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An Evaluation of Engineering Control Technology for Spray Painting

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

AN EVALUATION OF ENGINEERING CONTROL TECHNOLOGY FOR SPRAY PAINTING

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ABSTRACT

A series of field surveys of 11 finishing operations provided information for an evaluation of control technology for spray painting and coating processes; this information was supplemented by a literature review. The field studies were conducted in the automobile refinishing, wood and metal furniture, transportation equipment (non-automotive), heavy machinery, and appliance finishing industries. The processes that were selected provide representative coverage of spray finishing operations relative to the number of exposed workers, different control techniques, physical size of the workpiece, and the coating systems that are typically used. The level of control of selected health hazards is discussed, and available control options evaluated. Case study summaries presented for each of the sites surveyed include:

- An analysis of the hazard
- Engineering controls and work practices
- Ventilation measurements
- Air sampling data
- Personal protective equipment
- Evaluation and discussion

The results of this study should be usable as a reference source for anyone interested in the adequate protection of the worker who sprays paints and coatings.

CONTENTS

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SECTION I. INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) is charged with the responsibility of conducting research and developing criteria for the advancement of health and safety in the workplace. In order to expand the knowledge of available options for the solution of occupational health problems and the constraints that influence the selection of these options, NIOSH has sponsored a series of industry-wide control technology evaluations. The goals of these evaluations or assessments are to stimulate private industry to prevent hazardous exposures of workers, and to establish a catalog of solutions by documenting successful application of control measures. These studies seek to identify the best control techniques practiced by different companies, encourage the dissemination of this knowledge across industries, and outline control technology research needs; this is all done to aid in the voluntary application of demonstrated control technologies.

This report presents the findings of a state-of-the-art study of available technology associated with the spray application of industrial finishes. Manual rather than automatic application was emphasized in this study because of its greater potential for worker exposure. Spray finishing operations were selected for study for several reasons. First, industrial finishes employ many substances long recognized as health hazards. Spray booths have been widely used to control these hazards, but no systematic study of their effectiveness had been undertaken. Second, coatings technology has changed rapidly with the introduction of many new materials, some of which represent toxic hazards. Last, parallel developments in paint application methods promised new ways of reducing worker exposure in spray finishing operations.

The study began with a review of available data on industrial finishing processes and equipment, and any hazards associated with their use. Based upon this information, five Standard Industrial Classification (SIC) groups directly associated with spray finishing were identified for inclusion in the study.[1] These industries are:

- Automobile refinishing (SIC major group 75--automotive re- pair, services, and garages)
- Wood and metal furniture finishing (SIC major group 25--furniture and fixtures)
- Appliance finishing (SIC group 363--household appliances)
- Non-automotive transportation equipment (SIC major group 37--transportation equipment, excluding subgroup 3711--motor vehicles and passenger car bodies)

- Heavy machinery (SIC major group 35--machinery, except electrical

Nineteen candidate plants were selected for walk-through surveys. The walk-through surveys were conducted to further identify control measures, to select plant locations for evaluating specific processes and controls, and to finalize sampling and documentation strategies. In-plant studies of engineering control technology were completed for 11 spray finishing proceses. Results of these studies are included in this report as individual case studies. Each case study involves a distinct process and evaluates the techniques used to reduce or eliminate employee exposure to potentially harmful chemicals. The selected processes are directly related to one of the above industries. These processes are representative of the industry based upon the number of exposed workers, different control techniques, and diversity of operations.

Other considerations governing the selection of processes that were studied include:

- Coating type and toxicity
- Application techniques
- Engineering controls and work practices
- Personal protective equipment
- Product size and shape
- Substrate materials
- Required finish performance and appearance

The report is organized in two parts. The first presents an overview of coatings technology, application methods, and the finishing practices of the industries studied. Also included are summaries of the potential health hazards, control methods reported in the literature, and the procedures used to evaluate these control methods. Closing this part are the authors' conclusions and recommendations regarding these control methods. The second part, or appendix, of this report contains the case studies upon which these conclusions and recommendations are based. Immediately following this introduction is a paint/process/ control matrix (Table 1) that is intended to serve as a key to the individual case studies. Each of these case studies includes:

- A description of the process
- An analysis of the hazard
- Engineering controls, protective equipment, and work practices
- Ventilation measurements
- Air sampling data

- Evaluation and discussion

The diversity of spray finishing operations, coating formulations, and the materials to be coated make it difficult to apply general engineering control design to specific operations. Thus, it may not be possible to use one of the methods exactly as it is found in the case studies. Therefore, emphasis in the case studies has been placed on the principles of control employed, rather than on specific design requirements.

Case Study	Page	Paint Type	Hazard Evaluated	Application Method	Ventilation Equipment
Case Study 1 Powder Coating - Small Parts	1-1	Thermosetting acrylic powder	Total dust	Compressed air electrostatic	Bench type spray booth; air recirculation
Case Study 2 Wood Furniture Finishing	2-1	Acrylic lacquer; oleoresin stain; nitrocellulose lacquer	Mist, solvents	Airless; some compressed air; robot	Open side draft booth
Case Study 3 Metal Furniture: Solvent and Waterborne Coatings	3-1	Alkyd baking enamel; acrylic emulsion	Mist, lead, solvents	Compressed air; manual and reciprocator	Side draft booth w/intergal supply air
Case Study 4 Railroad Car Finishing	4-1	Air dry alkyd enamel	Mist, lead, chromium, solvents	Airless	Semi-downdraft spray booth
Case Study 5 Auto Refinishing	5-1	Air dry alkyd; urethane modified alkyd	Mist, lead, chromium, isocyanates, solvents	Compressed air	Drive-through side draft booth
Case Study 6 Appliance Finishing	6-1	Thermosetting acrylic enamel	Mist, lead, solvents	Electrostatic bell with compressed air and electrostatic reinforcement	Downdraft spray room; side draft booth w/ integral supply air.
Case Study 7 Light Aircraft Finishing	7-1	2-part epoxy primer 2-part urethane topcoat	Mist, chromium lead, isocyanates, organotin, solvents	Compressed air	Downdraft booth w/ integral supply air
Case Study 8 Heavy Equipment Finishing	8-1	Air dry alkyd enamel	Mist, lead, chromium, solvents	Airless electrostatic; airless pole gun; paint heated	Downdraft booth w/ integral supply air. Ventilated pit for underground painting
Case Study 9 Metal Furniture: Conventional and High Solids Coatings	9-1	Thermosetting acrylic and high-solids polyester enamels	Mist, lead, solvents	Airless electrostatic on reciprocators with air spray reinforcement, airless on interiors	Downdraft booth; Side draft booth
Case Study 10 Paint Storage and Mixing	10-1	Various	Solvents	- - - - - - -	General ventilation

Table 1. Paint/process/control matrix.

SECTION II. INDUSTRIAL COATING TECHNOLOGY

INTRODUCTION

Coatings can be defined as liquid or liquefiable materials that can be converted to solid protective, decorative, or functional adherent films after application as a thin layer.[2] The term "coating" includes paints, varnishes, and powders.

CLASSIFICATION

Liquid coatings can be classified into two broad groups, those that use organic solvents as the primary liquid and those that employ water. The main difference is that most solvent-type coatings exist as true solutions, where the polymer is dissolved in the liquid solvent, whereas most waterborne coatings are emulsions of pigments and binders in water.

Coatings can also be classified according to their end use as "trade sales" paints and "industrial finishes." "Trade sales" products are stock-type commodities, generally distributed through wholesale and retail channels. "Industrial finishes" are products that are specifically formulated to meet conditions of application and use of the products to which they are applied. They are produced for manufacturers, rather than for contractor or general public use.

For the purposes of industrial health, it is most useful to categorize coatings according to the mechanism of film formation. These mechanisms give some indication of the hazard involved. These mechanisms can be categorized as either thermoplastic or convertible. A thermoplastic material is one that becomes soft or fluid when heated, and regains its original properties upon cooling. A convertible material is one that undergoes an irreversible chemical change during film formation.

Thermoplastic Film Formation

Thermoplastic materials can form coating films by solvent evaporation, by heat fluxing, or by coalescence.[3]

Coatings that form films solely by the evaporation of a solvent are termed "lacquers". The film that is formed by this process is susceptible to deterioration by the solvent used in manufacture. Lacquers are noted for quick drying properties. These coatings may be baked to accelerate drying, to improve adhesion, or to increase gloss.

Thermoplastic films can also be formed by heat fluxing. In this method, a coating material is changed from a solid to a liquid then back again; this phase change is brought about by a change in temperature.

Water emulsions of thermoplastic materials form films by coalescence. In latex coatings, the dispersed solids are coated with an emulsifier to prevent flocculation; typically the dispersed solids have a particle size of less than one micron. The formulation of those products utilizes a coalescing agent that permits film formation by the contact and fusion of adjacent resin solids upon evaporation of the water.

Film Formation by Convertible Binders

Convertible binders form paint films by irreversible transformations brought about through oxidation, heat conversion, catalytic action, chemical cross-linking, or moisture activation.[3]

Coatings that contain drying oils produce films by oxygen conversion. These oils absorb oxygen from the air, forming oil-peroxides, which subsequently decompose, cross-linking the polymer by covalent bonding. Lead and cobalt soaps are commonly used in the formulation in order to accelerate drying. Water soluble binders can be produced by the reaction of an amine with an acidic resin/oil, resulting in an amine salt.

Heat can be applied to oxygen-convertible coatings in order to accelerate the reactions; however, there are true heat convertible, or thermosetting, resins that require the application of heat to initiate the reaction. This reaction can be accomplished by the use of a single resin or the combination of two resins that interact to form insoluble polymers. These resins are often combined with thermoplastic or oxygen-convertible resins in order to promote specific desirable properties.

