATOR	LITHIUM HYDROXIDE	20300	SALT	SALT	3.172E-01	0	SALT	3.1522105	5.401	0.150
ACCELERATOR	SODIUM GLUCONATE	11.73	SALT	SALT	2.383E-01	0	SALT	4.1964357	0.003	0.000
MICROETCH	COPPER SULFATE; OR CUPRIC S	13300	SALT	SALT	2.639E-01	0	SALT	3.7899764	3.848	0.098
MICROETCH	SULFURIC ACID	20900	SALT	SALT	2.926E-01	0	SALT	3.4178254	6.047	0.154
MICROETCH	HYDROGEN PEROXIDE	17500	SALT	SALT	3.810E-01	0	SALT	2.6246018	5.063	0.129
MICROETCH	SODIUM PERSULFATE	151000	SALT	SALT	2.438E-01	0	SALT	4.1016677	43.687	1.116
ACID DIP	SULFURIC ACID	191400	SALT	SALT	2.954E-01	0	SALT	3.3846709	95.769	1.414

SPARGED TANK VOLATILIZATION - BUBBLE DESORPTION

BATHS	CHEMICALS	cm/s	KOL02	temp corrected	cm/min	min	cm2/cm3	mg/min
MICROETCH	COPPER SULFATE; OR CUPRIC S	1.129E-02	SALT	0.005276499	0.035156	0	0	0
MICROETCH	SULFURIC ACID	1.129E-02	SALT	0.005276499	0.035156	0	0	0
MICROETCH	HYDROGEN PEROXIDE	1.129E-02	SALT	0.005276499	0.035156	0	0	0
MICROETCH	SODIUM PERSULFATE	1.129E-02	SALT	0.005276499	0.035156	0	0	0

AEROSOLS FROM SPARGED TANK - AEROSOL GENERATION AND TRANSPORT

BATHS	CHEMICALS	FT	FA	FD	RA	cm	M/M/B	RE	mg/min
MICROETCH	COPPER SULFATE; OR CUPRIC S	8.034E-01	1.132E+00	1.000E+00	1.766E-02	SALT	SALT	6.876E-03	0.073797
MICROETCH	SULFURIC ACID	8.034E-01	1.132E+00	1.000E+00	1.766E-02	SALT	SALT	6.876E-03	0.115967
MICROETCH	HYDROGEN PEROXIDE	8.034E-01	1.132E+00	1.000E+00	1.766E-02	SALT	SALT	6.876E-03	0.097102
MICROETCH	SODIUM PERSULFATE	8.034E-01	1.132E+00	1.000E+00	1.766E-02	SALT	SALT	6.876E-03	0.837849

OPEN TANK VOLATILIZATION SHEET: NON-CONVEYORIZED ORGANIC PALLADIUM

BATHS	BATH ID	CHEM ID	CHEMICALS	Chem conc in bath mg/L	temp corrected atm.m ³ /mol	unitless H _y	cm/sec k _g	mg/min F _{y,o}
CONDITIONER	1	51	SODIUM CARBONATE	9310	SALT	SALT	2.576E-01	0
MICROETCH	2	58	SODIUM PERSULFATE	75000	SALT	SALT	2.346E-01	0
MICROETCH	2	50	SODIUM BISULFATE	75000	SALT	SALT	2.694E-01	0
PRE-DIP	3	24	HYDROCHLORIC ACID	3125	SALT	SALT	3.347E-01	0
CONDUCTOR	4	24	HYDROCHLORIC ACID	3000	SALT	SALT	3.597E-01	0
CONDUCTOR	4	56	SODIUM HYPOPHOSPHITE	3060	SALT	SALT	2.885E-01	0
POST-DIP	5	51	SODIUM CARBONATE	12650	SALT	SALT	2.768E-01	0
POST-DIP	5	66	TRISODIUM CITRATE 5.5-HYD	12650	SALT	SALT	2.311E-01	0

OPEN TANK VOLATILIZATION SHEET: CONVEYORIZED ORGANIC PALLADIUM

<u>BATHS</u>	<u>BATH ID</u>	<u>CHEM ID</u>	<u>CHEMICALS</u>	<u>Chem conc in bath</u> mg/L	temp corrected atm.m ³ /mol	<u>H_y</u>	unitless <u>H_y</u>	cm/sec <u>k_g</u>	mg/min <u>F_{y,o}</u>
CONDITIONER	1	51	SODIUM CARBONATE	9310	SALT	SALT	SALT	2.084E-01	0
MICROETCH	2	58	SODIUM PERSULFATE	75000	SALT	SALT	SALT	2.199E-01	0
MICROETCH	2	50	SODIUM BISULFATE	75000	SALT	SALT	SALT	2.525E-01	0
PRE-DIP	3	24	HYDROCHLORIC ACID	3125	SALT	SALT	SALT	4.051E-01	0
CONDUCTOR	4	24	HYDROCHLORIC ACID	3000	SALT	SALT	SALT	2.396E-01	0
CONDUCTOR	4	56	SODIUM HYPOPHOSPHITE	3060	SALT	SALT	SALT	1.922E-01	0
POST-DIP	5	51	SODIUM CARBONATE	12650	SALT	SALT	SALT	2.569E-01	0
POST-DIP	5	66	TRISODIUM CITRATE 5.5-HYD	12650	SALT	SALT	SALT	2.144E-01	0

OPEN TANK VOLATILIZATION SHEET: CONVEYORIZED CARBON

<u>BATHS</u>	<u>BATH ID</u>	<u>CHEM ID</u>	<u>CHEMICALS</u>	mg/L	temp corrected atm.m ³ /mol	unitless	cm/sec	mg/min
				<u>Chem conc in bath</u>	<u>H_y</u>	<u>H_y</u>	<u>k_g</u>	<u>F_{y,o}</u>
CLEANER	1	16	ETHANOLAMINE	12700	1.35834E-07	5.061E-06	2.629E-01	12.66293
CONDITIONER	2	16	ETHANOLAMINE	34500	4.43127E-08	1.798E-06	2.629E-01	12.21822
CARBON BLACK 1	3	42	POTASSIUM HYDROXIDE	20400	SALT	SALT	2.613E-01	0
CARBON BLACK 2	4	42	POTASSIUM HYDROXIDE	20400	SALT	SALT	2.613E-01	0
MICROETCH	5	58	SODIUM PERSULFATE	200000	SALT	SALT	1.868E-01	0
MICROETCH	5	62	SULFURIC ACID	1840	SALT	SALT	2.241E-01	0
MICROETCH	5	10	COPPER SULFATE; OR CUPRI	5000	SALT	SALT	2.021E-01	0
								ConveyORIZED

OPEN TANK VOLATILIZATION SHEET: CONVEYORIZED GRAPHITE

<u>BATHS</u>	<u>BATH ID</u>	<u>CHEM ID</u>	<u>CHEMICALS</u>	<u>Chem conc in bath</u> mg/L	temp corrected atm.m ³ /mol H _y	unitless H _y	cm/sec k _g	mg/min F _{y,o}
CLEANER/CONDITIONER	1	40	POTASSIUM CARBONATE	7390	SALT	SALT	2.699E-01	0
CLEANER/CONDITIONER	1	16	ETHANOLAMINE	19730	1.24601E-07	4.675E-06	3.246E-01	9.652376
CLEANER/CONDITIONER								
CLEANER/CONDITIONER								
CLEANER/CONDITIONER								
GRAPHITE	2	23	GRAPHITE	45500	SALT	SALT	5.237E-01	0
GRAPHITE	2	3	AMMONIA	1950	1.81804E-06	7.362E-05	4.662E-01	21.58228
GRAPHITE								
GRAPHITE								
GRAPHITE								
MICRO ETCH	4	62	SULFURIC ACID	59130	SALT	SALT	2.821E-01	0
MICRO ETCH	4	58	SODIUM PERSULFATE	56890	SALT	SALT	2.351E-01	0
MICRO ETCH	4	36	PEROXYMONOSULFURIC ACI	30090	SALT	SALT	2.569E-01	0
MICRO ETCH	4	10	COPPER SULFATE; OR CUPRI	2670	SALT	SALT	2.544E-01	0

OPEN TANK VOLATILIZATION SHEET: CONVEYORIZED CONDUCTIVE POLYMER

<u>BATHS</u>	<u>BATH ID</u>	<u>CHEM ID</u>	<u>CHEMICALS</u>	<u>Chem conc in bath</u> mg/L	temp corrected atm.m ³ /mol	unitless H _y	cm/sec k _g	mg/min F _{y,o}
MICRO ETCH 1	1	36	PEROXYMONOSULFURIC ACID; O	100000	SALT	SALT	2.910E-01	0
MICRO ETCH 1	1	62	SULFURIC ACID	20000	SALT	SALT	3.195E-01	0
MICRO ETCH 2	2	36	PEROXYMONOSULFURIC ACID; O	100000	SALT	SALT	2.910E-01	0
MICRO ETCH 2	2	62	SULFURIC ACID	20000	SALT	SALT	3.195E-01	0
CLEANER/CONDITIONER	3	51	SODIUM CARBONATE	7500	SALT	SALT	3.028E-01	0
CATALYST	4	38	PHOSPHORIC ACID	2750	SALT	SALT	2.535E-01	0
CATALYST	4	55	SODIUM HYDROXIDE	900	SALT	SALT	3.156E-01	0
CONDUCTIVE POLYMER	5	38	PHOSPHORIC ACID	26850	SALT	SALT	3.014E-01	0
CONDUCTIVE POLYMER	5	43	1H-PYRROLE	3000	SALT	SALT	3.290E-01	0

ConveyORIZED

RECEPTOR INTAKE DOSES FROM NON-CONVEYORIZED PROCESSES

ELECTROLESS COPPER						General Population Inhale DOSE mg/kg.day	Line Operator mg/day Dermal exposure	Lab Tech mg/day
CHEMICALS	mg/min	Total Across Process	Line Operator	Line Operator	Lab Tech			
	FY, TOT	mg/m3	Inhale DOSE	Dermal DOSE				
		Chemical Air Conc.	mg/kg.day	mg/kg.day	mg/kg.day			
AMMONIUM CHLORIDE	0.00E+00	0.00E+00	0.00E+00	8.42E-02	2.07E-03	0.00E+00	7.03E+00	1.73E-01
BENZOTRIAZOLE	1.24E-01	5.54E-03	6.64E-04	2.48E-03	6.10E-05	5.56E-08	2.07E-01	5.09E-03
BORIC ACID	1.71E-01	7.64E-03	9.15E-04	3.27E-02	8.03E-04	7.65E-08	2.73E+00	6.71E-02
COPPER CHLORIDE(I)	7.56E-02	3.38E-03	4.05E-04	4.37E-02	1.07E-03	3.39E-08	3.65E+00	8.98E-02
COPPER SULFATE; OR CUPRIC SULFAT	8.31E-02	3.71E-03	4.45E-04	4.89E-02	1.20E-03	3.72E-08	4.08E+00	1.00E-01
DIMETHYLAMINOBORANE	1.94E+00	8.66E-02	1.04E-02	3.92E-03	9.63E-05	8.67E-07	3.27E-01	8.04E-03
DIMETHYLFORMAMIDE	1.42E+00	6.33E-02	7.58E-03	1.13E-03	2.77E-05	6.34E-07	9.41E-02	2.31E-03
ETHANOLAMINE	9.92E+00	4.44E-01	5.31E-02	1.01E-02	2.49E-04	4.44E-06	8.46E-01	2.08E-02
ETHYLENE GLYCOL	3.33E+00	1.49E-01	1.78E-02	2.46E-03	6.05E-05	1.49E-06	2.05E-01	5.05E-03
ETHYLENEDIAMINE-TETRAACETIC ACID	5.11E-01	2.29E-02	2.74E-03	1.69E-05	4.15E-07	2.29E-07	1.41E-03	3.46E-05
FLUOBORIC ACID	2.20E+00	9.82E-02	1.18E-02	3.92E-01	9.64E-03	9.84E-07	3.28E+01	8.05E-01
FORMALDEHYDE	1.37E+01	6.15E-01	2.63E-02	1.07E-02	2.64E-04	2.64E-06	2.51E+00	6.17E-02
FORMIC ACID	3.51E+01	1.57E+00	1.88E-01	3.48E-02	8.54E-04	1.57E-05	2.90E+00	7.13E-02
HYDROCHLORIC ACID	5.43E-03	2.43E-04	2.91E-05	8.96E-01	2.20E-02	2.43E-09	7.48E+01	1.84E+00
HYDROGEN PEROXIDE	1.66E-01	7.41E-03	8.87E-04	1.30E-01	3.20E-03	7.42E-08	1.09E+01	2.67E-01
HYDROXYACETIC ACID	3.14E-02	1.40E-03	1.68E-04	2.42E-02	5.94E-04	1.41E-08	2.02E+00	4.96E-02
ISOPROPYL ALCOHOL, 2-PROPANOL	5.24E+02	2.34E+01	2.81E+00	3.13E-02	7.68E-04	2.35E-04	2.61E+00	6.42E-02
MAGNESIUM CARBONATE	9.99E-03	4.47E-04	5.35E-05	7.85E-03	1.93E-04	4.47E-09	6.55E-01	1.61E-02
METHANOL	2.31E+02	1.03E+01	1.24E+00	1.13E-02	2.78E-04	1.03E-04	9.43E-01	2.32E-02
p-TOLUENE SULFONIC ACID	0.00E+00	0.00E+00	0.00E+00	3.99E-03	9.79E-05	0.00E+00	3.33E-01	8.18E-03
PALLADIUM	0.00E+00	0.00E+00	0.00E+00	3.73E-02	9.17E-04	0.00E+00	3.12E+00	7.66E-02
POTASSIUM BISULFATE	1.15E-01	5.14E-03	6.15E-04	9.02E-02	2.22E-03	5.15E-08	7.53E+00	1.85E-01
POTASSIUM CYANIDE	2.52E-03	1.13E-04	1.35E-05	1.46E-03	3.58E-05	1.13E-09	1.22E-01	2.99E-03
POTASSIUM HYDROXIDE	2.33E-03	1.04E-04	1.25E-05	5.44E-03	1.34E-04	1.04E-09	4.54E-01	1.12E-02
POTASSIUM PERSULFATE	8.16E-02	3.65E-03	4.37E-04	6.41E-02	1.57E-03	3.65E-08	5.35E+00	1.31E-01
POTASSIUM SULFATE	1.60E-01	7.15E-03	8.56E-04	1.26E-01	3.08E-03	7.16E-08	1.05E+01	2.58E-01
POTASSIUM-SODIUM TARTRATE	3.55E-01	1.59E-02	1.90E-03	2.06E-01	5.05E-03	1.59E-07	1.72E+01	4.22E-01
SODIUM BISULFATE	0.00E+00	0.00E+00	0.00E+00	4.56E-01	1.12E-02	0.00E+00	3.81E+01	9.36E-01
SODIUM CARBONATE	5.65E-04	2.53E-05	3.03E-06	3.27E-04	8.03E-06	2.53E-10	2.73E-02	6.71E-04
SODIUM CHLORITE	0.00E+00	0.00E+00	0.00E+00	2.95E-02	7.25E-04	0.00E+00	2.47E+00	6.06E-02
SODIUM CYANIDE	2.61E-03	1.17E-04	1.40E-05	1.51E-03	3.71E-05	1.17E-09	1.26E-01	3.10E-03
SODIUM HYDROXIDE	1.18E-01	5.26E-03	6.30E-04	8.51E-02	2.09E-03	5.27E-08	7.11E+00	1.75E-01
SODIUM HYPOPHOSPHITE	0.00E+00	0.00E+00	0.00E+00	5.61E-02	1.38E-03	0.00E+00	4.68E+00	1.15E-01
M-NITROBENZENE SULFONIC ACID	9.14E-04	4.09E-05	4.90E-06	8.78E-07	2.16E-08	4.10E-10	7.33E-05	1.80E-06
SODIUM SULFATE	0.00E+00	0.00E+00	0.00E+00	8.26E-02	2.03E-03	0.00E+00	6.89E+00	1.69E-01
STANNOUS CHLORIDE	0.00E+00	0.00E+00	0.00E+00	7.30E-01	1.79E-02	0.00E+00	6.10E+01	1.50E+00
SULFURIC ACID	1.24E+00	5.57E-02	6.67E-03	1.19E+00	2.92E-02	5.58E-07	9.94E+01	2.44E+00
TARTARIC ACID	1.17E-02	5.21E-04	6.24E-05	5.74E-05	1.41E-06	5.22E-09	4.79E-03	1.18E-04
TRIETHANOLAMINE; OR 2,2,2-NITRILOT	0.00E+00	0.00E+00	0.00E+00	3.45E-03	8.48E-05	0.00E+00	2.88E-01	7.08E-03
2-ETHOXYETHANOL	1.46E+03	6.51E+01	7.79E+00	1.37E-01	3.37E-03	6.52E-04	1.14E+01	2.81E-01

NON-FORMALDEHYDE ELECTROLESS COPPER							General Population Inhale DOSE mg/kg.day	Line Operator		Lab Tech
CHEMICALS	mg/min	Total Across Process	Inhale DOSE	Line Operator	Lab Tech	mg/kg.day		mg/day	mg/day	
	FY, TOT	mg/m3	mg/kg.day	Dermal DOSE	D			Dermal exposure		
	Chemical Air Conc.									
COPPER SULFATE; OR CUPRIC SULFAT	2.74E-01	1.22E-02	1.47E-03	1.68E-01	2.66E-04	1.23E-07	1.40E+01	2.22E-02		
HYDROCHLORIC ACID	0.00E+00	0.00E+00	0.00E+00	2.17E-02	3.43E-05	0.00E+00	1.81E+00	2.87E-03		
HYDROGEN PEROXIDE	9.36E-02	4.19E-03	5.01E-04	1.18E-01	1.87E-04	4.19E-08	9.87E+00	1.56E-02		
ISOPROPYL ALCOHOL, 2-PROPANOL	7.34E+01	3.28E+00	3.93E-01	1.31E-02	2.08E-05	3.29E-05	1.10E+00	1.74E-03		
POTASSIUM HYDROXIDE	1.49E-03	6.67E-05	7.99E-06	2.20E-03	3.48E-06	6.68E-10	1.83E-01	2.91E-04		
POTASSIUM PERSULFATE	5.68E-02	2.54E-03	3.04E-04	7.17E-02	1.14E-04	2.54E-08	5.99E+00	9.50E-03		
SODIUM CHLORITE	0.00E+00	0.00E+00	0.00E+00	3.31E-02	5.25E-05	0.00E+00	2.76E+00	4.38E-03		
SODIUM HYDROXIDE	1.74E-03	7.78E-05	9.31E-06	2.20E-03	3.48E-06	7.79E-10	1.83E-01	2.91E-04		
STANNOUS CHLORIDE	0.00E+00	0.00E+00	0.00E+00	6.94E-02	1.10E-04	0.00E+00	5.79E+00	9.19E-03		
SULFURIC ACID	1.48E-01	6.63E-03	7.94E-04	1.67E-01	2.65E-04	6.64E-08	1.39E+01	2.21E-02		

TIN PALLADIUM						General Population Inhale DOSE mg/kg.day	Line Operator Lab Tech		
CHEMICALS	mg/min FY, TOT	Total Across Process mg/m3 Chemical Air Conc.	Inhale DOSE mg/kg.day	Line Operator Dermal DOSE mg/kg.day D	Lab Tech mg/kg.day D		Inhale DOSE mg/kg.day	mg/day	mg/day
								Dermal exposure	Dermal exposure
1,3-BENZENEDIOL	0.00E+00	0.00E+00	0.00E+00	9.72E-03	9.70E-05	0.00E+00	8.12E-01	8.10E-03	
COPPER CHLORIDE(I)	0.00E+00	0.00E+00	0.00E+00	2.26E-02	2.26E-04	0.00E+00	1.89E+00	1.88E-02	
COPPER SULFATE; OR CUPRIC SULFAT	7.38E-02	3.30E-03	3.95E-04	1.25E-01	1.25E-03	3.31E-08	1.05E+01	1.04E-01	
ETHANOLAMINE	2.00E+01	8.92E-01	1.07E-01	2.69E-02	2.68E-04	8.94E-06	2.24E+00	2.24E-02	
FLUOBORIC ACID	1.76E+00	7.89E-02	9.45E-03	1.68E-01	1.67E-03	7.90E-07	1.40E+01	1.40E-01	
HYDROCHLORIC ACID	0.00E+00	0.00E+00	0.00E+00	2.95E-01	2.94E-03	0.00E+00	2.46E+01	2.45E-01	
HYDROGEN PEROXIDE	9.71E-02	4.34E-03	5.20E-04	1.55E-01	1.55E-03	4.35E-08	1.30E+01	1.29E-01	
ISOPROPYL ALCOHOL, 2-PROPANOL	2.94E+02	1.32E+01	1.58E+00	1.61E-02	1.61E-04	1.32E-04	1.34E+00	1.34E-02	
LITHIUM HYDROXIDE	0.00E+00	0.00E+00	0.00E+00	1.80E-01	1.80E-03	0.00E+00	1.50E+01	1.50E-01	
PALLADIUM	0.00E+00	0.00E+00	0.00E+00	8.52E-03	8.50E-05	0.00E+00	7.11E-01	7.09E-03	
PALLADIUM CHLORIDE	0.00E+00	0.00E+00	0.00E+00	5.32E-03	5.31E-05	0.00E+00	4.45E-01	4.43E-03	
POTASSIUM CARBONATE	0.00E+00	0.00E+00	0.00E+00	2.88E+00	2.87E-02	0.00E+00	2.40E+02	2.40E+00	
SODIUM BISULFATE	0.00E+00	0.00E+00	0.00E+00	7.94E-01	7.92E-03	0.00E+00	6.63E+01	6.61E-01	
SODIUM CHLORIDE	0.00E+00	0.00E+00	0.00E+00	8.99E+00	8.97E-02	0.00E+00	7.51E+02	7.49E+00	
SODIUM HYDROXIDE	0.00E+00	0.00E+00	0.00E+00	2.57E-01	2.57E-03	0.00E+00	2.15E+01	2.14E-01	
SODIUM PERSULFATE	8.38E-01	3.75E-02	4.49E-03	1.34E+00	1.34E-02	3.75E-07	1.12E+02	1.12E+00	
STANNOUS CHLORIDE	0.00E+00	0.00E+00	0.00E+00	2.82E-01	2.81E-03	0.00E+00	2.36E+01	2.35E-01	
SULFURIC ACID	1.16E-01	5.19E-03	6.21E-04	1.89E+00	1.89E-02	5.19E-08	1.58E+02	1.58E+00	
TRIETHANOLAMINE; OR 2,2,2-NITRILOT	0.00E+00	0.00E+00	0.00E+00	2.36E-03	2.35E-05	0.00E+00	1.97E-01	1.96E-03	
VANILLIN	8.09E-02	3.62E-03	4.33E-04	2.99E-03	2.99E-05	3.62E-08	2.50E-01	2.49E-03	

ORGANIC PALLADIUM							General Population Inhale DOSE mg/kg.day	Line Operator Lab Tech mg/day mg/day Dermal exposure				
CHEMICALS	mg/min FY, TOT	Total Across Process mg/m3 Chemical Air Conc.	Inhale DOSE mg/kg.day	Line Operator Dermal DOSE mg/kg.day	Lab Tech mg/kg.day							
HYDROCHLORIC ACID	0.00E+00	0.00E+00	0.00E+00	6.39E-02	2.16E-04	0.00E+00	5.33E+00	1.81E-02				
SODIUM BISULFATE	0.00E+00	0.00E+00	0.00E+00	7.82E-01	2.65E-03	0.00E+00	6.53E+01	2.21E-01				
SODIUM CARBONATE	0.00E+00	0.00E+00	0.00E+00	2.29E-01	7.76E-04	0.00E+00	1.91E+01	6.48E-02				
SODIUM HYPOPHOSPHITE	0.00E+00	0.00E+00	0.00E+00	3.19E-02	1.08E-04	0.00E+00	2.67E+00	9.03E-03				
SODIUM PERSULFATE	0.00E+00	0.00E+00	0.00E+00	7.82E-01	2.65E-03	0.00E+00	6.53E+01	2.21E-01				
TRISODIUM CITRATE 5.5-HYDRATE; OR	0.00E+00	0.00E+00	0.00E+00	6.70E-03	2.27E-05	0.00E+00	5.60E-01	1.90E-03				