Certain resins can be made to cure at room temperature by using a catalyst. However, coatings made from these resin systems have the disadvantage that they are normally two-component systems.

Resins can form paint films by the action of a cross-linking agent. This method of film formation is often confused with catalytic conversion, because both are two-package systems. Polymerization by means of a cross-linking agent is initiated at ambient temperatures by the reaction of a polymer and a monomer, or by the reaction of two polymers, rather than the catalyzed reaction of a single constituent. An insoluble, three dimensional molecular structure results from the cross-linking of the molecules of two materials.

Certain urethane resins form films by the reaction between isocyanate groups and airborne moisture.

COMPOSITION

The major constituents in industrial finishes can be grouped into four general categories: 1) binders, or film formers; 2) pigments; 3) volatile solvents; and 4) additives.

Binders

Binders, or film formers, are the non-volatile portion of the liquid components of a coating. They bind, or cement, the pigments and the paint film to the material to which it is applied. Synthetic resins, natural resins, and drying oils are the three categories of binders used in paint; synthetic resins represent over 90 percent of binder usage. The consumption of various resins by the coatings industry is listed in Table 2.

Table 2. Estimated consumption of important resins in paints and coatings.[4]

Resins	Millions of pounds				
	1973	1974	1975	1976	1977
Alkyd	760	750	695	705	715
Acrylic	361	383	348	395	408
Vinyl	413	395	367	389	406
Epoxy	94	109	83	112	126
Urethane	69	67	60	83	90
Amino	74	74	63	81	85
Cellulosic	63	56	50	55	57
Phenolic	29	27	24	25	25
Chlorinated rubber	13	13	14	13	13
Styrene-butadiene	30	25	24	21	20
Polyester	26	27	25	34	39
Natural	22	21	19	17	16
Linseed Oil	84	58	45	42	40
Other	183	194	184	185	187

Some of the more important resins are discussed in the following sections.

Acrylic Resins--

The term "acrylic resin" applies to the polymers and copolymers of the esters of acrylic and methacrylic acids. Acrylic resins can be classified into thermoplastic and thermosetting types.[5]

Thermoplastic acrylic resins are used in lacquer-type finishes for automobiles. Heat after application causes these resins to flow, resulting in a high gloss finish. The physical properties of these resins are highly dependent on the alcohol that is used to prepare the acrylate or methacrylate ester. Methanol, ethanol, butanol, and 2-ethyl hexanol are commonly used alcohols.

Thermosetting acrylic resins incorporate carboxyl or hydroxyl groups to provide reaction sites for cross-linking agents. Resins with pendent carboxyl groups usually employ an epoxy resin as the cross-linking agent; those with hydroxyl groups employ an amino resin. Isocyanates are used to cross-link acrylic resins that are hydroxyl modified in two-package, air drying, paint systems. Acrylonitrile, acrylamide, styrene, and vinyl toluene are often used in thermosetting acrylic resins.

Both thermoplastic and thermosetting acrylic resins are also used in emulsion coatings. The thermoplastic emulsions are used primarily in trade sales paints. The resins used in thermosetting acrylic emulsions are similar to those used in solution-type coatings.

Alkyd Resins--

Alkyds are oil-modified polyester resins made by the condensation of a polycarboxylic acid with a monoglyceride. The monoglyceride is produced by the reaction between a polyalcohol and a fatty acid. Glycerol and pentaerythritol are often used for the polyalcohol, and phthalic anhydride is typically used for the polycarboxylic acid.[6]

Variations in the type and amount of the fatty acid that is used can produce variations in the final film and drying properties. Alkyds with low oil content are commonly combined with amino resins to produce industrial baking enamels. Alkyds with higher oil content are used in air drying finishes. Finishes made from these materials cure by oxidation and the subsequent polymerization of unsaturated double bonds in the drying oil.[6]

Polyester resins, on the other hand, are considered "oil-free" alkyds. Polyester resins can be combined with amino resins to produce high quality baking enamels, or used alone as the polyol component in two-package urethane coatings.[7]

Amino Resins--

Amino resins are based on the reaction of formaldehyde with urea or melamine. These resins are seldom used alone, but are generally used as cross-linking agents in baking enamels. They can be used with alkyds, epoxies, and thermosetting acrylic enamels.[6]

Cellulosic Resins--

Cellulose is a natural polymer characterized by pendent hydroxyl groups. As such, it can form esters of inorganic and organic acids as well as ether compounds. Cellulose nitrate, or nitrocellulose, is the only inorganic ester of cellulose that is used in large volume. Nitrocellulose is manufactured by treating purified wood pulp or cotton linters with a mixture of nitric and sulfuric acids. Nitrocellulose lacquers are used for finishing furniture and refinishing automobiles, largely because of their rapid air-drying characteristics.[8]

Cellulose is reacted with acetic anhydride to form cellulose acetate. It is a useful component of heat resistant coatings because of its high melting point. A mixed ester, known as cellulose acetate butyrate, is obtained by the reaction of cellulose with acetic and butyric acids and their anhydrides. Cellulose acetate butyrate, modified with acrylic resins, is used in both furniture and automobile finishes. Cellulose derivatives by themselves produce coatings with inferior properties, so they are combined with modifiers, either plasticizers or compatible resins, to enhance their performance. The phthalates, aryl phosphates, polymerized oils, and liquid resins are all used to plasticize cellulosics.[8]

Epoxy Resins--

The most commonly used epoxy resins are derived from the condensation of bisphenol A with epichlorohydrin. Resins with increasing molecular weight are produced by increasing the ratio of bisphenol A to epichlorohydrin. Resins employed in the paint industry have molecular weights varying from 400 to 4,000. Liquid resins with molecular weights of 400 are modified by the addition of reactive diluents (glycidyl ethers) for use in solventless, two-package coatings. Solid resins with molecular weights of about 1,000 are dissolved in solvents or dispersed in water as one component of two-package coatings. Resins with molecular weights of around 1,400 are applied as powders, together with dicyandiamide, or are used as reaction partners with fatty acids for producing epoxy esters. Resins with molecular weights ranging from 2,900 to 4,000 are combined with phenolic resins, melamine, and carbamides to form high quality baking finishes.[9]

Epoxy coatings can be classified into three principal categories, based on the method of cure: 1) two-package or amine-cured coatings, 2) epoxy baking enamels, and 3) epoxy esters.[6]

Two-package epoxy coatings consist of two separate components that are mixed just prior to use. One component consists of either a solid resin in solution, or a modified liquid resin; the other component is a curing agent, most commonly a polyamino compound. The coating cures by the room temperature reaction of the terminal epoxide groups with the hydrogen atoms of primary or secondary amines.

The principal types of amine curing agents that are available are polyamines, polyamine-adducts, and amine-terminated polyamide resins. Typical polyamines are diethylene triamine, triethylene tetramine, and tetraethylene pentamine. Polyamine-adducts are amine-terminated epoxy resins that are formed by pre-reacting an epoxy resin that is relatively low in molecular weight with an excess of polyamine, resulting in a curing agent with little free amine. Polyamides are the reaction products of polyamines and dimerized vegetable fatty acids. Polyamide-cured systems are not quite as chemically resistant, nor do they cure as rapidly, as the polyamine systems, but they are less irritating and offer longer pot-life.

Epoxy resins with molecular weights ranging from 2,900 to 4,000 may be combined with thermosetting phenolic and amino resins to produce high quality baking finishes. The large number of reactive groups in both the epoxy and the phenolic or amino resin gives a highly cross-linked structure which, when cured, is hard, tough, and solvent resistant. Epoxy powder coatings belong to the thermosetting category and exhibit the same general properties as epoxy baking enamels. The curing agents are usually friable solids, dry blended with the powdered resin, pigments, and additives. Curing agents include dicyandiamide, aromatic amines, and polyanhydrides.

Epoxy esters are prepared by reacting solid epoxy resins with drying oil fatty acids. Curing takes place at ambient temperatures, through the oxidation of the oil, as in alkyd paints, or it may be accelerated by baking. Although these esters are superior to alkyds in certain respects, they have the same handling and processing characteristics as alkyds.

Urethane Resins--

Urethanes are polymers that result from the reaction of isocyanates with materials that possess hydroxyl groups. Toluene diisocyanate is the most widely used isocyanate, followed by the so-called prepolymers. They are adducts of polyols with isocyanates, in which either of the components is in considerable excess of the other. The resulting intermediate is a medium molecular weight polymer that has reactive isocyanate groups. In addition to toluene diisocyanate, diphenyl methane diisocyanate is another aromatic isocyanate of commercial importance. Aliphatic isocyanates are used for coatings with superior light fastness and gloss retention. Important aliphatic isocyanates include hexamethylene diisocyanate, methylene dicyclohexyl diisocyanate and isophorone diisocyanate.[10]

Urethane coatings can be classified according to curing mechanisms as: oil-modified, moisture-cured, blocked, prepolymer plus catalyst, prepolymer/polyol, and lacquers.[10]

Oil-modified urethane coatings are made by reacting a drying oil with an isocyanate to form an urethane-oil resin. The ratio of isocyanate to hydroxyl is adjusted in order to leave no reactive isocyanate groups in the finished resin. Oil modified urethane coatings are one-package systems that cure by the oxidation of the unsaturated oil portion of the polymer. Driers, such as cobalt naphthenate, catalyze air drying.

Moisture-cured urethane coatings are one-package prepolymer systems that are characterized by the presence of terminal isocyanate groups. These systems cure into useful films by reacting the free isocyanate groups with ambient moisture.