RECEPTOR INTAKE DOSES FROM CONVEYORIZED PROCESSES

ELECTROLESS COPPER									
CHEMICALS	mg/min FY, TOT	Total Across Process mg/m3 Chemical Air Conc.	Line Operator	Line Operator	Lab Tech	General Population Inhale DOSE mg/kg day	Line Operator	Lab Tech	
			Inhale DOSE	Dermal DOSE			mg/day	mg/day	
			mg/kg day	mg/kg day			Dermal exposure		
AMMONIUM CHLORIDE	0.00E+00	0.00E+00	0.00E+00	2.09E-02	2.07E-03	0.00E+00	1.75E+00	1.73E-01	
BENZOTRIAZOLE	1.32E-01	5.91E-03	0.00E+00	6.30E-04	6.10E-05	5.92E-08	5.26E-02	5.09E-03	
BORIC ACID	2.60E-01	1.16E-02	0.00E+00	9.17E-03	8.03E-04	1.66E-07	7.66E-01	6.71E-02	
COPPER CHLORIDE(I)	3.63E-01	1.62E-02	0.00E+00	9.80E-03	1.07E-03	1.63E-07	8.18E-01	8.98E-02	
COPPER SULFATE, OR CUPRIC SULFATE	3.83E-01	1.71E-02	0.00E+00	1.11E-02	1.20E-03	1.72E-07	9.30E-01	1.00E-01	
DIMETHYLAMINOBORANE	2.95E+00	1.32E-01	0.00E+00	1.10E-03	9.63E-05	1.32E-06	9.18E-02	8.04E-03	
DIMETHYLFORMAMIDE	3.19E+00	1.42E-01	0.00E+00	2.80E-04	2.77E-05	1.43E-06	2.34E-02	2.31E-03	
ETHANOLAMINE	2.23E+01	9.98E-01	0.00E+00	2.52E-03	2.49E-04	1.00E-05	2.10E-01	2.08E-02	
ETHYLENE GLYCOL	6.25E+00	2.79E-01	0.00E+00	6.46E-04	6.05E-05	2.80E-06	5.40E-02	5.05E-03	
ETHYLENEDIAMINE-TETRAACETIC ACID (	2.45E+00	1.10E-01	0.00E+00	3.78E-06	4.15E-07	1.10E-06	3.16E-04	3.46E-05	
FLUOBORIC ACID	2.42E+00	1.08E-01	0.00E+00	9.09E-02	9.64E-03	1.08E-06	7.59E+00	8.05E-01	
FORMALDEHYDE	3.66E+01	1.63E+00	0.00E+00	2.41E-03	2.64E-04	7.02E-06	5.62E-01	6.17E-02	
FORMIC ACID	7.90E+01	3.53E+00	0.00E+00	8.64E-03	8.54E-04	3.54E-05	7.21E-01	7.13E-02	
HYDROCHLORIC ACID	2.61E-02	1.17E-03	0.00E+00	2.23E-01	2.20E-02	1.17E-08	1.86E+01	1.84E+00	
HYDROGEN PEROXIDE	1.82E-01	8.13E-03	0.00E+00	3.65E-02	3.20E-03	8.15E-08	3.05E+00	2.67E-01	
HYDROXYACETIC ACID	7.07E-02	3.16E-03	0.00E+00	6.01E-03	5.94E-04	3.17E-08	5.02E-01	4.96E-02	
ISOPROPYL ALCOHOL, 2-PROPANOL	1.04E+03	4.64E+01	0.00E+00	7.84E-03	7.68E-04	4.65E-04	6.54E-01	6.42E-02	
MAGNESIUM CARBONATE	1.10E-02	4.90E-04	0.00E+00	2.20E-03	1.93E-04	4.91E-09	1.84E-01	1.61E-02	
METHANOL	4.28E+02	1.91E+01	0.00E+00	2.74E-03	2.78E-04	1.92E-04	2.29E-01	2.32E-02	
p-TOLUENE SULFONIC ACID	0.00E+00	0.00E+00	0.00E+00	9.91E-04	9.79E-05	0.00E+00	8.27E-02	8.18E-03	
PALLADIUM	0.00E+00	0.00E+00	0.00E+00	9.28E-03	9.17E-04	0.00E+00	7.75E-01	7.66E-02	
POTASSIUM BISULFATE	1.26E-01	5.64E-03	0.00E+00	2.53E-02	2.22E-03	5.65E-08	2.11E+00	1.85E-01	
POTASSIUM CYANIDE	1.21E-02	5.41E-04	0.00E+00	3.27E-04	3.58E-05	5.42E-09	2.73E-02	2.98E-03	
POTASSIUM HYDROXIDE	2.54E-03	1.13E-04	0.00E+00	1.36E-03	1.34E-04	1.14E-09	1.14E-01	1.12E-02	
POTASSIUM PERSULFATE	8.95E-02	4.00E-03	0.00E+00	1.80E-02	1.57E-03	4.01E-08	1.50E+00	1.31E-01	
POTASSIUM SULFATE	1.75E-01	7.84E-03	0.00E+00	3.52E-02	3.08E-03	7.86E-08	2.94E+00	2.58E-01	
POTASSIUM-SODIUM TARTRATE	1.71E+00	7.63E-02	0.00E+00	4.60E-02	5.05E-03	7.65E-07	3.84E+00	4.22E-01	
SODIUM BISULFATE	0.00E+00	0.00E+00	0.00E+00	1.13E-01	1.12E-02	0.00E+00	9.47E+00	9.36E-01	
SODIUM CARBONATE	2.71E-03	1.21E-04	0.00E+00	7.32E-05	8.03E-06	1.22E-09	6.11E-03	6.71E-04	
SODIUM CHLORITE	0.00E+00	0.00E+00	0.00E+00	6.84E-03	7.25E-04	0.00E+00	5.71E-01	6.06E-02	
SODIUM CYANIDE	1.25E-02	5.61E-04	0.00E+00	3.38E-04	3.71E-05	5.62E-09	2.82E-02	3.10E-03	
SODIUM HYDROXIDE	5.56E-01	2.49E-02	0.00E+00	1.96E-02	2.09E-03	2.49E-07	1.64E+00	1.75E-01	
SODIUM HYPOPHOSPHITE	0.00E+00	0.00E+00	0.00E+00	1.30E-02	1.38E-03	0.00E+00	1.09E+00	1.15E-01	
M-NITROBENZENE SULFONIC ACID	9.96E-04	4.46E-05	0.00E+00	2.23E-07	2.16E-08	4.46E-10	1.86E-05	1.80E-06	
SODIUM SULFATE	0.00E+00	0.00E+00	0.00E+00	2.05E-02	2.03E-03	0.00E+00	1.71E+00	1.69E-01	
STANNOUS CHLORIDE	0.00E+00	0.00E+00	0.00E+00	1.82E-01	1.79E-02	0.00E+00	1.52E+01	1.50E+00	
SULFURIC ACID	1.41E+00	6.31E-02	0.00E+00	3.20E-01	2.92E-02	6.33E-07	2.67E+01	2.44E+00	
TARTARIC ACID	5.59E-02	2.50E-03	0.00E+00	1.29E-05	1.41E-06	2.51E-08	1.07E-03	1.18E-04	
TRIETHANOLAMINE; OR 2,2,2-NITRILOTRI	0.00E+00	0.00E+00	0.00E+00	8.58E-04	8.48E-05	0.00E+00	7.16E-02	7.08E-03	
2-ETHOXYETHANOL	1.55E+03	6.94E+01	0.00E+00	3.48E-02	3.37E-03	6.95E-04	2.90E+00	2.81E-01	

Note: All Formaldehyde exposures are calculated as Lifetime Average Daily Dosages (LADDs)

TIN PALLADIUM									
CHEMICALS	mg/min	Total Across Process	Line Operator	Line Operator	Lab Tech	General Population	Line Operator	Lab Tech	
	FY, TOT	mg/m3	Inhale DOSE	Dermal DOSE	Inhale DOSE				
	Chemical Air Conc.	mg/kg day	mg/kg day	mg/kg day	mg/kg day				
1,3-BENZENEDIOL	0.00E+00	0.00E+00	0.00E+00	3.04E-03	9.70E-05	0.00E+00	2.54E-01	8.10E-03	
COPPER CHLORIDE(I)	0.00E+00	0.00E+00	0.00E+00	8.13E-03	2.26E-04	0.00E+00	6.78E-01	1.88E-02	
COPPER SULFATE; OR CUPRIC SULFATE	3.42E-01	1.53E-02	0.00E+00	4.87E-02	1.25E-03	1.53E-07	4.06E+00	1.04E-01	
ETHANOLAMINE	5.23E+01	2.34E+00	0.00E+00	1.24E-02	2.68E-04	2.34E-05	1.03E+00	2.24E-02	
FLUOBORIC ACID	1.33E+01	5.96E-01	0.00E+00	6.02E-02	1.67E-03	5.98E-06	5.03E+00	1.40E-01	
HYDROCHLORIC ACID	0.00E+00	0.00E+00	0.00E+00	1.13E-01	2.94E-03	0.00E+00	9.42E+00	2.45E-01	
HYDROGEN PEROXIDE	4.50E-01	2.01E-02	0.00E+00	6.06E-02	1.55E-03	2.02E-07	5.06E+00	1.29E-01	
ISOPROPYL ALCOHOL, 2-PROPANOL	2.34E+02	1.05E+01	0.00E+00	8.41E-03	1.61E-04	1.05E-04	7.02E-01	1.34E-02	
LITHIUM HYDROXIDE	0.00E+00	0.00E+00	0.00E+00	6.47E-02	1.80E-03	0.00E+00	5.40E+00	1.50E-01	
PALLADIUM	0.00E+00	0.00E+00	0.00E+00	2.67E-03	8.50E-05	0.00E+00	2.23E-01	7.09E-03	
PALLADIUM CHLORIDE	0.00E+00	0.00E+00	0.00E+00	1.67E-03	5.31E-05	0.00E+00	1.39E-01	4.43E-03	
POTASSIUM CARBONATE	0.00E+00	0.00E+00	0.00E+00	1.04E+00	2.87E-02	0.00E+00	8.70E+01	2.40E+00	
SODIUM BISULFATE	0.00E+00	0.00E+00	0.00E+00	3.42E-01	7.92E-03	0.00E+00	2.86E+01	6.61E-01	
SODIUM CHLORIDE	0.00E+00	0.00E+00	0.00E+00	3.54E+00	8.97E-02	0.00E+00	2.95E+02	7.49E+00	
SODIUM HYDROXIDE	0.00E+00	0.00E+00	0.00E+00	9.24E-02	2.57E-03	0.00E+00	7.72E+00	2.14E-01	
SODIUM PERSULFATE	3.88E+00	1.74E-01	0.00E+00	5.23E-01	1.34E-02	1.74E-06	4.37E+01	1.12E+00	
STANNOUS CHLORIDE	0.00E+00	0.00E+00	0.00E+00	8.83E-02	2.81E-03	0.00E+00	7.38E+00	2.35E-01	
SULFURIC ACID	5.38E-01	2.40E-02	0.00E+00	1.22E+00	1.89E-02	2.41E-07	1.02E+02	1.58E+00	
TRIETHANOLAMINE; OR 2,2,2-NITRILOTRI	0.00E+00	0.00E+00	0.00E+00	1.23E-03	2.35E-05	0.00E+00	1.03E-01	1.96E-03	
VANILLIN	2.55E+00	1.14E-01	0.00E+00	9.37E-04	2.99E-05	1.14E-06	7.82E-02	2.49E-03	

ORGANIC PALLADIUM									
CHEMICALS	mg/min FY, TOT	Total Across Process mg/m3 Chemical Air Conc.	Line Operator	Line Operator	Lab Tech	General Population Inhale DOSE mg/kg day	Line Operator mg/day Dermal exposure	Lab Tech mg/day Dermal exposure	
			Inhale DOSE	Dermal DOSE					
			mg/kg day	mg/kg day	mg/kg day				
			↓	↓	↓				
HYDROCHLORIC ACID	0.00E+00	0.00E+00	0.00E+00	1.77E-02	2.16E-04	0.00E+00	1.48E+00	1.81E-02	
SODIUM BISULFATE	0.00E+00	0.00E+00	0.00E+00	1.49E-01	2.65E-03	0.00E+00	1.24E+01	2.21E-01	
SODIUM CARBONATE	0.00E+00	0.00E+00	0.00E+00	4.77E-02	7.76E-04	0.00E+00	3.98E+00	6.48E-02	
SODIUM HYPOPHOSPHITE	0.00E+00	0.00E+00	0.00E+00	6.18E-03	1.08E-04	0.00E+00	5.16E-01	9.03E-03	
SODIUM PERSULFATE	0.00E+00	0.00E+00	0.00E+00	1.49E-01	2.65E-03	0.00E+00	1.24E+01	2.21E-01	
TRISODIUM CITRATE 5.5-HYDRATE; OR S	0.00E+00	0.00E+00	0.00E+00	1.37E-03	2.27E-05	0.00E+00	1.14E-01	1.90E-03	