Blocked urethane coatings are one-package systems. They are relatively inert at room temperature because the isocyanate has been reacted with a "blocking agent." Phenol, caprolactam, cresol, and methyl ethyl ketoxime are typical blocking agents that volatilize or break down when heated to 160°C or higher. When this occurs, the isocyanate radicals are released and readily react with substances, such as polyesters, that have active hydrogen groups. This reaction is normally catalyzed with dibutyltin dilaurate.

Prepolymer-plus-catalyst urethane coatings are two-package systems that cure by reacting an isocyanate prepolymer with a relatively small amount of catalyst, such as a monomeric polyol or polyamine contained in a second package. This coating system is essentially the same as the moisture-cured system, except that the catalyst is provided in a separate package to allow an accelerated cure. Methyl diethanolamine is a common catalyst.

Prepolymer/polyol urethane coatings are two-package systems that cure by reacting a prepolymer with a substantial quantity of a second package containing a polyol or polyamine and a small amount of catalyst. Polyols typically found include: polyethers, polyesters, polycaprolactone polyols, and castor oil derivatives. Dibutyltin dilaurate and zinc octoate are a typical catalysts.

Urethane lacquers are one-package coating systems that dry by simple solvent evaporation. In these lacquers, prereacted urethane polymers are combined with nitrocellulose or thermoplastic acrylics to produce a durable finish.

Vinyl Resins--

Vinyl resins for surface coatings are based on the following monomers: vinyl chloride, vinylidene chloride, vinyl acetate, and other vinyl esters. These resins are used in coatings as solutions in volatile organic solvents, as dispersions in plasticizers or volatile organic non-solvents, as dry powders, and as latexes.[11]

Vinyl solution coatings contain vinyl resins with low to medium molecular weights. Copolymers are more readily soluble and are preferred for solution coatings. Vinyl resins may be modified with carboxylic acid groups in order to increase adhesion to metal substrates, or hydroxyl-modified in order to improve adhesion to cellulosic materials, wash primers, or alkyd resins. Phthalate, adipate, and phosphate plasticizers are incorporated at levels of 5 to 30 percent of the resin weight in order to improve flexibility and impact resistance. Because vinyl resins are sensitive to heat and ultraviolet light, a variety of organo metallic compounds are used to inhibit resin degradation.

In vinyl dispersion coatings, resins with very high molecular weights are dispersed as discrete particles in a liquid. If this liquid contains only plasticizers, the dispersion is called a "plastisol". If this liquid contains organic solvents, the dispersion is called an "organosol". Dispersion coatings cure by baking; the high temperature softens the resin particles and increases the solvent action of the liquid portion, causing the particles to fuse. Vinyl powder coatings are similar to vinyl dispersions. Film formation also requires a fusion step; however, greater melting and flow are required for powders.

Vinyl latexes are emulsions of resins in water. The major use for latexes is in exterior house paints; they are not industrially important.

The most important coating application for polyvinyl butyral resins is in the preparation of corrosion inhibiting "wash primers." These coatings consist of polyvinyl butyral, phosphoric acid, and a corrosion inhibiting chromate pigment carried in a mixture of alcohols.

Pigments

Pigments are finely powdered insoluble solids dispersed in a liquid medium. Pigments significantly effect the properties of a coating system, and may be used for corrosion inhibition, reinforcement, and filler, as well as for color and opacity. Overall pigment use in paint and coatings is reported in Table 3. Pigments fall into three general classes: white, colored, and metallic.[6]

White pigments reflect incident light completely, if the refractive index is greater than that of the binder. The important white pigments can be divided into two main categories--reactive and non-reactive.

The reactive pigments include lead carbonate, sulfate, and silicate, and the oxides of antimony and zinc. They react with oleoresinous and acidic binders. The use of these pigments is mainly limited to construction, bridges, and industrial maintenance. The main non-reative pigments are titanium dioxide and lithopone. Pigments that appear white when exposed to the air, but exhibit little hiding power because of low refractive indices are termed "supplemental" or "extender" pigments. They are used to control gloss, texture, or viscosity.

Common extender pigments include barium sulfate; calcium carbonate, silicate, and sulfate; silica (quartz, synthetic and diatomaceous silica); and the silicates: clay, talc, and mica.[6]

Table 3. Estimated consumption of important pigments in paints and coatings.[4]

Pigments	Millions of pounds 1973	1974	1975	1976	1977
Titanium dioxide	864	791	711	787	796
Calcium carbonate	415	420	400	410	421
Talc	357	316	300	345	331
Clay	280	290	290	294	305
Silica	125	140	130	145	154
Iron oxide	115	105	95	104	115
Chromium	94	80	65	80	85
Barytes (barium sulfate)	95	85	76	78	81
Zinc dust	58	55	52	69	75
Other extenders and fillers	53	50	45	50	55
Zinc oxide	52	34	25	30	31
Aluminum	28	24	23	28	26
Lead (corrosion inhibiting)	26	26	23	22	22
Carbon black	22	19	18	19	20
Other colored inorganic)	15	14	14	17	19
Other organic	17	17	15	17	18
Other white opaque	10	9	8	9	9
Cuprous oxide	6	6	5	6	8
Phthalocyanine	5	5	4	5	6
Other	4	4	3	4	4

Colored pigments reflect only a certain part of the visible spectrum. The colored pigments can be divided into two basic groups--inorganic and organic. Many of the organic pigments are dyestuff-based; the dyestuff is combined with an inorganic compound to render it insoluble.

Metallic powders of aluminum or zinc may be used as pigments. These powders may be incorporated to produce a metallic effect, or may be included to provide corrosion protection by galvanic action.

Solvents

The primary function of solvents is to dissolve the binders and to provide a consistency suitable for application. Because the solvent evaporates, the least expensive combination of solvents is used, as long as the solvent will dissolve the binders and give the desired viscosity.

Solvency and volatility are the prime factors in determining the usefulness of solvents. Solvency is largely a function of the kind of binder. Polar resins require polar solvents; non-polar resins require non-polar solvents. The volatility of the solvents affects the evaporation rate, which in turn influences the behavior of the coating during application and drying. The optimum evaporation rate is dependent upon the method of application.

Solvent use in paint and coatings is reported in Table 4.

Table 4. Estimated consumption of important solvents in paints and coatings.[4]

Pigments	Millions of pounds 1973	1974	1975	1976	1977
Aliphatic hydrocarbons	1603	1375	1280	1185	1120
Methyl ethyl ketone	380	342	319	345	357
Xylenes	544	435	363	325	300
Other aromatics	421	399	326	305	290
Toluene	326	250	268	260	255
Ethanol	200	210	200	200	200
Acetone	200	184	175	190	196
Glycol ethers and ether esters	180	194	176	190	195
n-Butanol	140	155	135	145	151
Isopropanol	121	125	115	120	125
Ethyl acetate	120	103	91	110	110
Methyl isobutyl ketone	122	125	103	105	105
Butyl acetates	93	86	80	84	86
Other ketones and esters	70	75	70	74	75
Ethylene glycol	57	52	48	54	56
Propyl acetates	60	55	50	53	54
Other alcohols	40	42	40	41	41
Other solvents	40	40	36	38	38
Propylene glycol	30	32	29	33	34
Methylene chloride	15	15	14	15	15
Other glycols	1	1	1	1	1

Additives

Many items in a paint formulation are used in relatively small quantitites for the purposes of manufacturing ease, package stability, application ease, and final appearance or performance. These items are collectively referred to as additives, and rarely exceed 1 or 2 percent of the total formulation. They can be classified by function as paint driers, anti-skinning agents, mildew inhibitors, rheological modifiers, and latex paint additives.[12]

Paint Driers--

The oldest and most important class of paint additive is the paint driers. They promote the drying, curing, or hardening of oxidizable coating vehicles, such as those found in alkyd, oleoresinous, epoxy ester, and urethane-oil paints. The principal materials used as paint driers are metal soaps of naphthenic acid or tall oil fatty acid. Cobalt is the most active of the metal driers, followed by manganese. Lead is the most commonly used metal soap because of its through drying properties. Cobalt and manganese are used at levels ranging from 0.02 percent to 0.06 percent metal, based on total vehicle solids. Lead is used at levels of 0.5 to 1.0 percent. Other metals used in driers include barium, calcium, cerium, iron, zinc, and zirconium.[12]

Anti-Skinning Agents--

These agents act as anti-oxidants, inhibiting skin formation in the package, but they are volatile enough that drying proceeds after paint application. Oximes and substituted phenols are two chemical classes used as anti-skinning agents in paint; the oxime is the most common by far. Oximes also function by forming complexes with metal driers, impairing their action until the oxime has evaporated.[12]

Mildew Inhibitors--

Fungicides are incorporated in exterior house paints and in some interior industrial maintenance paints in order to prevent mildew growth on the dried paint film. The phenyl mercury compounds are the most widely used fungicides. Mercury concentration levels in paints normally range from 0.5 to 2.0 percent of the total paint. Other fungicides used in paints include cuprous oxide, copper-8-quinolinolate, and phthalimides.[12]

Rheological Modifiers--

This group of paint additives includes compounds used to prevent the settling of pigments or the sagging of the applied paint film. Materials used for these purposes include soaps, modified drying oils, and clays.[12]

Latex Paint Additives--

In contrast to solvent-type paints, latexes consist of both pigment and binder dispersed in a liquid medium. Anionic surfactants are used to maintain pigment dispersion and non-ionic surfactants are used to stabilize the total dispersed system. Because of the presence of the surfactants, anti-foaming agents are required to prevent foam formation in manufacture and use. Proteins, cellulose derivatives, polysaccharides, and water-soluble acrylic polymers are used to modify paint consistency. Ether alcohols, tributyl phosphate, pine oil, and other solvents are incorporated as temporary plasticizers, which promote coalescence of the latex particles. Alkyl mercury compounds, tributyltin oxide, and chlorinated phenols are common latex preservatives.[12]

SECTION III. SPRAY APPLICATION METHODS

Industrial finishes are commonly applied by spraying because of the excellent finish that can be obtained and the speed at which the coating material can be applied. The spray can be generated by compressed air, by hydraulic pressure, or by electrostatic forces. This section briefly describes these three methods. Section IV describes the industries in which spray painting was studied for this report. The hazards associated with these methods and their relative advantages in terms of worker protection are discussed in Sections V and VI.

COMPRESSED AIR METHOD

The compressed air spray gun is the most widely used because of its versatility, its low cost, and because it creates a high quality finish. In this method, compressed air provides the energy to atomize the finish. The atomization is produced by an air nozzle. Two types of nozzles are used: external mix and internal mix nozzles. In the external mix nozzle, the coating and the compressed air exit from separate orifices and are mixed outside the nozzle. The air jet atomizes and shapes the spray fan. Internal mix nozzles combine the compressed air and finishing materials in a chamber inside the nozzle. The atomized mixture is shaped by the geometry of the chamber opening.

Finishing materials can be delivered to the spray gun under pressure, or by the siphoning action of a siphon-fed, external mix nozzle. Siphon-type guns require small paint containers attached directly to the spray gun, thus they are limited to low volume applications. Because siphon-fed guns require more compressed air than pressure-fed equipment, they produce more stray mist.

Heated paint can be applied by air-atomized equipment. Heating the paint lowers the viscosity, which reduces the amount of solvent required. The finish cools rapidly after it is sprayed, which creates an applied coat that is much more viscous than a coat that is sprayed unheated. This process permits application of heavier films; applications also dry more rapidly. Finishes can be applied at lower air pressures, which reduces the amount of stray mist generated.

AIRLESS METHOD

Airless spray equipment atomizes paint by forcing it through a very small orifice at a very high pressure. The airless spray gun consists simply of a device to hold the orifice and a valve for shutting off the flow. The size and shape of the nozzle determine the volume of material sprayed and the geometry of the spray pattern. The hydraulic pressure necessary for atomization is provided by a high pressure pump that is operated by compressed air or an electric motor.

Like air-atomized equipment, airless systems can be used to spray heated paint with similar advantages. In addition, with airless systems, lower hydraulic pressures can be used and finer atomization can be achieved.

The high pressures associated with the airless method carry with it the hazard of hypodermic injection for persons who may accidentally contact the spray. Because the paint may spread under the skin through even a tiny wound, immediate medical attention is required.

ELECTROSTATIC METHOD

In electrostatic spraying, an electrical charge is applied to the atomized coating particles, either by the creation of an ionized zone within the spray cone area, or by imparting a charge to the fluid stream prior to its release from the spray gun head. The charged, atomized paint particles are attracted to the conductive object being finished by the electrostatic potential between the paint and the object.

The atomization can be achieved by the use of air-atomizing or airless type equipment, or solely by the use of electrostatic means. In this last method, the coating material is introduced into the center of a rapidly spinning disk or bell, which is charged to a high potential. As the coating reaches the edge of the disk or bell, the repulsive forces of the like charges causes the coating to atomize.

SECTION IV. INDUSTRIAL FINISHING PRACTICES

This section describes the industries in which spray finishing operations were studied. Included in this summary are the SIC codes of the subject industry, the application process, and the commonly used resin systems, solvents, and pigments.

AUTOMOBILE REFINISHING

This industry is classified under SIC major group 75 (Automotive Repairs, Services, and Garages). It includes the following categories: SIC 7535 (Paint Shops) and SIC 7531 (Automotive Repair Shops). These are establishments primarily engaged in automotive painting and refinishing, and car body repairing.[1]

The automotive refinishing industry was considered separately from the automobile producing industry because of the nature of the establishments performing this work. Many of these shops can be characterized as being small, poorly ventilated, with few or no controls. Only modern, larger automobile paint shops use auto refinishing booths.

The surface that is to be painted is normally cleaned, sealed, and sanded before paint application. These operations are usually performed by hand. Coatings are normally applied by hand-held air atomizing equipment. The coating material is generally cured by air drying.

Alkyd enamels are used for total body repainting because, unlike the case with lacquer finishes, no hand rubbing is needed to gain a high gloss surface film. The rapid cure of lacquer finishes permits blending of spot repairs into undamaged areas, which makes this type of finish more popular in body repair shops. The air drying alkyds are more typically applied in spray booths because of their susceptibility to contamination by airborne dust. The commonly used resins, solvents, and pigments are shown in Table 5.

WOOD FURNITURE

This section includes industrial products described in the SIC major group 25 (Furniture and Fixtures). These establishments are primarily engaged in the manufacture of wooden household and office furniture; upholstered furniture on wooden frames; television, radio, and sewing machine cabinets; furniture for schools, churches, libraries, and assembly halls. Also included are establishments engaged in manufacturing wooden shelving, lockers, store fixtures; prefabricated partitions; plastic laminated fixture tops and related fabricated products.[1]

Before coating, the wood surface is prepared and pretreated in several steps, such as sealing, glazing, sanding, and polishing. These techniques are used for both natural wood and unfinished exterior or interior grades of plywood. Some materials may require solvent wiping and sanding. Coating material is generally applied in several layers, which requires intervening steps like sanding, rubbing, daubing, and polishing. These procedures are performed by hand and, therefore, the workers are exposed not only to the liquid coating material itself, but to the wood dust that may also contain the coating material. Coating materials are predominately applied by hand. Sometimes electrostatic spray techniques are used; they require the use of a conductive primer (applied by dipping), or controlled moisture content.

Table 5. Automobile refinishing (resins, solvents, and pigments as percent of total consumption).[4]

Resins	Percent	Solvents	Percent	Pigments	Percent
Alkyd	47	Xylene	32	Titanium dioxide	33
Acrylic	31	Ethyl acetate	12	Talc	14
Cellulosic	11	Toluene	10	Clay	12
Urethane	7	MEK	10	Barytes	12
Other	4	Butyl acetate	9	Chromium	8
		Other	27	Iron oxide	6
				Lead	6
				Other	9

The most common types of resins, solvents and pigments are included in Table 6.

Table 6. Wood furniture (resins, solvents and pigments as percent of total consumption)[4]

Resins	Per-cent	Solvents	Per-cent	Pigments	Per-cent
Alkyd	42	Toluene	27	Titanium dioxide	26
Cellulosic	27	Xylene	15	Talc	25
Amino	8	n-Butanol	12		
Other	23				
		Ethanol	10	Silica	18
		Isopropanol	10	Calcium carbonate	15
		MEK	8	Iron oxide	8
		MIBK	7	Other	8
		Other	11		

METAL FURNITURE

This industry is classified under SIC major group 25 (Furniture and Fixtures) and 34 (Fabricated Metal Products except Machinery and Transportation Equipment). These establishments are engaged in the manufacture of metal household and office furniture, garden furniture, cabinets, chairs, storage and display cases, metal partitions, shelving, metal doors, lockers, industrial and work benches, and restaurant furniture. They also include products such as metal doors, window and door frames, hardware cabinets and different types of hardware (locks, hinges, and so forth).[1]

The metal surface to be coated is cleaned and pretreated. Most plants use automated three-stage or five-stage pretreatment processes, incorporating hot water rinses, phosphoric acid baths, and chromic acid rinses.

Alkyd baking enamels are most used. Various acrylics (both thermosetting and emulsion), high solids polyesters, and powders are also used in lesser quantities. Electrostatic spray guns are used in both automatic and hand-held versions.

Both liquid paint and powder coating lines are highly automated, but hand-held conventional and airless spray guns are still used in reinforcement operations. It is common for defective coatings to be manually reworked. The commonly used resins, solvents, and pigments are shown in Table 7.

Table 7. Metal furniture (and fixtures).
(resins, solvents, and pigments as percent of total consumption)[4]

Resins	Percent	Solvents	Percent	Pigments	Percent
Alkyd	39	Aliphatic hydrocarbons	36	Titanium dioxide	60
Amino	12	Xylene	18	Iron	9
Acrylic	11	Toluene	10	Barytes	7
		MEK	10	Talc	6
Vinyl	11	Other aromatics	9	Calcium carbonate	6
Polyester	6	n-Butanol	5	Chromium	3
Other	16	Other	12	Other	9
Cellulosic	5				

MAJOR APPLIANCES

This industry is a part of SIC major group 34 (Fabricated Metal Products, except Machinery and Transportation Equipment) and 36 (Electrical and Electronic Machinery, Equipment, and Supplies). These establishments are primarily engaged in the manufacture of household ovens, ranges, grills, freezers, refrigerators, and laundry machinery. They also include different types of heaters, gas-oil burners, domestic furnaces, air conditioners, and different types of refrigeration equipment.[1]

Before coating, the metal surfaces are prepared in order to remove rust, oil, and other unwanted material, and to passivate the surface. Treatment generally involves eight automated stages, consisting of alkali cleaning, double water rinsing, and a zinc-phosphate bath, followed by water, chromic acid, and deionized water rinsing.

Primers are generally applied by electrocoating in a water bath that contains 8 to 10 percent paint material. As alternatives to this method, dip and flow coating techniques can be utilized. Some primers are still applied by manual or automatic spraying.