GRAPHITE									
CHEMICALS	mg/min FY, TOT	Total Across Process mg/m3 Chemical Air Conc.	Line Operator	Line Operator	Lab Tech	General Population Inhale DOSE mg/kg day	Line Operator mg/day Dermal exposure	Lab Tech mg/day	
			Inhale DOSE	Dermal DOSE					
			mg/kg day	mg/kg day	mg/kg day				
AMMONIA	2.16E+01	9.65E-01	0.00E+00	4.18E-03	3.32E-04	9.67E-06	3.49E-01	2.77E-02	
COPPER SULFATE; OR CUPRIC SULFATE	0.00E+00	0.00E+00	0.00E+00	1.10E-02	4.54E-04	0.00E+00	9.19E-01	3.79E-02	
ETHANOLAMINE	9.65E+00	4.32E-01	0.00E+00	5.32E-03	3.19E-04	4.44E-06	4.44E-01	2.66E-02	
GRAPHITE	0.00E+00	0.00E+00	0.00E+00	9.76E-02	7.74E-03	0.00E+00	8.15E+00	6.47E-01	
POTASSIUM CARBONATE	0.00E+00	0.00E+00	0.00E+00	2.10E-02	1.26E-03	0.00E+00	1.75E+00	1.05E-01	
PEROXYMONOSULFURIC ACID; OR POTA	0.00E+00	0.00E+00	0.00E+00	1.24E-01	5.12E-03	0.00E+00	1.04E+01	4.28E-01	
SODIUM PERSULFATE	0.00E+00	0.00E+00	0.00E+00	2.35E-01	9.68E-03	0.00E+00	1.96E+01	8.08E-01	
SULFURIC ACID	0.00E+00	0.00E+00	0.00E+00	2.44E-01	1.01E-02	0.00E+00	2.04E+01	8.40E-01	

CARBON									
CHEMICALS	mg/min FY, TOT	Total Across Process mg/m3 Chemical Air Conc.	Line Operator	Line Operator	Lab Tech	General Population Inhale DOSE mg/kg day	Line Operator mg/day Dermal exposure	Lab Tech mg/day	
			Inhale DOSE	Dermal DOSE					
			mg/kg day	mg/kg day	mg/kg day				
			↓	↓	↓				
COPPER SULFATE, OR CUPRIC SULFATE	0.00E+00	0.00E+00	0.00E+00	1.74E-02	1.44E-04	0.00E+00	1.46E+00	1.20E-02	
ETHANOLAMINE	2.49E+01	1.11E+00	0.00E+00	9.59E-03	1.29E-04	1.11E-05	8.00E-01	1.07E-02	
POTASSIUM HYDROXIDE	0.00E+00	0.00E+00	0.00E+00	7.32E-02	1.17E-03	0.00E+00	6.11E+00	9.78E-02	
SODIUM PERSULFATE	0.00E+00	0.00E+00	0.00E+00	6.98E-01	5.74E-03	0.00E+00	5.83E+01	4.79E-01	
SULFURIC ACID	0.00E+00	0.00E+00	0.00E+00	6.42E-03	5.28E-05	0.00E+00	5.36E-01	4.41E-03	

RECEPTOR RISKS FROM NON-CONVEYORIZED PROCESSES

ELECTROLESS COPPER												
Receptor: Line Operator												
CHEMICALS	Inhalation Route			Dermal Route			Inhalation Route			Dermal Route		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE
AMMONIUM CHLORIDE	NA	no data	no data	NA	no data	1.948E+04	NA	no data	no data	NA	no data	7.929E+05
BENZOTRIAZOLE	NA	no data	no data	NA	no data	8.783E+03	NA	no data	no data	NA	no data	3.575E+05
BORIC ACID	NA	no data	no data	NA	no data	1.720E+03	NA	no data	no data	NA	no data	7.002E+04
COPPER CHLORIDE(I)	NA	no data	4.232E+02	NA	no data	9.601E-01	NA	no data	5.059E+06	NA	no data	3.907E+01
COPPER SULFATE; OR CUPRIC SULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
DIMETHYLAMINOBORANE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
DIMETHYLFORMAMIDE	NA	8.848E-01	no data	NA	no data	2.218E+04	NA	7.399E-05	no data	NA	no data	9.028E+05
ETHANOLAMINE	NA	no data	6.831E+01	NA	no data	6.319E+03	NA	no data	8.167E+05	NA	no data	2.572E+05
ETHYLENE GLYCOL	NA	no data	4.965E+02	NA	1.230E-03	no data	NA	no data	5.936E+06	NA	3.023E-05	no data
ETHYLENEDIAMINE-TETRAACETIC ACID (ED	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
FLUOBORIC ACID	NA	no data	no data	NA	no data	1.963E+00	NA	no data	no data	NA	no data	7.987E+01
FORMALDEHYDE	1.196E-03	no data	4.845E-01	NA	1.504E+01	no data	1.200E-07	no data	5.792E+03	NA	3.695E-01	no data
FORMIC ACID	NA	no data	8.999E+01	NA	no data	no data	NA	no data	1.076E+06	NA	no data	no data
HYDROCHLORIC ACID	NA	1.453E-02	no data	NA	no data	no data	NA	1.216E-06	no data	NA	no data	no data
HYDROGEN PEROXIDE	NA	no data	2.543E+04	NA	no data	2.419E+02	NA	no data	3.040E+08	NA	no data	9.847E+03
HYDROXYACETIC ACID	NA	no data	no data	NA	no data	2.069E+03	NA	no data	no data	NA	no data	8.420E+04
ISOPROPYL ALCOHOL, 2-PROPANOL	NA	no data	9.981E+01	NA	no data	6.395E+02	NA	no data	1.193E+06	NA	no data	2.603E+04
MAGNESIUM CARBONATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
METHANOL	NA	no data	3.692E+02	NA	2.260E-02	no data	NA	no data	4.413E+06	NA	5.552E-04	no data
p-TOLUENE SULFONIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
PALLADIUM	NA	no data	no data	NA	no data	1.272E+00	NA	no data	no data	NA	no data	5.177E+01
POTASSIUM BISULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
POTASSIUM CYANIDE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
POTASSIUM HYDROXIDE	NA	no data	no data	NA	5.833E-01	no data	NA	no data	no data	NA	no data	no data
POTASSIUM PERSULFATE	NA	no data	1.827E+05	NA	no data	no data	NA	no data	1.945E+09	NA	no data	no data
POTASSIUM SULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
POTASSIUM:SODIUM TARTRATE	NA	no data	5.008E+03	NA	no data	no data	NA	no data	5.986E+07	NA	no data	no data
SODIUM BISULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM CARBONATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM CHLORITE	NA	no data	9.437E+05	NA	no data	no data	NA	no data	1.128E+10	NA	no data	no data
SODIUM CYANIDE	NA	no data	no data	NA	no data	1.694E+01	NA	no data	no data	NA	no data	6.892E+02
SODIUM HYDROXIDE	NA	no data	no data	NA	7.553E-01	no data	NA	no data	no data	NA	1.856E-02	no data
SODIUM HYPOPHOSPHITE	NA	no data	9.064E+02	NA	no data	no data	NA	no data	1.084E+07	NA	no data	no data
M-NITROBENZENE SULFONIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM SULFATE	NA	no data	no data	NA	no data	5.087E+03	NA	no data	no data	NA	no data	2.070E+05
STANNOUS CHLORIDE	NA	no data	no data	NA	3.927E+01	no data	NA	no data	no data	NA	9.649E-01	no data
SULFURIC ACID	NA	no data	2.829E+00	NA	no data	no data	NA	no data	3.382E+04	NA	no data	no data
TARTARIC ACID	NA	no data	no data	NA	no data	3.032E+04	NA	no data	no data	NA	no data	1.234E+06
TRIETHANOLAMINE; OR 2,2,2-NITRILOTRIS E	NA	no data	no data	NA	no data	9.271E+03	NA	no data	no data	NA	no data	3.773E+05
2-ETHOXYETHANOL	NA	1.364E+02	no data	NA	3.424E-01	no data	NA	1.141E-02	no data	NA	8.413E-03	no data

NON-FORMALDEHYDE ELECTROLESS COPPER												
Receptor: Line Operator												
CHEMICALS	Inhalation Route			Dermal Route			Inhalation Route			Dermal Route		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE
COPPER SULFATE; OR CUPRIC SULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
HYDROCHLORIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
HYDROGEN PEROXIDE	NA	no data	4.503E+04	NA	no data	2.665E+02	NA	no data	5.383E+08	NA	no data	1.681E+05
ISOPROPYL ALCOHOL, 2-PROPANOL	NA	no data	7.127E+02	NA	no data	1.522E+03	NA	no data	8.520E+06	NA	no data	9.596E+05
POTASSIUM HYDROXIDE	NA	no data	2.539E+05	NA	no data	no data	NA	no data	3.035E+09	NA	no data	no data
POTASSIUM PERSULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM CHLORITE	NA	no data	no data	NA	no data	1.512E+01	NA	no data	no data	NA	no data	9.533E+03
SODIUM HYDROXIDE	NA	no data	6.137E+04	NA	no data	no data	NA	no data	7.336E+08	NA	no data	no data
STANNOUS CHLORIDE	NA	no data	no data	NA	3.730E+00	no data	NA	no data	no data	NA	5.914E-03	no data
SULFURIC ACID	NA	no data	2.375E+01	NA	no data	no data	NA	no data	2.839E+05	NA	no data	no data

TIN PALLADIUM												
Receptor: Line Operator												
CHEMICALS	Inhalation Route			Dermal Route			Inhalation Route			Dermal Route		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE
1,3-BENZENEDIOL	NA	no data	no data	NA	no data	1.028E+04	NA	no data	no data	NA	no data	1.031E+06
COPPER CHLORIDE(I)	NA	no data	no data	NA	no data	1.856E+00	NA	no data	no data	NA	no data	1.861E+02
COPPER SULFATE; OR CUPRIC SULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
DIMETHYLAMINOBORANE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
ETHANOLAMINE	NA	no data	3.396E+01	NA	no data	2.382E+03	NA	no data	4.060E+05	NA	no data	2.388E+05
FLUOBORIC ACID	NA	no data	no data	NA	no data	4.591E+00	NA	no data	no data	NA	no data	4.603E+02
HYDROCHLORIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
HYDROGEN PEROXIDE	NA	no data	4.341E+04	NA	no data	2.028E+02	NA	no data	5.189E+08	NA	no data	2.034E+04
ISOPROPYL ALCOHOL, 2-PROPANOL	NA	no data	1.776E+02	NA	no data	1.243E+03	NA	no data	2.123E+06	NA	no data	1.246E+05
LITHIUM HYDROXIDE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
PALLADIUM	NA	no data	no data	NA	no data	5.575E+00	NA	no data	no data	NA	no data	5.590E+02
PALLADIUM CHLORIDE	NA	no data	no data	NA	no data	8.921E+00	NA	no data	no data	NA	no data	8.945E+02
POTASSIUM CARBONATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM BISULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM CHLORIDE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM HYDROXIDE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM PERSULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
STANNOUS CHLORIDE	NA	no data	no data	NA	1.517E+01	no data	NA	no data	no data	NA	1.513E-01	no data
SULFURIC ACID	NA	no data	3.037E+01	NA	no data	no data	NA	no data	3.630E+05	NA	no data	no data
TRIETHANOLAMINE; OR 2,2,2-NITRILOTRIS E	NA	no data	no data	NA	no data	1.357E+04	NA	no data	no data	NA	no data	1.361E+06
VANILLIN	NA	no data	no data	NA	no data	1.283E+03	NA	no data	no data	NA	no data	1.286E+05

ORGANIC PALLADIUM												
Receptor: Line Operator												
CHEMICALS	Inhalation Route			Dermal Route			Inhalation Route			Dermal Route		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE
HYDROCHLORIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM BISULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM CARBONATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM HYPOPHOSPHITE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
SODIUM PERSULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
TRISODIUM CITRATE 5.5-HYDRATE; OR SODI	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data