Top coating is usually accomplished by electrostatic spraying. Both automatic and hand-held electrostatic guns are used. The automatic equipment is typically an electrostatic bell or disk. Manual spray equipment is used primarily for reinforcement on less accessible surfaces and touch-up operations. The commonly used resins, solvents and pigments are shown in Table 8.

Table 8. Major appliances (resins, solvents, and pigments as percent of total consumption).[4]

Resins	Percent	Solvents	Percent	Pigments	Percent
Acrylic	43	Glycol ether and ether esters	21	Titanium dioxide	61
Epoxy-ester	17	Xylene	20	Iron oxide	10
Polyester	13	Aliphatic hydrocarbons	16	Talc	8
Amino	9	Other aromatics	11	Silica	6
Other	18	MEK	8	Chromium	5
		n-Butanol	7	Lead	2
		Toluene	7	Other	8
		Other	10		

TRANSPORTATION (non-automotive)

This section includes those industries covered by SIC major group 37 (Transportation Equipment). Included here are establishments engaged in manufacturing truck and bus bodies, truck beds, truck cabs, and different types of trailers, such as bus trailers, truck trailers, motor truck trailers, semitrailers for missle transportation, and so forth. It also includes establishments mainly engaged in building and rebuilding locomotives, and equipment for operation on rails for freight and passenger service, and establishments that manufacture or assemble all types of aircraft.[1]

Because of the size and shapes of these products, both primers and topcoats are generally applied by hand spray equipment. Railroad cars are painted primarily for protection against corrosion; aesthetic considerations are secondary. Application techniques (primarily airless) are therefore geared to providing a high film build in a minimum time. Truck finishes are also applied by hand-held spray guns and cured by baking or air drying. Alkyd-type finishes predominate in this industry.

In the aircraft industry two component epoxy and urethanes predominate because of their ability to produce a baked quality finish without baking. Airless spray equipment is generally not accepted because of aesthetics. The most commonly used resins, solvents and pigments are shown in Tables 9, 10, and 11.

Table 9. Trucks and buses (resins, solvents, and pigments as percent of total consumption).[4]

Resins	Percent	Solvents	Percent	Pigments	Percent
Alkyd	40	Aliphatic hydrocarbons	26	Titanium dioxide	35
Acrylic	30	Acetone	14	Barytes	15
Amino	16	Xylene	13	Lead	9
Epoxy ester	6	Other aromatics	12	Chromium	8
Other	8	Toluene	7	Talc	8
		Butanol	7	Iron oxide	8
		MEK	7	Other	17
		Other	14		

Table 10. Railroads (Resins, Solvents and Pigments as Percent of Total Consumption).[4]

Resins	Percent	Solvents	Percent	Pigments	Percent
Alkyd	50	Aliphatic hydrocarbons	38	Titanium dioxide	43
Epoxy	16	Other aromatics	12	Talc	13
Urethane	8	Glycol ether and ether esters	10	Silica	8
Acrylic	7	Xylene	9	Chromium	8
Amino	6	n-Butanol	8	Barytes	5
Other	13	MEK	10	Iron oxide	8
		Acetone	8	Lead	3
		Toluene	5	Other	12
		Other ketones	5		

Table 11. Other transportation (resins, solvents, and pigments as percent of total consumption).[4]

Resins	Percent	Solvents	Percent	Pigments	Percent
Urethane	33	Aliphatic hydrocarbons	23	Titanium dioxide	47
Epoxy	19	Other aromatics	18	Talc	16
Alkyd	14	Acetone	9	Silica	11
		Glycol ether and ether esters	6	Barytes	6
Acrylic	10	Toluene	6	Iron oxide	6
Other	24	Xylene	6	Chromium	4
		n-Butanol	6	Lead	4
		Isopropanol	5	Other	6
		Ethanol	5		
		MEK	5		
		MIBK	5		
		Other	6		

MACHINERY AND EQUIPMENT

This section is included in the SIC major group 35 (Machinery except Electrical). The categories covered here are: SIC 3523 (Farm Machinery and Equipment) and 3531 (Construction Machinery and Equipment). The establishments considered here are engaged in manufacturing all kinds of farm machinery and equipment for use in the preparation and maintenance of the soil, planting and harvesting, and for use in performing other farm operations and processes. The category also includes the heavy equipment that is generally used in construction industries, such as bulldozers, scrapers, concrete mixers, cranes, dredging machines, pavers, and power shovels.[1]

Coating application is generally by airless or electrostatic-airless spray technology; however, dipping and flow coating are also used. Despite some automatization, most top coating is done by hand-spray equipment. As a curing method, air-dry and force-dry techniques are mainly used. The most common resins, solvents, and pigments can be found in Table 12.

Table 12. Machinery and equipment (resins, solvents, and pigments as percent of total consumption).[4]

Resins	Percent	Solvents	Percent	Pigments	Percent
Alkyd	48	Aliphatic hydrocarbons	51	Titanium dioxide	54
Acrylic	13	Other aromatics	9	Talc	9
Amino	11	Xylene	6	Chromium	6
		Other ketones	6	Lead	2
Epoxy	5	Other	28	Clay	6
				Other	23
Urethane	5				
Other	18				

SECTION V. HEALTH HAZARDS IN SPRAY FINISHING

ROUTES OF ENTRY

Toxic substances can gain entry to the body through inhalation, skin contact, and ingestion, although this last route is of little industrial importance. Many industrial chemicals penetrate or react with the surface of the skin, and cause injury either at the point of contact or act as a systemic poison. In spray finishing operations, contact with chemicals that are likely to penetrate the skin most often occurs during mixing and cleanup operations. Because many contaminants can be inhaled easily and remain in the lung or be absorbed into the bloodstream, inhalation ranks as the most significant route of entry in spray finishing.

CONTAMINANT GENERATION

In evaluating the hazards of spray finishing, both the method of application and the paint formulation require analysis. The method of application determines the degree of atomization, the relative efficiency in depositing the coating material on the object, and the site of deposition in the respiratory tract.

Compressed air spraying atomizes liquid paint by directing a high velocity air jet at the paint stream as it exits from a fluid nozzle. The flow of air conveys the finely atomized droplets to the object being painted. Hama and Bonkowski[13] note that approximately 20 percent of the droplets are smaller than 12 microns. In airless spraying, the paint is atomized by forcing it through a small orifice under very high pressure. This method produces less fog than compressed air spraying because not as many fine droplets are produced. Hama and Bonkowski note that only 2 percent of the spray droplets in airless painting are less than 12 microns. In electrostatic spraying, the paint can be atomized with compressed air, by hydraulic pressure as in airless spraying, or solely by electrostatic forces. Because the charged paint particles are directed to a grounded object by electrostatic forces, paint delivery is more efficient.

TOXIC SUBSTANCES

The toxic substances encountered in spray finishing fall into the broad categories of pigments, synthetic resins, solvents, and additives. The substances in widest use in each of these categories are discussed in the following sections.

Inorganic Pigments

Aluminum--

Finely divided aluminum metal is used to produce "metallic" paints. No acute or chronic toxicity has been demonstrated in humans from aluminum metal.

Barite (Barytes)--

Barite is a crystalline mineral consisting essentially of barium sulfate. Because it is insoluble, the potential for barium poisoning is low.

Pneumoconiosis has been reported in workers inhaling barium containing dusts.[14]

Calcium--

Calcium carbonate is widely used as an extender pigment in paint. It is considered a nuisance particulate.[15]

Chromium--

Both trivalent and hexavalent forms of chromium are used in paint pigments. The trivalent form occurs in the pigments chromium oxide green and Guignet's green (hydrated chromium oxide). The trivalent compounds possess a low order of toxicity.[14] Hexavalent chromium occurs as the chromates of barium, lead, strontium, and zinc. Hexavalent chromium compounds have been implicated in excess lung cancer death rates in workers who produce chromates from chromite ore and in handlers of chromium pigments. Hueper and Payne[16] determined that hexavalent chromium acts as a carcinogenic agent when it is present in a form that provides for adequate biological availability, and that its availability is a function of the solubility of the chromium compound.

Lead--

Various lead compounds are used as pigments in paints. These include the acetate, antimonate, borate, carbonate, chromate, molybdate, oxides, oxychloride, phosphite, phosphosilicate, and sulfate. Piper[17] notes that in spite of the differing solubilities of these materials in water, the hazard of plumbism, or chronic lead poisoning, is always present and must be treated seriously. The toxic effects of lead exposure are well documented. Lead poisoning is manifested by general weakness; anorexia; insomnia; pains in the muscles, joints, and abdomen; and anemia.

Silica and Silicates--

Silica (both crystalline and amorphous), and the silicates clay, diatomaceous earth, mica, and talc are widely used as extender pigments. With the exception of clay, all have been demonstrated to produce fibrosis of the lung. A preliminary study of the health hazards in the painting trades suggested that "mixed dust pneumoconiosis" is common among painters.[18] While extender pigments are used in substantial quantitites in some paint formulations, these materials may be at least partially locked up by encapsulation in the resinous binder.

Titanium Dioxide--

Titanium dioxide is the pigment in greatest use in paints. It is considered a nuisance dust.[15] A preliminary study of the health hazards in the painting trades conducted in 1974 found that individuals who were heavily exposed to titanium had comparitively few abnormalities that could be attributed to this metal.[18]

Zinc and Zinc Oxide--

No acute or chronic illness has been attributed to zinc oxide dust or metallic zinc. Zinc oxide dust is considered a nuisance particulate.[15]

Organic Pigments

Toxicity data for the majority of these materials is limited to acute oral toxicities. In terms of the mean lethal dose (LD_{50}), most organic pigments are innocuous; in rats they possess acute oral toxicities greater than 10 grams per kilogram of body weight.[19]

The chronic hazards posed by these materials are largely unknown. Many of the pigments are based on dyestuffs; the dyestuff is combined with an inorganic compound to produce an insoluble pigment. The dyestuffs have been studied more extensively than the pigments, and several have been implicated as cancer risks. In paint the biological availability of these materials is probably limited by the insolubility of the pigments and their partial encapsulation in the paint resin matrix. Fat and/or water soluble dyes are used in some wood stains, increasing the potential hazard.

Synthetic Resins

Acrylic Resins--

No evidence exists that would suggest any unusual toxicity for the acrylic resins, although the potential does exist that unreacted monomer could be present. Of these monomers, acrylonitrile represents the greatest hazard. Isocyanates are used to cross-link or "harden" certain acrylic paint systems. The hazards of isocyanates are discussed under the heading "Urethane Resins." Dimethyl ethanolamine, a cross-linking agent used in certain acrylic emulsion coatings, has been reported to induce asthma and rhinitis.[20]

Alkyd Resins--

Piper[17] cites no major hazards from this group of resins, and notes that none of the potentially noxious raw materials used in manufacture is likely to remain free. Alkyd resins have a long history of use with no reports of any chronic hazards.

Alkyd paints employ metal soaps of organic acids to catalyze the oxidation of the drying oil component. Because lead soaps are commonly used, lead is a potential hazard in any drying-oil-type paint (alkyd, epoxy ester, oleoresin, and urethane-oil). Lead used as an oxidation catalyst may comprise 0.5 to 1.0 percent of the paint solids by weight.

Amino Resins--

These resins are used as cross-linking agents in alkyd, acrylic, and epoxy baking enamels. Piper[17] notes that traces of formaldehyde may be present, but seldom in sufficient quantities to present a hazard.

Cellulose Resins--

Cellulose resins possess no known toxic hazards. Coatings produced from cellulosic resins contain substantial quantities of modifying resins or plasticizers. These plasticizers include castor oil, dibutyl phthalate, tributyl phosphate, tricresyl phosphate, dioctyl phthalate, and others. The toxicity of these materials is discussed under "Plasticizers".

Epoxy Resins--

Epoxides are alkylating agents of moderate reactivity. In biological systems, epoxies react with amino acids, nucleic acids, and with phosphate groups. Reaction with proteins will give rise to antigens probably responsible for allergenic activity; the alkylation of membrane constituents is involved in irritation; and reactions with DNA are associated with gene mutation and cancer.[9]

Epoxy resins used in coatings are most commonly based on epichlorohydrin and bisphenol-A. In his comprehensive review of epoxy resins used in surface coatings, Lemon[21] reports that extensive testing of these resins indicated no significant toxicity following regular ingestion or exposure to their vapors. No skin cancer was produced by long term percutaneous exposure. Skin irritation was produced only by the liquid resin grades.

Liquid epoxy resins are primarily used in solvent-free and waterborne two-component epoxy paints. These liquid resins are modified by the addition of reactive diluents (glycidyl ethers). These reactive diluents are themselves irritants to the skin, the eyes, and the respiratory tract.

Aliphatic and aromatic polyamines, polyamine adducts, and polyamides are used as curing agents in two component epoxy coating systems. The aliphatic amines are potent irritants and sensitizers; the aromatic amines are somewhat less potent. The polyamide resins are relatively harmless. Acid anhydrides and formaldehyde resins are used as cross-linking agents in powder coatings and baking enamels. The acid anhydrides are irritants and sensitizers.[22]

Epoxy resins are commonly reacted with fatty acids to produce epoxy esters. Because coatings produced with these resins contain no unreacted epoxy groups, no hazard exists.

Urethane Resins--

Organic isocyanates are the principle hazard associated with urethane coatings. Isocyanates can cause severe irritation to the conjunctiva, and respiratory distress. They react with various protein functional groups and should be capable of forming antigens.[23] A typical response to isocyanate inhalation, either as a vapor or an aerosol, is the manifestation of an asthma-like syndrome, characterized by a feeling of chest constriction and difficult breathing, sometimes accompanied by a dry, irritant cough. A small percentage of the population may become sensitized to isocyanates, whereupon the above symptoms are produced on exposure to even low airborne concentrations.[24]

The degree of isocyanate hazard varies with the type of urethane coating. Oil urethanes and urethane lacquers contain no unreacted isocyanate and thus represent little or no hazard. Moisture-cured urethane varnishes and two package urethane coatings contain reactive isocyanate groups. Most contain polymeric isocyanates to minimize the hazards of vapor inhalation. Hardy and Devine[24] attribute adverse respiratory effects to the inhalation of isocyanate-containing aerosols. They state that inhalation of any species with multiple unreacted isocyanate groups may impair respiratory function or give rise to sensitization. They cite many cases of respiratory distress among automobile refinishers in the United Kingdom since two-component urethane coatings containing aliphatic isocyanates were introduced in 1976.

In his review of the hygienic aspects of urethane coatings, Ziegler[25] reports on aerosol inhalation studies in rats of monomeric toluene diisocyanate (TDI), hexamethylene diisocyanate (HDI), and polyisocyanates based on these materials. While TDI and HDI possessed comparable acute toxicities, the polyisocyanates did not. The toxicity of the monomeric materials was an order of magnitude greater than the TDI-based polyisocyanate, but only slightly greater than that based on HDI. He also reports that Ames tests conducted on these polyisocyanates indicate that they are not mutagenic.

Vinyl Resins--

The principle hazard associated with vinyl resins used in surface coatings is the potential for residual vinyl chloride monomer. Like cellulosic coatings, vinyl resins are combined with substantial quantities of plasticizer to improve their properties as film-formers.

Solvents

Alcohols--

Ethanol, n-butanol, and isopropanol are the alcohols most used in paint. Their principal physiological effect is irritation of the mucous membranes of the eyes and upper respiratory tract. Methanol receives limited use as a paint solvent. It is a poison to the central nervous system and to the optic nerve.[26]

Esters--

Ethyl, butyl, and propyl acetate are aliphatic esters used in large quantities as lacquer solvents. The aliphatic esters are irritants to the mucous membranes of the eyes and upper respiratory tract; at high concentrations they can cause headache, drowsiness, and unconsciousness. Prolonged exposure to the skin can cause irritation, which is a result of the defatting action of these solvents. No chronic hazards have been associated with these solvents.[26]

Glycols and Glycol Derivatives

Ethylene and propylene glycol are the principle glycols used in paint. Inhalation of ethylene glycol may result in central nervous system depression and hematopoietic dysfunction. Propylene glycol posseses very low toxicity and is unlikely to pose any hazard.[26]

Ethylene glycol ethers are mildly irritating to the skin. The vapor may cause conjunctivitis and upper respiratory tract irritation. Temporary corneal clouding may also result and may last several hours. The acetate derivatives cause greater eye irritation than the parent compounds. The butyl and methyl ethers may penetrate skin readily.

Ketones--

Acetone, methyl ethyl ketone, and methyl isobutyl ketone are the ketones most used as paint solvents. On contact with the skin, these solvents may produce a dermatitis after repeated exposure. High vapor concentrations are irritating to the conjunctiva and mucous membranes of the nose and throat and can produce narcosis. No chronic systemic effects are known to exist.[26]

Petroleum Distillates--
Petroleum distillates are the materials in greatest use as paint solvents. The term includes complex mixtures of solvents distilled from petroleum and distinguished by their boiling ranges and aromatic content. These materials are irritating to the skin, to the conjunctiva, and to the mucous membranes of the upper respiratory tract. One fraction, hexane, is reportedly associated with peripheral neuropathy. The lower boiling mixtures may contain benzene, a well known blood poison.[27]

Toluene and Xylene--
Toluene and xylene are the most important aromatic hydrocarbons used as paint solvents. Both compounds may cause irritation of the eyes, respiratory tract, and skin, and high concentrations produce depression of the central nervous system. Commercial grades of toluene may contain benzene. High concentrations of xylene may cause pulmonary edema, anorexia, nausea, vomiting, and abdominal pain.[26]

Additives

Other products added to paint include driers, anti-skinning agents, surfactants, plasticizers, and fungicides. With the exception of the plasticizers, these materials represent only a small fraction of the coating formulation. Toxicity data for many of those substances is limited to acute oral toxicities. Because of the variety of paint additives, only the most common materials are discussed here.

Paint Driers--
These materials include the metallic salts of tall oil and naphthenic acids. Fassett[22] reports that the acute oral toxicity of the metal naphthenates is low; the oral LD_{50} in rats ranges from 4 to more than 6 grams/kilogram.

Plasticizers--
This group of additives includes castor oil, dibutyl phthalate, dioctyl phthalate, tributyl phosphate, tricresyl phosphate, polyester resins, sulphonamides, and chlorinated diphenyls. Tributyl phosphate excites the central nervous system and is a respiratory irritant.[22] The chlorinated diphenyls have been implicated in cancer of the skin and liver.[28] The phthalates are relatively inert materials.

SECTION VI. CONTROL OF HEALTH HAZARDS

This section presents the control methods that were discussed in the literature or studied in the field surveys. These methods involve the application of the basic control principles of substitution, isolation, ventilation, and work practices.

SUBSTITUTION

Substituting less hazardous materials, equipment, or even a less hazardous process, may be the least expensive, as well as the most positive, method of controlling an occupational hazard. In order to minimize the hazards in spray finishing, coating materials should be formulated with relatively safe ingredients, and with a minimum amount of solvent.