RECEPTOR RISKS FROM CONVEYORIZED PROCESSES

ELECTROLESS COPPER												
Receptor: Line Operator												
CHEMICALS	Inhalation Route			Dermal Route			Receptor: General Population			Receptor: Lab Technician		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Inhalation Route	Hazard Quotient	MOE	Cancer Risk	Dermal Route
												Hazard Quotient
												MOE
AMMONIUM CHLORIDE	NA	no data	no data	NA	no data	7.838E+04	NA	no data	no data	NA	NA	7.929E+05
BENZOTRIAZOLE	NA	no data	no data	NA	no data	3.459E+04	NA	no data	no data	NA	NA	3.575E+05
BORIC ACID	NA	no data	no data	NA	no data	6.133E+03	NA	no data	no data	NA	NA	7.002E+04
COPPER CHLORIDE(I)	NA	no data	no data	NA	no data	4.286E+00	NA	no data	1.054E+06	NA	NA	3.907E+01
COPPER SULFATE, OR CUPRIC SULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
DIMETHYLAMINOBORANE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
DIMETHYLFORMAMIDE	NA	no data	no data	NA	no data	8.925E+04	NA	1.665E-04	no data	NA	NA	9.028E+05
ETHANOLAMINE	NA	no data	no data	NA	no data	2.542E+04	NA	no data	3.629E+05	NA	NA	2.572E+05
ETHYLENE GLYCOL	NA	no data	no data	NA	3.231E-04	no data	NA	no data	3.166E+06	NA	3.023E-05	no data
ETHYLENEDIAMINE-TETRAACETIC ACID (	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
FLUOBORIC ACID	NA	no data	no data	NA	no data	8.469E+00	NA	no data	no data	NA	NA	7.987E+01
FORMALDEHYDE	NA	no data	no data	NA	3.368E+00	no data	3.194E-07	no data	2.177E+03	NA	3.695E-01	no data
FORMIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	4.781E+05	NA	NA	no data
HYDROCHLORIC ACID	NA	no data	no data	NA	no data	no data	NA	5.836E-06	no data	NA	NA	no data
HYDROGEN PEROXIDE	NA	no data	no data	NA	no data	8.626E+02	NA	no data	2.771E+08	NA	NA	9.847E+03
HYDROXYACETIC ACID	NA	no data	no data	NA	no data	8.324E+03	NA	no data	no data	NA	NA	8.420E+04
ISOPROPYL ALCOHOL, 2-PROPANOL	NA	no data	no data	NA	no data	2.552E+03	NA	no data	6.022E+05	NA	NA	2.603E+04
MAGNESIUM CARBONATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
METHANOL	NA	no data	no data	NA	5.489E-03	no data	NA	no data	2.377E+06	NA	5.552E-04	no data
p-TOLUENE SULFONIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
PALLADIUM	NA	no data	no data	NA	no data	5.118E+00	NA	no data	no data	NA	NA	5.177E+01
POTASSIUM BISULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
POTASSIUM CYANIDE	NA	no data	no data	NA	1.306E-01	no data	NA	no data	no data	NA	NA	no data
POTASSIUM HYDROXIDE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	1.433E-02	no data
POTASSIUM PERSULFATE	NA	no data	no data	NA	no data	no data	NA	no data	1.785E+09	NA	NA	no data
POTASSIUM SULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
POTASSIUM-SODIUM TARTRATE	NA	no data	no data	NA	no data	no data	NA	no data	5.456E+07	NA	NA	no data
SODIUM BISULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM CARBONATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM CHLORITE	NA	no data	no data	NA	no data	7.308E+01	NA	no data	no data	NA	NA	6.892E+02
SODIUM CYANIDE	NA	no data	no data	NA	1.692E-01	no data	NA	no data	no data	NA	1.856E-02	no data
SODIUM HYDROXIDE	NA	no data	no data	NA	no data	no data	NA	no data	2.295E+06	NA	NA	no data
SODIUM HYPOPHOSPHITE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
M-NITROBENZENE SULFONIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM SULFATE	NA	no data	no data	NA	no data	2.047E+04	NA	no data	no data	NA	NA	2.070E+05
STANNOUS CHLORIDE	NA	no data	no data	NA	9.761E+00	no data	NA	no data	no data	NA	9.649E-01	no data
SULFURIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	2.981E+04	NA	NA	no data
TARTARIC ACID	NA	no data	no data	NA	no data	1.354E+05	NA	no data	no data	NA	NA	1.234E+06
TRIETHANOLAMINE, OR 2,2,2-NITRILOTRI	NA	no data	no data	NA	no data	3.730E+04	NA	no data	no data	NA	NA	3.773E+05
2-ETHOXYETHANOL	NA	no data	no data	NA	8.696E-02	no data	NA	1.216E-02	no data	NA	8.413E-03	no data

TIN PALLADIUM												
Receptor: Line Operator												
CHEMICALS	Inhalation Route			Dermal Route			Receptor: General Population			Receptor: Lab Technician		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Inhalation Route	Hazard Quotient	MOE	Cancer Risk	Dermal Route
												Hazard Quotient
												MOE
1,3-BENZENEDIOL	NA	no data	no data	NA	no data	3.286E+04	NA	no data	no data	NA	NA	1.031E+06
COPPER CHLORIDE(I)	NA	no data	no data	NA	no data	5.169E+00	NA	no data	no data	NA	NA	1.861E+02
COPPER SULFATE, OR CUPRIC SULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
ETHANOLAMINE	NA	no data	no data	NA	no data	5.163E+03	NA	no data	1.550E+05	NA	NA	2.388E+05
FLUOBORIC ACID	NA	no data	no data	NA	no data	1.279E+01	NA	no data	no data	NA	NA	4.603E+02
HYDROCHLORIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
HYDROGEN PEROXIDE	NA	no data	no data	NA	no data	5.195E+02	NA	no data	1.120E+08	NA	NA	2.034E+04
ISOPROPYL ALCOHOL, 2-PROPANOL	NA	no data	no data	NA	no data	2.379E+03	NA	no data	2.667E+06	NA	NA	1.246E+05
LITHIUM HYDROXIDE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
PALLADIUM	NA	no data	no data	NA	no data	1.781E+01	NA	no data	no data	NA	NA	5.590E+02
PALLADIUM CHLORIDE	NA	no data	no data	NA	no data	2.850E+01	NA	no data	no data	NA	NA	8.945E+02
POTASSIUM CARBONATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM BISULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM CHLORIDE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM HYDROXIDE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM PERSULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
STANNOUS CHLORIDE	NA	no data	no data	NA	4.749E+00	no data	NA	no data	no data	NA	1.513E-01	no data
SULFURIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	7.832E+04	NA	NA	no data
TRIETHANOLAMINE, OR 2,2,2-NITRILOTRI	NA	no data	no data	NA	no data	2.599E+04	NA	no data	no data	NA	NA	1.361E+06
VANILLIN	NA	no data	no data	NA	no data	4.098E+03	NA	no data	no data	NA	NA	1.286E+05

ORGANIC PALLADIUM												
Receptor: Line Operator												
CHEMICALS	Inhalation Route			Dermal Route			Receptor: General Population			Receptor: Lab Technician		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Inhalation Route	Hazard Quotient	MOE	Cancer Risk	Dermal Route
												Hazard Quotient
												MOE
HYDROCHLORIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM BISULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM CARBONATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM HYPOPHOSPHITE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM PERSULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
TRISODIUM CITRATE 5.5-HYDRATE, OR S	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data

GRAPHITE												
Receptor: Line Operator												
CHEMICALS	Inhalation Route			Dermal Route			Receptor: General Population			Receptor: Lab Technician		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Inhalation Route	Hazard Quotient	MOE	Cancer Risk	Dermal Route
												Hazard Quotient
												MOE
AMMONIA	NA	no data	no data	NA	no data	no data	NA	3.384E-04	no data	NA	NA	no data
COPPER SULFATE, OR CUPRIC SULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
ETHANOLAMINE	NA	no data	no data	NA	no data	1.203E+04	NA	no data	8.392E+05	NA	NA	2.008E+05
GRAPHITE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
POTASSIUM CARBONATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
PEROXYMONOSULFURIC ACID, OR POTA	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM PERSULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SULFURIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data

CARBON												
Receptor: Line Operator												
CHEMICALS	Inhalation Route			Dermal Route			Receptor: General Population			Receptor: Lab Technician		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Inhalation Route	Hazard Quotient	MOE	Cancer Risk	Dermal Route
												Hazard Quotient
												MOE
COPPER SULFATE, OR CUPRIC SULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
ETHANOLAMINE	NA	no data	no data	NA	no data	6.676E+03	NA	no data	3.256E+05	NA	NA	4.978E+05
POTASSIUM HYDROXIDE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SODIUM PERSULFATE	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data
SULFURIC ACID	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	NA	no data

CONDUCTIVE POLYMER												
CHEMICALS	Receptor: Line Operator						Receptor: General Population			Receptor: Lab Technician		
	Inhalation Route			Dermal Route			Inhalation Route			Dermal Route		
	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE	Cancer Risk	Hazard Quotient	MOE
	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data
	NA	no data	no data	NA	no data	no data	NA	no data	no data	NA	no data	no data

EXPOSURE PARAMETERS FOR NON-CONVEYORIZED PROCESSES

ELECTROLESS COPPER

	For Inhalation										For Dermal	
	IR	ET	h/day	day/year	years	kg	AT	days	For Cancer	Non-Cancer	For Cancer	Non-Cancer
OPERATOR	m3/hr	h/day	h/day	day/year	years	kg	AT	days	m3/kg day	m3/kg day	1/kg	1/kg
LINE OPERATOR	1.25	8	306	306	25	70	25550	9125	0.042773274	0.119765166	0.004277327	0.011976517
LAB TECH												
min/occur	occur/yr	min/occur	occur/yr	min/occur	occur/yr	min/occur	occur/yr	min/occur	CONVEYOR	occur/yr	h/day	h/day
CHEM	FREQ	CHEM	FREQ	CHEM	FREQ	CHEM	FREQ	CHEM	FILTER	FREQ	Dermal Contact	Dermal Contact
REPLACEMENT		AMPLING							REPLACE			
LINE OPERATOR									CLEAN		0.42	0.42
LAB TECH											0.010319874	0.010319874

NON-FORMALDEHYDE ELECTROLESS COPPER

	For Inhalation										For Dermal	
	IR	ET	h/day	day/year	years	kg	AT	days	For Cancer	Non-Cancer	For Cancer	Non-Cancer
OPERATOR	m3/hr	h/day	h/day	day/year	years	kg	AT	days	m3/kg day	m3/kg day	1/kg	1/kg
LINE OPERATOR	1.25	8	306	306	25	70	25550	9125	0.042773274	0.119765166	0.004277327	0.011976517
LAB TECH												
min/occur	occur/yr	min/occur	occur/yr	min/occur	occur/yr	min/occur	occur/yr	min/occur	CONVEYOR	occur/yr	h/day	h/day
CHEM	FREQ	CHEM	FREQ	CHEM	FREQ	CHEM	FREQ	CHEM	FILTER	FREQ	Dermal Contact	Dermal Contact
REPLACEMENT		AMPLING							REPLACE			
LINE OPERATOR									CLEAN		0.47	0.47
LAB TECH											0.000745324	0.000745324

TIN PALLADIUM

IN FALLOUT												

ORGANIC PALLADIUM

ORGANIC PALLADIUM												
For Inhalation												
For Dermal												
For Cancer												
Non-Cancer												
m3/day												
kg												
days												
m3/kg day												
Exposure Factor												
0.004277327												
0.119765166												
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0.011976517												
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ELECTROLESS COPPER											
							For Inhalation		For Dermal		
	m3/hr	hr/day	day/year	years	kg	For Cancer days	Non-Cancer days	For Cancer m3/kg day	Non-Cancer m3/kg day	For Cancer 1/kg	Non-Cancer 1/kg
OPERATOR	IR	ET	EF	ED	BW	AT	AT	Exposure Factor	Exposure Factor	Exposure Factor	Exposure Factor
LINE OPERATOR	1.25	8	306	25	70	25550	9125	0.042773274	0.119765166	0.004277327	0.011976517
LAB TECH			306	25	70	25550	9125			0.004277327	0.011976517
	min/occur CHEM REPLACEMENT	occur/yr FREQ	min/occur CHEM AMPLING	occur/yr FREQ	min/occur CHEM ADDITIONS	occur/yr FREQ	min/occur FILTER REPLACE	occur/yr FREQ	min/occur CONVEYOR CLEAN	occur/yr FREQ	hr/day Dermal Contact
LINE OPERATOR	180	57	5	720			20	100	288	92	0.121419047
LAB TECH			5	720							0.010319874
CONVEYORIZED BATH-SPECIFIC EXPOSURE DURATIONS											
CONDITIONER/CLEANER	180	24	5	720			20	100	288	92	0.104391256
MICROETCH	180	50	5	720			20	100	288	92	0.117807091
PRE-DIP	180	24	5	720			20	100	288	92	0.104391256
CATALYST	180	24	5	720			20	100	288	92	0.104391256
ACCELERATOR	180	10.3	5	720			20	100	288	92	0.097322142
ELECTROLESSCOPPER	180	4	5	720			20	100	288	92	0.094071382
ACID DIP	180	50	5	720			20	100	288	92	0.117807091
ANTI-TARNISH	180	28.4	5	720			20	100	288	92	0.106661628
TIN PALLADIUM											
							For Inhalation		For Dermal		
	m3/hr	hr/day	day/year	years	kg	For Cancer days	Non-Cancer days	For Cancer m3/kg day	Non-Cancer m3/kg day	For Cancer 1/kg	Non-Cancer 1/kg
OPERATOR	IR	ET	EF	ED	BW	AT	AT	Exposure Factor	Exposure Factor	Exposure Factor	Exposure Factor
LINE OPERATOR	1.25	8	306	25	70	25550	9125	0.042773274	0.119765166	0.004277327	0.011976517
LAB TECH		8	306	25	70	25550	9125			0.004277327	0.011976517
	min/occur CHEM REPLACEMENT	occur/yr FREQ	min/occur CHEM AMPLING	occur/yr FREQ	min/occur CHEM ADDITIONS	occur/yr FREQ	min/occur FILTER REPLACE	occur/yr FREQ	min/occur CONVEYOR CLEAN	occur/yr FREQ	hr/day Dermal Contact
LINE OPERATOR	180	77	2	520			20	74	288	92	0.234360216
LAB TECH			2	520							0.00568464
CONVEYORIZED BATH-SPECIFIC EXPOSURE DURATIONS											
CLEANER/CONDITIONER	180	141.32	2	520			20	74	288	92	0.297643378
PRE-DIP	180	151.04	2	520			20	74	288	92	0.307206691
CATALYST	180	20.13	2	520			20	74	288	92	0.17840696
ACCELERATOR	180	46.81	2	520			20	74	288	92	0.204656879
MICROETCH	180	65	2	520			20	74	288	92	0.222553656
ACID DIP	180	230	2	520			20	74	288	92	0.384893856
ACID DIP	180	50	5	720			20	100	288	92	0.117807091
ANTI-TARNISH	180	28.4	5	720			20	100	288	92	0.106661628
ORGANIC PALLADIUM											
							For Inhalation		For Dermal		
	m3/hr	hr/day	day/year	years	kg	For Cancer days	Non-Cancer days	For Cancer m3/kg day	Non-Cancer m3/kg day	For Cancer 1/kg	Non-Cancer 1/kg
OPERATOR	IR	ET	EF	ED	BW	AT	AT	Exposure Factor	Exposure Factor	Exposure Factor	Exposure Factor
LINE OPERATOR	1.25	8	306	25	70	25550	9125	0.042773274	0.119765166	0.004277327	0.011976517
LAB TECH		8	306	25	70	25550	9125			0.004277327	0.011976517
	min/occur CHEM REPLACEMENT	occur/yr FREQ	min/occur CHEM AMPLING	occur/yr FREQ	min/occur CHEM ADDITIONS	occur/yr FREQ	min/occur FILTER REPLACE	occur/yr FREQ	min/occur CONVEYOR CLEAN	occur/yr FREQ	hr/day Dermal Contact
LINE OPERATOR	108	48	2	250			20	50	288	92	0.15059849
LAB TECH			2								

Appendix C: Sample Modeling and Exposure Calculations

Inhalation Exposure to Line Operators

Inhalation exposure will only be quantified for line operators, with lab technician inhalation exposure being proportional to the amount of time spent in the process area for each MHC process. This section models formaldehyde transfer with the three mechanisms discussed earlier: surface desorption, bubble desorption, and aerosol generation.

Sample calculations regarding the electroless copper MHC process line are presented for determining formaldehyde air concentrations in the process area. When chemical volatilization from MHC alternatives was actually modeled, chemical emissions from multiple baths were added together to arrive at air concentrations and all three mass transfer mechanisms were only applied in sparged bath situations. The surface desorption model only (Eq. 1) was used for all unsparged baths to determine emission rates of contaminants. The electroless copper bath is modeled for illustration purposes here, and the tables below contain parameter assumptions used for modeling.

Electroless Copper Bath Data

Exposure Parameter	Value used	Reference/Comments
Formaldehyde Bath Concentration (mg/L)	3,680	MSDS and PDS information provided by MHC process suppliers, average of all formaldehyde concentrations
Temperature (°C)	38.89	Source Release Assessment: CCPCT, 1996
Volume (m ³)	0.867	same as above
Surface Area (m ²)	0.771	same as above
Height (cm)	112.36	volume divided by surface area, conservative in models
Distance Across Surf. (m)	0.878	square root of surface area, conservative in model
Air Sparging Rate (L/min)	53.8	Perry's Handbook, 1984, as cited in Memorandum to CCPCT (Robinson and Cox, 1995)
Air Sparging bubble diameter at tank surface: assumed constant over tank depth (cm)	0.2	based on correspondence with manufacturers, and Perry, 1984:

From CTSA Draft: *Printed Wiring Board Industry MHC Process* (CCPCT, 1996)

Process Room Data

Exposure Parameter	Value used	Reference/Comments
Air Velocity across bath surfaces (m/s)	0.508	EPA, 1995: recommended value (most conservative)
Process Room Volume (m ³)	1065	Workplace Practices Survey: geometric mean, CCPCT, 1996
Air Turnover Rate in Process Room (min ⁻¹)	0.021	Sensitivity Analysis of Modeled Air Concentrations for Several Chemicals, conservative
k, dimensionless room air mixing factor	1	EPA RM2 correspondence: G. Froiman, 1996

From CTSA Draft: *Printed Wiring Board Industry MHC Process* (CCPCT, 1996)

Worker Exposure Data

Exposure Parameter	Value used	Reference/Comments
Inhalation Rate (m ³ /hr)	1.25	NIOSH, 1976 from CEB (Exposure Guidelines Manual, 1991)
Exposure Time spent in process area (hr/day)	8	Workplace Practices Survey: 90th percentile (CCPCT, 1996)
Exposure Frequency (days/yr)	306	Workplace Practices Survey: 90th percentile (CCPCT, 1996)
Exposure Duration (yrs)	25	Bureau of Labor Statistics, 1990: 90th percentile for job tenure
Body Weight (kg)	70	Average for adult males, (EPA, 1991b)
Averaging Time for long term exposure estimates (days)	9125 non-carcinogenic 25550 carcinogenic	25 & 70 years · 365 days/year, respectively, based on averaging time assumptions for risk, (EPA 1992b)

From CTSA Draft: *Printed Wiring Board Industry MHC Process* (CCPCT, 1996)

The values and assumptions presented in the Process Room and Worker Exposure data tables above are used for all MHC alternatives, but those values in the Bath Parameters table are only specific to the electroless copper process. The bath and process parameters specific to each MHC process alternative are presented in Appendix B. Some of these parameters have more uncertainty than others because their assumed values are not based on collected data from several sources. Parameters which are not specifically based on collected survey information are the sparged air flow rate, bubble diameter, and liquid surface distance from the tank rim. The models were found to be largely insensitive to moderate changes in these

parameters during the sensitivity analysis, however, and it was unnecessary to revise them further (see Section II: Sensitivity and Uncertainty Analysis of Air Models).

The first step in predicting exposure levels to formaldehyde in the workplace was to calculate surface desorption rates from the bath using Eq. 1 and 2 from the Literature Review. All equation numbering in this Appendix is taken from the Literature Review numbering system and order. The molecular diffusion coefficient of formaldehyde in air was calculated as:

$$D_{Y, AIR} = 4.09E-5 T^{1.9} (1/29 + 1/M)^{0.5} M^{-0.33} / P_T \quad (\text{Eq. 2})$$

$$= 0.174 \text{ cm}^2/\text{sec}$$

where: $T = 298.15 \text{ K}$ (based on 25°C room air)
 $M = 30.03 \text{ g/mol}$
 $P_{TOT} = 1 \text{ atm}$

Now the volatilization rate of formaldehyde from the electroless bath due to surface desorption is calculated. This was added to the emission rate contributions from sparging and aerosol transport later to arrive at a total emission rate for formaldehyde. It should be noted that the following emission mechanism is the only one employed for those baths which are not air sparged.

$$F_{Y,O} = 2 C_{L,Y} H_Y A \left[\frac{D_{Y,AIR} V_Z}{\pi z} \right]^{0.5} \quad (\text{Eq. 1})$$

$$= 10.37 \text{ mg/min}$$

where: $C_{L,Y} = 3680 \text{ mg/L}$, formaldehyde steady state concentration in bath
 $H_Y = 1.7E-5$ dimensionless, corrected below for temp. and units
 $A = 0.771 \text{ m}^2$
 $D_{Y, air} = 0.174 \text{ cm}^2/\text{sec}$, from above (Eq. 2)
 $V_Z = 0.508 \text{ m/sec}$
 $z = 0.878 \text{ m}$

Henry's constant is very sensitive to temperature and must be corrected with the Van't Hoff equation (Eq. 9) before using it in the surface or bubble desorption models.

$$H_{Y @ \text{TEMP } T} = H_{Y @ 25^\circ\text{C}} \exp \left[\left(\frac{\Delta H_{GAS} - \Delta H_{AQUEOUS}}{R} \right) \left(\frac{1}{298.15} - \frac{1}{273.15 + T} \right) \right] \quad (\text{Eq. 9})$$

$$= 4.35E-7 \text{ atm}\cdot\text{m}^3/\text{mol}$$

where: $H_{Y @ 25^\circ\text{C}} = 2.35E-7 \text{ atm}\cdot\text{m}^3/\text{mol}$

$$\begin{aligned}\Delta H_{\text{GAS}} &= -27.7 \text{ kcal/mol} \\ \Delta H_{\text{AQ}} &= -35.9 \text{ kcal/mol} \\ T &= 38.89 \text{ }^{\circ}\text{C}\end{aligned}$$

The temperature corrected Henry's constant can then be adjusted for units from basic concepts:

$$\begin{aligned}H_Y &= \frac{H_{Y, \text{UNITS @ TEMP. } T}}{8.205\text{E}-5 \cdot T} \\ &= 1.69\text{E}-5 \text{ unitless}\end{aligned}$$

where:

$$\begin{aligned}H_{Y, \text{UNITS @ TEMP. } T} &= 4.35\text{E}-7 \text{ atm}\cdot\text{m}^3/\text{mol} \\ T &= 312.04 \text{ }^{\circ}\text{K} (38.89 \text{ }^{\circ}\text{C bath temperature})\end{aligned}$$

This corrected Henry's constant was also used when calculating the emission rate contribution from bubble desorption. This air-sparged induced volatilization rate was calculated using equations 3-10 from the Literature review. The overall mass transfer coefficient for oxygen in water was then calculated so that it could later be correlated with the mass transfer coefficient of formaldehyde:

$$\begin{aligned}K_{\text{OL}, \text{O}_2} &= 0.31 \left(\frac{d_b^3 (\rho_{\text{H}_2\text{O}} - \rho_{\text{AIR}}) g}{\mu_{\text{H}_2\text{O}} D_{\text{O}_2}} \right)^{1/3} \frac{D_{\text{O}_2}}{d_b} \quad (\text{Eq. 4}) \\ &= 0.678 \text{ cm/min}\end{aligned}$$

where:

$$\begin{aligned}d_b &= 0.2 \text{ cm, bubble diameter assumed constant throughout tank} \\ \rho_{\text{H}_2\text{O}} &= 0.997 \text{ g/cm}^3, @ 25 \text{ }^{\circ}\text{C} (\text{Dean, 1985}) \\ \rho_{\text{AIR}} &= 0.00118 \text{ g/cm}^3, @ 25 \text{ }^{\circ}\text{C} (\text{Dean, 1985}) \\ g &= 980 \text{ cm/sec}^2 \\ \mu_{\text{H}_2\text{O}} &= 0.0089 \text{ g/cm}\cdot\text{sec}, @ 25 \text{ }^{\circ}\text{C} (\text{Dean, 1985}) \\ D_{\text{O}_2} &= 2.1\text{E}-5 \text{ cm}^2/\text{sec}, @ 25 \text{ }^{\circ}\text{C} (\text{Cussler, 1984})\end{aligned}$$

These water and oxygen numbers were entered at 25 °C because the difference in computed emission rates due to changing each parameter to represent actual temperatures in the tanks is negligible (see Sensitivity and Uncertainty Analysis). The molecular diffusion coefficient for formaldehyde in water was estimated with the following relation:

$$D_y (\text{cm}^2 / \text{sec}) = \frac{13.26\text{E}-5}{\mu_{\text{H}_2\text{O}}^{1.14} \cdot V_M^{0.589}} \quad (\text{Eq. 5})$$

$$= 1.81\text{E-}5 \text{ cm}^2/\text{sec}$$

where: $V_M = 36.8 \text{ cm}^3/\text{mol}$
 $\mu_{\text{H}_2\text{O}} = 0.89 \text{ centipoise, @ } 25^\circ\text{C}$