Substitution of Materials

Pigments--

Organic pigments can be used in place of the principle lead- and chromium-containing pigments used in industrial finishes. However, the organic pigments are less durable, have reduced corrosion resistance, and have a tendency to fade. Besides lead and chromium, other heavy metals (cadmium, antimony, arsenic, and water soluble barium) are used to a limited extent in paint pigments. Most of these pigments also contain lead, thus, eliminating lead may remove other heavy metals.

Webb[29,30] describes available lead-free pigments and their properties. He notes that a lead-free color with properties exactly matching a lead-containing color will cost more. To hold down costs, he suggests changing the color of the product to the browns, blues, violets, whites, grays, blacks, or certain shades of green that can be made inexpensively with lead-free pigments. Similarly, costs can be held down in a switch to a lead-free pigment if some reduction in pigment performance, such as bleed resistance, color intensity, light fastness, and heat resistance, is accepted.

Panush[31] discusses the shortcomings of some traditional non-chromate pigments for use in automotive finishes, citing poor color matching, increased cost, and weakened durability to exposure. He lists those pigments that have potential for non-chromate automotive colors.

Considerable interest has been shown in the automobile and ship building industries in metal primers that contain metallic zinc dust in place of zinc chromate. Metallic zinc protects the metal substrate by galvanic action rather than by inhibition and, unlike zinc chromate, zinc dust is of low toxicity.

Solvents--

Several alternatives exist for either reducing or eliminating organic solvents in industrial finishing. These include waterborne, non-aqueous dispersion, high solids, or powder coating techniques. Development of these techniques has been hastened by legislation that limits the release of volatile organic hydrocarbons into the environment, and by the increasing cost of the solvent materials.

Waterborne finishes have some distinct advantages over high solids, powder, and other types of solvent-substitute coatings for many applications. These advantages include low flammability, reduced solvent toxicity and odor, water cleanup, reduced environmental pollution, and lower energy requirements[32]. The greatest advantage is that, in many cases, waterborne coatings can be applied and air-dried or oven-cured in existing coating lines with little or no modification. On a cost-per-square-foot painted basis, waterborne coatings are competitive with solvent-based.[33] Waterborne coatings can take the form of emulsions or solutions. In general, the emulsion systems allow a higher solids content and lower levels of organic co-solvents than the water soluble coatings. Two problem areas arise in waterborne coatings: 1) waterborne coatings are applied at higher viscosity, making atomization more difficult, and 2) waterborne coatings are conductive, requiring special precautions in electrostatic spraying. The atomization difficulties may require the use of higher air pressures for atomization, which may increase the spray painter's exposure to overspray and noise.[34] In addition, questions have been raised about the coupling solvents and pH control materials used in waterborne coatings.

A second option for the reduction of solvent content is the use of high-solids coatings. The effect of increasing solids content from the 20 percent that is typical of solution coatings to 60 percent is to reduce solvent consumption for equal coverage by a factor of 6. The resins used in low solids finishes are generally not suitable for high-solids coatings. In formulating sprayable high-solids coatings, it is necessary to use lower molecular weight polymers to minimize the rise in viscosity. In addition to molecular weight reduction, the resin manufacturer must incorporate reactive groups to each small polymer chain, because at some point, it is necessary to combine the shorter chains, to assure satisfactory performance of the applied coating. The more the molecular weight of the resin is reduced, the higher the solids content can be raised. However, when more combination is required, more catalyst and/or curing agent must be added. As catalyst content is increased, paint stability decreases to the point where it is necessary to package the two components (resin and curing agent) separately. Unfortunately, the more reactive fast curing products are also generally more toxic.[35] Current high-solids coatings are dominated by alkyd and oil-free polyester resins, but high solids acrylics, epoxies, and polyurethanes are in the development stage.[36]

Non-aqueous dispersions (NADs) are a third option to reduce total solvent content. NAD systems can achieve a higher usable solids content of 50 to 60 percent, compared to the the 20 percent of a typical solution system.[37] Non-aqueous dispersion finishes are sometimes considered hybrids of solution systems and conventional emulsions. The aliphatic hydrocarbons, which in general are lower in toxicity than oxygenated solvents, can be used as the main solvent component in NAD systems, although they are poorer solvents for common resins.

Powder coatings represent the ultimate step in the removal of solvent hazards from paint spraying. Powder coating requires not only special application equipment (electrostatic or flame spray guns) but special powder recovery booths. Other limitations include difficulties with frequent color changes, metallic finishes, and wood and plastic substrates. Advantages of powder coatings include the lack of solvent emissions, low energy consumption, and the ability to produce a heavy coating in a single pass.[38] This coating technique has been most successful in the appliance industry, which is the largest industrial user of powder coatings.[39]

Isocyanates--
The monomeric isocyanates are well known irritants and sensitizers. The use of heat-cured, blocked isocyanate prepolymers eliminates the hazard during spray application. In these coating systems, phenol, caprolactam, cresol, or methyl ethyl ketoxime may be used as blocking agents that will volatilize or breakdown upon heating at temperatures above 160°C.[40]

Epoxy Curing Agents--
Amine-cured epoxy coatings have a dermatitis potential; asthma-like symptoms and urticaria have been reported. Key[41] discusses polyamides used as curing agents. These products are non-toxic, non-irritating, and provide a longer pot-life, but they possess somewhat lower resistance to chemical attack and do not cure as rapidly as polyamine systems. Key also suggests the use of Cardura(R)E ester in place of the more irritating and sensitizing glycidyl ethers as reactive diluents.

Substitution of Equipment

The use of airless atomization, heated paint, and electrostatic attraction in place of conventional, compressed air spray equipment can significantly reduce the amount of stray mist or fog produced. Compressed air spraying atomizes liquid paint by directing a high velocity air jet at the paint stream as it exits from a nozzle. The flow of air conveys the finely atomized droplets to the object being painted. This stream of air is deflected when it strikes the object. The paint particles of sufficient mass are not deflected and deposit themselves on the object. Hama and Bonkowski[13] note that droplets less than approximately 12 microns are of insufficient mass to deposit on the object being painted and are deflected with the "bounce-back" air stream. They note that approximately 20 percent of the droplets in conventional paint spraying are smaller than 12 microns. Additional paint mist is lost when the spray pattern does not completely contact the object. Total paint losses of 50 percent are not uncommon.

In airless spraying, the paint is atomized by forcing it through a small orifice under very high pressure. This method produces less fog than compressed air spraying because not as many fine droplets are produced. Hama and Bonkowski note that only 2 percent of the spray droplets in airless painting are less than 12 microns. The phenomena of "bounce-back" is largely reduced because the paint droplets are conveyed to the object being painted by their own momentum rather than by a stream of air. Other advantages of airless or high pressure spraying include high capacity, compatibility with high-solids coating, adequate coverage of awkward shapes, and negligible stray mist. Some disadvantages include relatively high cost, limited pattern and flow adjustment, and difficulties in overlapping.[42]

In electrostatic spraying, the paint can be atomized with compressed air, by hydraulic pressure as in airless spraying, or solely by electrostatic forces. Electrostatic spray guns can be used with waterborne, solvent, and powder coatings. Although the equipment used for each of these applications differs considerably, the operating principle is similar. Paint particles are electrically charged as they leave the gun and are attracted to the grounded workpiece. The chief advantage of electrostatic spraying is the improved working environment and the paint economy that is achieved.[42] Electrostatic systems usually permit use of substantially less exhaust and make-up air than conventional compressed air spraying for the same painted surface area. This technique also provides significant wrap around, coats sharp edges, and can be highly automated. However, null points in the electrostatic field (caused by recesses or object interiors) may not be coated.

One function of the solvent in a coating material is to dilute the coating in order to obtain a viscosity suitable for spraying. Another means to achieve the same lowered viscosity is by applying heat. This concept can be applied to both conventional and airless spray painting, which results in a decreased solvent requirement. With lowered spraying viscosity, atomizing energy can be reduced; this produces a more gentle spray with less bounceback. Limitations include the heat tolerance of the paint and the necessity for more complicated equipment.[42]

ISOLATION

Isolation can be achieved by the use of a physical barrier, or by the separation of the worker from the hazard by time or space.

Physical Barriers

Certain paint components can either penetrate or react with the surface of the skin and cause injury either at the point of contact, or act as a systemic poison. Protective clothing acts as a barrier between the hazard and the worker's skin. Careful selection of gloves, aprons, and sleeves that are not adversely affected by the resins and solvents is necessary. Key[41] recommends neoprene for gloves and vinyl for aprons and sleeves. He suggests white cotton glove interliners to minimize sweating. Protective creams and ointments can also be used, but are less effective than gloves.

Respirators are another type of physical barrier. There are basically two kinds of respirators--those that provide the worker with a clean atmosphere from an external source (supplied-air respirators), and those that attempt to remove the contaminant(s) from the workroom environment before they are inhaled (air-purifying respirators). The selection and use of an adequate respirator requires knowledge of: the capabilities and limitations of the equipment, the possible concentration and mode of action of the toxic materials, and the duration of the required protection. Generally, a respiratory protection program should be viewed as only an interim measure, not as a substitute for suitable engineering controls. Where respiratory protection is required, a full facepiece style is recommended because of increased wearing comfort, higher degree of protection, and the added eye protection.

Distance

Automation of the paint application process is one means of isolating the worker from the hazard. There are two fundamentally different methods of automating spray finishing operations. The first method involves mounting the spray guns in fixed positions or on a reciprocating assembly. The product items are painted as they pass by the assembly on a conveyor. The parts may be rotated as they are painted. This type of automation is designed and built for the requirements of a limited product line, where the size and shape of the objects finished are easily definable. Manual paint sprayers are often required for touch-up. The second method of automation involves the use of programmed robots. These machines can accommodate production runs of various sizes and shapes. Since they can duplicate virtually all of the movements of a manual spray painter, the use of robots allows for the removal of workers from potentially hazardous areas or unhealthful working conditions.