Now, the overall mass transfer coefficient of formaldehyde in water can be calculated by correlating with the molecular diffusivity of oxygen:

$$K_{\text{OL},Y} = \left(\frac{D_Y}{D_{\text{O}_2}} \right) K_{\text{OL},\text{O}_2} \quad (\text{Eq. 3})$$

$$= 0.584 \text{ cm/min}$$

where: $D_Y = 1.81\text{E-}5 \text{ cm}^2/\text{sec}$, from above
 $D_{\text{O}_2} = 2.10\text{E-}5 \text{ cm}^2/\text{sec}$, from above
 $K_{\text{OL},\text{O}_2} = 0.678 \text{ cm/min}$

This mass transfer coefficient, like Henry's constant, was then corrected for temperature as follows:

$$K_{\text{OL},Y @ \text{Temp. } T} = K_{\text{OL},Y @ 25^\circ\text{C}} \cdot 1.024^{(T-25)} \quad (\text{Eq. 6})$$

$$= 0.812 \text{ cm/min}$$

where: $T = 38.89^\circ\text{C}$

The interfacial area of each bubble per unit volume must be calculated to determine the amount of desorption that can occur along the surface area, based on the mass transfer efficiency of the chemical and the bubble rise time. The bubble rise time is first calculated from the following expression:

$$t_b = \frac{18h \mu_{\text{H}_2\text{O}}}{d_b^2 (\rho_{\text{H}_2\text{O}} - \rho_{\text{AIR}})g} \quad (\text{Eq. 11})$$

$$= 0.00769 \text{ min}$$

where: $h = 112.36 \text{ cm}$

The interfacial area of the bubble is then calculated by:

$$a = \frac{6Q_G t_b}{V_L d_b} \quad (\text{Eq. 10})$$

$$= 0.0143 \text{ cm}^2/\text{cm}^3$$

where: $t_b = 0.00769 \text{ min}$, from above

$$\begin{aligned} Q_G &= 53,800 \text{ cm}^3/\text{min} \\ V_L &= 867,000 \text{ cm}^3 \end{aligned}$$

Finally, this information was combined in the Matter-Müller equation to determine the chemical emission rate from MHC baths due to bubble desorption:

$$\begin{aligned} F_{Y,S} &= Q_G H_Y c_{L,Y} \left[1 - \exp\left(\frac{K_{OL,Y} a V_L}{H_Y Q_G}\right) \right] \\ &= 3.36 \text{ mg/min} \end{aligned} \quad (\text{Eq. 8})$$

The third mechanism for chemical release to air from sparged baths is by aerosol transport. This mechanism is practically negligible for volatile substances when compared with surface and bubble desorption, but it is vitally important for salts and involatile substances because aerosol transport is the only way these substances can escape from the bath. Thus, it is important that this mechanism be included in the overall air transport model so that risk from these involatile substances can be determined. The first step in estimating the aerosol contribution to the overall chemical emission rate was to calculate the aerosol generation rate in the bath from air sparging:

$$\begin{aligned} R_A &= \left[5.5E-5 \left(\frac{Q_G}{A} \right) + 0.01 \right] F_T F_A F_D \\ &= 0.0146 \text{ mL/min/m}^2 \end{aligned} \quad (\text{Eq. 12})$$

where:

- $Q_G / A = (53.8 \times 10,000) / (7,714) = 69.74 \text{ L/min/m}^2$
- $F_T = 0.9358 @ 38.89^\circ\text{C}$, temperature correction factor
- $F_A = 1.132 @ 0.508 \text{ m/s}$, air velocity correction factor
- $F_D = 1 @ > 10\text{cm}$ liquid distance from tank rim assumption, correction factor

Equations for the correction factors (F_T , F_A) were developed with polynomial fits of the data in Figure 11 (Berglund and Lindh, 1987). These two equations were used to represent the Berglund and Lindh correction factors in the Visual Basic Excel® programs that calculated exposures. An equation for F_D was not developed because the graph is a horizontal line at the liquid distances ($> 10 \text{ cm}$) from the tank rim commonly encountered in MHC baths, and was thus set equal to 1.

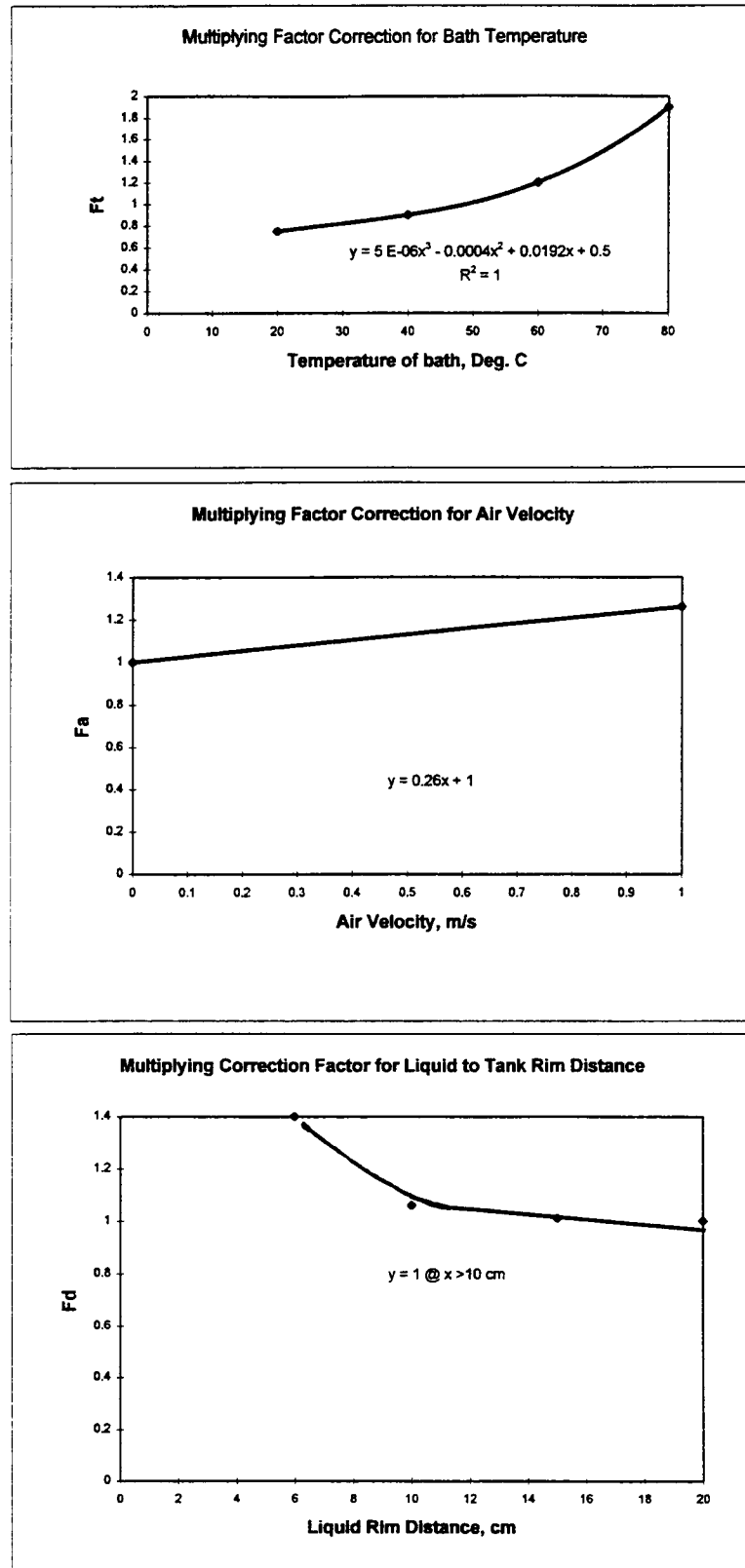


Figure 11. Linearized Correction Factor Graphs for Aerosol Model

The linearized graph equations of the data in Figure 11 are:

$$F_T = 5E-6 \cdot T^3 - 4E-4 \cdot T^2 + 0.0192 \cdot T + 0.5$$

$$= 0.9358$$

where: $T = 38.89^\circ\text{C}$, bath temperature

and: $F_A = 0.26 \cdot \text{Velocity} + 1$

$$= 1.132$$

where: Velocity = 0.508 m/s, air velocity across tank surface

The next step in determining the aerosol emission rate was to address the accumulation of contaminant at the air water interface. If this is significant, it could increase the aerosol contribution for chemical release by providing more contaminant mass that is sorbed at the surface.

The water-interface partitioning coefficient, k_{IW} is used to calculate the chemical mass sorbed at the air-water interface. Since formaldehyde is a gas at the temperatures encountered in the bath, interfacial tension data is not available and must be estimated by using values for other aldehydes (Hoff *et al.*, 1993). K_{IW} is calculated at 25°C for all chemicals because of a lack of data at other temperatures. In the case of some chemicals where surface tension data were not available, the interfacial-water coefficient was estimated from solubility data (Hoff *et al.*, 1993).

$$\log k_{IW} = -7.508 + \log \gamma_w + \frac{a_s(\sigma_{wa} - \sigma_{sa} - 1.35\sigma_{sw})}{2.303 R T} \quad (\text{Eq. 14})$$

$$= -6.848$$

$$k_{IW} = 1.418E-7 \text{ cm}$$

where:

γ_w	= 1.452, estimated from Lyman <i>et al.</i> (1982)
a_s	= $9.36 \times 10^8 \text{ cm}^2/\text{mol}$
σ_{wa}	= 72 dyne/cm
σ_{sa}	= 21.92 dyne/cm
σ_{sw}	= 14.6 dyne/cm
R	= $8.314 \times 10^7 \text{ erg/mol K}$
T	= 312 K

The ratio of contaminant mass sorbed at the air-water interface to mass in the gas volume of the bubble is calculated using the interfacial-water partitioning coefficient:

$$\frac{M_I}{M_b} = \frac{k_{IW}}{H_Y(d_b / 6)} \quad (\text{Eq. 12})$$

$$= 0.2504$$

where: k_{IW} = 1.418E-7 cm, from above
 H_Y = 1.69E-5, from above
 d_b = 0.2 cm

The aerosol generation rate, R_A is now used to estimate the fraction of bubble interface that is actually ejected as aerosols.

$$f_{IE} = \frac{R_A A d_b}{6 Q_G l_b} \quad (\text{Eq. 15})$$

$$= 0.01396$$

where: l_b = 5E-7 cm, thickness of bubble film (Rosen, 1978)

Finally, the formaldehyde mass transfer rate via aerosol transport was calculated by combining the air-sparged emission rate with the fractional contributions of contaminant mass sorbed at the interface and the amount of interface actually ejected as aerosols:

$$F_{Y,A} = \frac{M_I}{M_b} f_{IE} F_{Y,S} \quad (\text{Eq. 16})$$

$$= 0.0117 \text{ mg/min}$$

In determining the emission rate of salts from sparged baths, the following calculation was used:

$$F_{Y,A} (\text{SALTS}) = A \cdot R_A \cdot \text{Conc} \cdot 1\text{E-}03$$

where: A = Area of bath, m^2
 R_a = aerosol generation rate, mL/min/m^2 (calculated above)
 Conc = Chemical concentration in process bath, mg/L
 $1\text{E-}03$ = conversion factor for cm^3 to L

The contribution from each of the three air transport mechanisms were then combined to estimate steady state formaldehyde air concentrations in the process room.

The total emission rate for each chemical from these mechanisms was also used to arrive at outdoor air concentrations based on dispersion modeling. The steady-state formaldehyde air concentration in the process room was estimated as:

$$C_Y = \frac{F_{Y,T}}{(V_R R_V k)} \quad (\text{Eq. 18})$$

$$= 0.615 \text{ mg/m}^3$$

where:

$F_{Y,T}$	= 10.37 + 3.36 + 0.0117 = 13.74 mg/min, total emission rate of formaldehyde from all mechanisms (surface + bubble desorption + aerosol transfer)
V_R	= 1065 m ³ , room volume
R_V	= 0.021 min ⁻¹ , air turnover rate (corrected version from sensitivity analysis)
k	= 1, dimensionless air mixing factor

This chemical air concentration in the process room is used to estimate potential dose rates (PDRs) and lifetime average daily doses (LADDs) of formaldehyde due to inhalation exposures. The non-carcinogen effect PDR (inhalation) for line operators in the electroless copper process from formaldehyde is:

$$\text{PDR} = \frac{C_Y \cdot \text{IR} \cdot \text{EF} \cdot \text{ED}}{\text{BW} \cdot \text{AT}} \quad (\text{Eq. 21})$$

$$= 7.36\text{E-}2 \text{ mg/kg}\cdot\text{day}$$

where:

C_Y	= 0.615 mg/m ³
IR	= 1.25 m ³ /hr · 8hr/day = 10 m ³ /day, inhalation rate
EF	= 306 days/yr, exposure frequency
ED	= 25 years, exposure duration
BW	= 70 kg, body weight
AT	= 9125 days, averaging time

This dose rate was compared to chronic RfDs and NOAELs/LOAELs to determine the hazard potential from inhalation exposure in the form of HQs and MOEs. The carcinogen effect LADD (inhalation) for line operators in the electroless copper process from formaldehyde is:

$$\text{LADD} = \frac{C_Y \cdot \text{IR} \cdot \text{EF} \cdot \text{ED}}{\text{BW} \cdot \text{AT}} \quad (\text{Eq. 21})$$

$$= 2.63\text{E-}2 \text{ mg/kg}\cdot\text{day}$$

where:

C_Y	= 0.615 mg/m ³
$\text{IR}, \text{EF}, \text{ED}, \text{BW}$	= same as above

AT = 25550 days, averaging time

This LADD will be compared to slope factors based on carcinogenic effects to determine cancer risk due to formaldehyde inhalation in the workplace. The measures of exposure, or dosages (PDRs & LADDs) for the chemicals in all MHC processes are located at the end of this section.

Dermal Exposure to Line Operators and Lab Technicians

Dermal exposure will be quantified for line operators and laboratory technicians. The remaining workers' dermal exposure will be proportional to their amount of time spent in the process area, and risk from this exposure is likely to be negligible unless line operator dermal risks are extremely high. This section estimates formaldehyde exposure based on the steady state absorption model presented earlier. The following table (adapted from CCPCT, 1996) lists parameter values and assumptions used in dermal modeling.

Dermal Exposure Data

Exposure Parameter	Value used in Exp. Assess.	Reference/Comments
Surface area of skin contacting chemical, cm ²	1300	CEB, Table 4-13, routine immersion with both hands wearing no gloves
Line operator dermal exposure time to baths, hr/day	8	Workplace Practices Survey, CCPCT, 1996: 90th percentile
Number of baths in electroless line that workers spend exposure time amongst	19	Workplace Practices Survey, CCPCT, 1996: corrected for typical number of baths, including rinse baths
Line Operators Exposure Time per bath, hr/day	0.42	8 hr/day / 19 baths
Lab Technician Bath Sampling Exposure Time per bath, hr/day	0.0103	5 min/occur * 720 occur/yr, normalized for 306 day work year and 19 baths in MHC line, CCPCT, 1996

From CTSA Draft: *Printed Wiring Board Industry MHC Process* (CCPCT, 1996)

Some key assumptions were made concerning the dermal exposure time and frequency. As stated earlier, glove use is modeled here as non-existent because of

questionable results from the survey data. It was also difficult to determine the amount of time that line operator's and lab technician's were actually exposed to the baths based on the survey data and correspondence with manufacturers. Hence, a conservative exposure assumption of an 8 hour workday was divided among the number of baths in an MHC line (including rinse baths) to determine risk for line operators (non-conveyorized processes). For line operator exposure to conveyorized processes, the time spent on the following tasks was combined to estimate the overall exposure duration per bath: chemical replacement, chemical sampling, adding chemicals, filter replacement, and conveyorized system cleaning. This was done for each bath because the chemical replacement frequencies were found to vary significantly per bath (CCPCT, 1996). The equation used to calculate line operator dermal exposure to the conveyorized electroless copper bath is presented below:

$$ED_{\text{CONVEYORIZED}} = (\text{Chem. Repl.} \cdot \text{Freq}) + (\text{Sampling} \cdot \text{Freq}) + (\text{Additions} \cdot \text{Freq}) + (\text{Filter Repl.} \cdot \text{Freq}) + (\text{Conveyor Clean.} \cdot \text{Freq})$$

where: $ED_{\text{CONVEYORIZED}}$ = line operator exposure duration to conveyorized baths, min/year
 Chem. Repl. = chemical replacement duration bath, min/occurrence
 Sampling = chemical sampling duration per bath, min/occurrence
 Additions = chemical addition duration per bath, min/occurrence
 Filter Repl. = filter replacement duration per bath, min/occurrence
 Conveyor Clean. = conveyorized system cleaning per bath, min/occurrence
 Freq. = frequency of the above events, occurrences/year

An example of this calculation for line operator dermal exposure duration to the conveyorized electroless copper bath is as follows:

$$\begin{aligned} ED_{\text{CONV. EC BATH}} &= ((180 \cdot 4) + (5 \cdot 720) + (20 \cdot 100) + (288 \cdot 92))/19 \\ &= 1,727 \text{ min/year} = 0.094 \text{ hrs/day} \end{aligned}$$

This approach is consistent across MHC alternatives but does not account for preferential time spent in around particular baths.

This may seem excessively conservative at first, but it offers a simple way to approximate actual contact conditions without gloves since operators are constantly inserting their hands into baths and not cleaning them immediately afterwards. The

dermal absorption model used here is steady state and assumes that diffusion occurs in only one direction, so it is consistent with this approach. To use a non-steady state dermal absorption model, variable exposure durations would have to be developed to describe a typical work day. An estimate of this accuracy would require further study and data collection, and is thus beyond the scope of this work.

The first step in estimating dermal line operator exposure due to formaldehyde in the electroless copper bath was to determine K_p , the permeability coefficient. Equation 18 was used here because formaldehyde is an organic (a default assumption of 0.001 cm/hr was used for all inorganics per EPA, 1992).

$$\begin{aligned}\log K_p &= -2.72 + 0.71 \log K_{O/W} - 0.0061 MW & \text{(Eq. 19)} \\ &= -2.903\end{aligned}$$

$$K_p = 1.249E-3 \text{ cm/hr}$$

where: $\log K_{O/W} = 0.0$, calculated octanol-water partition coefficient (from ORNL Chemical Parameter Profiles, as in CCPCT, 1996)
 $MW = 30.03$ g/mole, molecular weight

The next equation calculates dermal exposure for line operators on a mg/day basis:

$$\begin{aligned}D &= S \cdot C \cdot K_p \cdot h \cdot 0.001 & \text{(Eq. 20)} \\ &= 2.51 \text{ mg/day}\end{aligned}$$

where: $S = 1300 \text{ cm}^2$, surface area of skin
 $C = 3680 \text{ mg/L}$, concentration in bath
 $K_p = 1.249E-3 \text{ cm/hr}$, from above
 $h = 0.42 \text{ hr/d}$, duration of contact with bath

Dermal exposure to formaldehyde for lab technicians on a mg/day basis was estimated as follows:

$$\begin{aligned}D &= S \cdot C \cdot K_p \cdot h \cdot 0.001 & \text{(Eq. 20)} \\ &= 0.0617 \text{ mg/day}\end{aligned}$$

where: $h = 0.0103 \text{ hr/d}$, duration of contact with bath

The PDR for line operator dermal exposure to formaldehyde is calculated as before (for inhalation):

$$PDR = \frac{D \cdot EF \cdot ED}{BW \cdot AT} \quad \text{(Eq. 22)}$$

$$= 3.01\text{E-}2 \text{ mg/kg}\cdot\text{day}$$

where: D = 2.51 mg/day, from above
 EF = 306 days/yr
 ED = 25 years
 BW = 70 kg
 AT = 9125 days (non-carcinogenic effects)

The PDR for lab technician dermal exposure to formaldehyde was similarly calculated:

$$\text{PDR} = \frac{D \cdot \text{EF} \cdot \text{ED}}{\text{BW} \cdot \text{AT}} \quad (\text{Eq. 22})$$

$$= 2.00 \text{ E-}4 \text{ mg/kg}\cdot\text{day}$$

where: D = 0.0167 mg/day, from above

These numbers were also used to calculate hazard risk in the Risk Characterization section. Carcinogen averaging times were not used to calculate LADDs here because formaldehyde has no established slope factors for cancer effects from the dermal exposure pathway. The formaldehyde dose rates in the spreadsheet tables contained in the appendices are LADDs.

Appendix D: Dilution Ventilation Rate Comparison Calculations

Dilution Ventilation Requirements - Ventilation Standards for Health Hazard Reduction (Comparison to Surveyed PWB Standards)

Dilution Ventilation Standard Design Method

based on mass of solvent generated, ft³/lb

$$Q_M = 3.87E8 \cdot SG \cdot K / (M \cdot TLV)$$

note: TLV and PELs are both described as measures of toxicity in text (both used here)
C1/TLV1 + C2/TLV2 + ... for mixtures of several substances

for Formaldehyde dilution : OSHA PEL=0.9375 mg/m³ 0.775 ppm

13.7 mg/min emission rate = 3.02E-5lb/min (steady-state assumption is valid for continuous operation rate of ventilation system)

formaldehyde

M, molecular weight = 30.03

TLV(PEL) exposure limit = 0.75 ppm

SG, specific gravity = 0.815 pure formaldehyde

SG (mixture) @ 0.43 ppm conc in air = 1.0000 from ASHRAE standards (1988)

K, safety factor (toxicity & air mix) = 11 note: highly toxic material classification w/poor room distribution characteristics (conservative assumption)

room size = 1065 m³

Q_M = 189010992.1 ft³/lb

ventilation rate w/emission = 5708.131961 ft³/min

air turnover rate w/ room volume = 0.180 min⁻¹

note: emission rates from MHC volatilization models for electroless copper

for multiple solvent dilution (mixtures) of several toxic substances

formaldehyde (as above), ethandamine (9.92 mg/min), isopropyl alcohol (524 mg/min), methanol (231 mg/min)

ethandamine isopropyl alcohol methanol

emission rate, for mg/min-conv to lb/min = 9.92 524 231

M, molecular weight = 61.08 60.09 32.04

TLV(PEL) exposure limit = 3 400 200 ppm

SG, specific gravity = 1.0117 0.78505 0.7915 pure solvent

estimated conc in workplace, ppm 0.153 8.2 6.78

SG (mixture) @electroless concs in air = 1.0000 1.0000 1.0000 from ASHRAE standards (1988)

K, safety factor (toxicity & air mix) = 11 8 8 note: highly toxic material classification w/poor room distribution characteristics (very conservative assumption)

room size = 1065 1065 1065 m³

Q_M = 2.32E+07 1.29E+05 4.83E+05 ft³/lb

ventilation rate w/emission = 507.011481 148.4897779 245.5350098 ft³/min

air turnover rate w/ room volume = 0.0133 0.0039 0.0055 min⁻¹

note: emission rates from MHC volatilization models - electroless copper

combined for comparison with Monte Carlo Distribution Runs

additive ventilation rate for dilution of all 4 chemicals = 6.61E+03 ft³/min

air turnover rate for mixture of all 4 chemicals (1.065 m³ room) = 0.17376217 min⁻¹

Source: Industrial Ventilation: A Manual of Recommended Practice, 1988 ACGIH and ASHRAE standards

Appendix E: Toxicity Tables

Toxicology Information for Chemicals in MHC Lines

Chemicals In MHC Processes	RfD _{INHALE} mg/kg-d	RfD _{DERMAL} mg/kg-d	N/L _{INHALE} mg/kg-d	N/L _{DERMAL} mg/kg-d
Formaldehyde		0.002	0.036 ^L	
1,3-Benzenediol				100 ^N
2-Butoxyethanol Acetate	0.0057			
Ammonia	0.029			
Ammonium Chloride				1640.3 ^N
Benzotriazole				21.8
Boric Acid				56.25 ^N
Copper Chloride(I)			0.17	0.042 ^L
Diethylene Glycol Methyl Ether				200 ^N
Diethylene Glycol N-Butyl Ether	0.0057			1000
Dimethylformamide	0.0086			
Ethanolamine			3.63 ^L	64 ^N
Ethylene Glycol		2	8.86	
Fluoboric Acid				0.77
Formic Acid			16.91 ^N	
Graphite			16 ^L	
Hydrochloric Acid	0.002			
Hydrogen Peroxide			22.57	31.5 ^N
Hydroxyacetic Acid				50 ^N
Isopropyl Alcohol, 2-Propanol			1071.4 ^N	80 ^N
Methanol		0.5	456	
Palladium, Palladium Chloride				0.0475 ^L
Potassium Cyanide		0.0025		
Potassium Hydroxide			2.03	
Potassium Sulfate			4.28 ^{TC}	
Sodium Carbonate			2.86 ^N	
Sodium Chlorite				0.5 ^N
Sodium Cyanide		0.002		
Sodium Hydroxide			0.57 ^L	
Sodium Sulfate				420 ^N
Stannous Chloride		0.0186		
Sulfuric Acid			0.019 ^N	
Triethanolamine				32 ^L

Source: Oak Ridge National Laboratory Chemical & Toxicity Profiles, DfE Printed Wiring Board CTSA Project, 1995, Daljit Sawheney's summaries of ORNL data

L: Lowest observed adverse effect level

N: No observed adverse effect level

TC: total concentration resulting in a sublethal effect

VITA

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