GENERAL VENTILATION

Ventilation systems can be either local or general in nature. A general ventilation system supplies and exhausts large volumes of air in an attempt to dilute air contaminants. General ventilation can successfully control the build up of explosive vapors in enclosed spaces.

The practice of placing a fan in a manhole, doorway, or window is not satisfactory because the air is circulated only at the opening; the fan does not move or dilute the air in other portions of the enclosed area. Munger[43] recommends that clean air be drawn into the enclosed space from an opening at the top by exhausting air from the lowest portion of the enclosed area as shown in Figure 1.

Reichenbach[44] describes a similar procedure for ventilating the spray painting of ship holds and tanks. He recommends that painters in enclosed areas should wear supplied-air type respirators. The fan capacity required for dilution ventilation can be calculated from the lower explosive limits for the solvents employed and the paint application rate, using the formulas in Industrial Ventilation: A Manual of Recommended Practice.[45]

LOCAL VENTILATION-SPRAY BOOTHS

Excessive quantities of air need to be handled to protect the breathing zone of a spray finisher solely by the use of general ventilation. Hence, indoor spray finishing operations are usually controlled by ventilated spray booths. They function by directing relatively uncontaminated air past the worker towards the process, and into a collection point or exhaust hood. The source of the uncontaminated air may be a tempered fresh air supply or simply general workroom air.

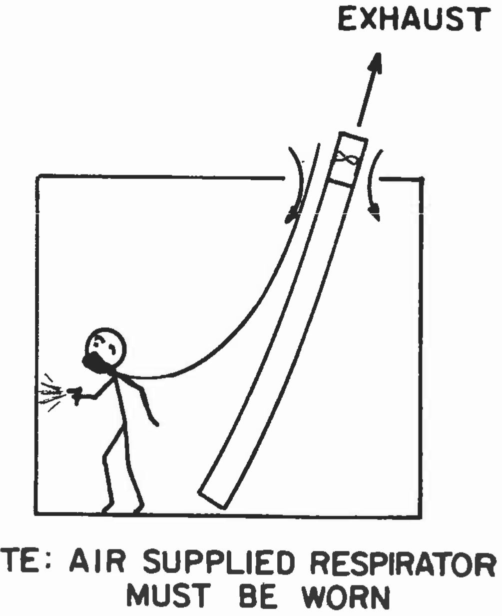


Figure 1. Ventilation of enclosed spaces.

For practical purposes, spray booths can be classified into two basic designs based on the direction of airflow. Booths with a horizontal airflow are termed "sidedraft booths." These booths take advantage of the momentum of the spray mist and can successfully be used when painting small- to medium-sized articles. With larger articles, it may not be possible to maintain adequate airflow on all sides of the object being painted, and rotating the workpiece may not be practical. In these situations, a downdraft spray booth permits greater protection, while allowing more freedom of movement for the painter.

Both sidedraft and downdraft booths will vary in size, in the degree of enclosure, in the method of air makeup, in air velocity, and in overspray control. These variations are illustrated in Figures 2 and 3, and discussed in the following sections.

Size

Spray booths range in size from small bench type models that are designed for spraying small objects to huge chambers that are capable of holding a large airplane. The basic consideration in determining the size of a spray paint booth is the size of the object being painted; adequate space around the top and sides of the object are needed to permit the painter easy access to these areas. The booth should be deep enough to allow the operator to work within the booth. If the object is transported by a conveyor, the booth must be sufficiently long to permit coating within the time the object remains inside the confines of the booth at the maximum line speed.

DRY TYPE

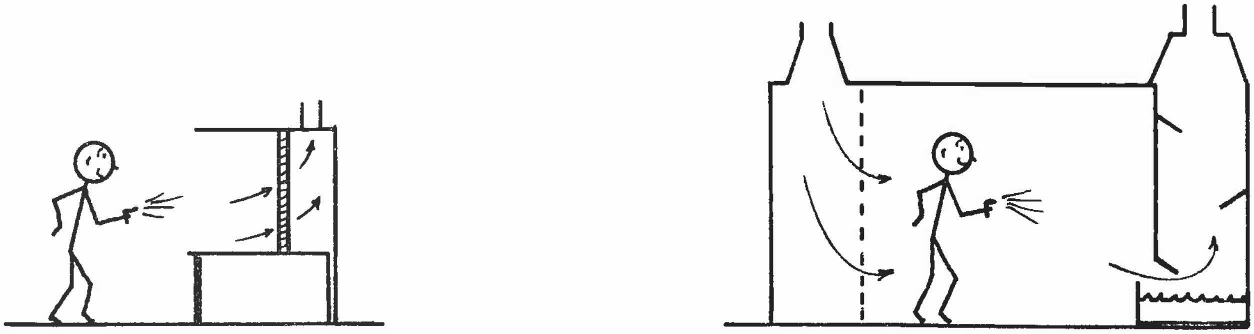
WATER WASH TYPE

OPEN

W/ENCLOSURE

W/ENCLOSURE

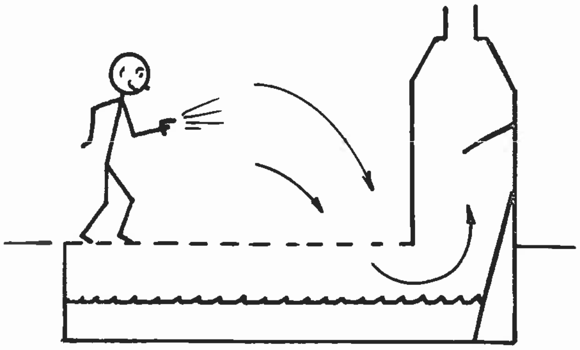
W/FILTER DOOR



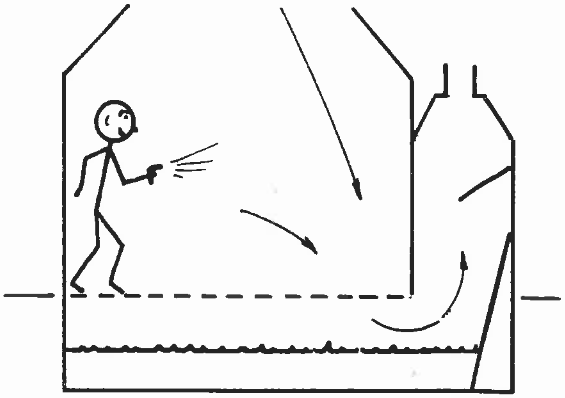
BENCH TYPE

W/INTEGRAL SUPPLY AIR

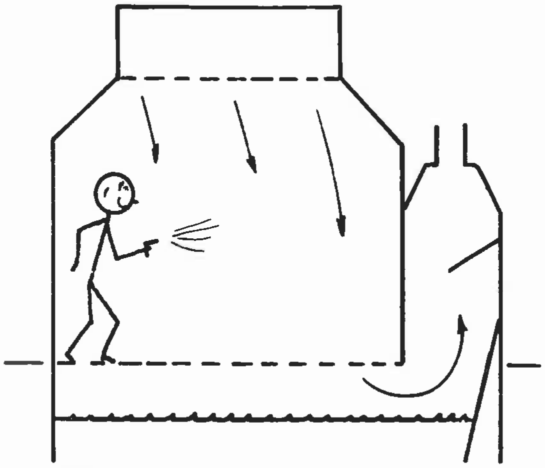
Figure 2. Sidedraft booth configurations.



OPEN



ENCLOSED



W/INTEGRAL SUPPLY AIR

Figure 3. Downdraft booth configurations.

Degree of Enclosure

Both sidedraft and downdraft booths are available in open or enclosed versions. Overspray is easier to control in a closed booth; random room air currents may upset the flow pattern designed for an open booth. In addition, an open booth is more costly to operate than an enclosed booth, because a larger volume of air is necessary in order to achieve a given air velocity at the operator's location.

Air Make-up

The air exhausted from the spray booth must be replaced in order to achieve optimum plant environmental control. Whether this air is supplied directly to the spray booth or to the general workroom is largely a function of how dusty the plant air is. Spray booths may be equipped with filter doors or fresh air inlet plenums to prevent plant dust from settling on freshly painted surfaces. Air should enter the booth at low velocity (200 fpm or less), and in the same direction as it is being exhausted to avoid unnecessary turbulence. Fresh air inlet plenums should be equipped with baffles or other positive means of air distribution.

Air Velocity

A key parameter in local ventilation system design is the control velocity, that is, the air velocity at the painter's position that is necessary in order to overcome room air currents and any turbulence generated by the process itself. The American Conference of Governmental Industrial Hygienists (ACGIH) Industrial Ventilation Manual[45], and the American National Standards Institute (ANSI) Z9.3-1964, "American Standard Safety Code for the Design, Construction, and Ventilation of Spray Finishing Operations"[46] contain design criteria for spray booths. Occupational Safety and Health Administration (OSHA) standards for the ventilation of spray finishing operations are presented in 29 CFR 1910.94.[47] Their recommendations are summarized in Table 13.

An airless finishing process can be controlled at lower control velocities than air spraying because it is a less turbulent operation. As the air pressure is increased the turbulence of the spray action increases and more fine spray particulates are generated. In discussing control velocities for spray booths, Hemeon[48] includes spray gun air pressure as a parameter in selecting the control velocity. For large booths, Hemeon recommends an air velocity of 125 fpm for atomizing air pressures less than 65 psig. For air pressures of 75 to 95 psig, he suggests 150 fpm.

Several spraying variables are not addressed by the ACGIH and ANSI/OSHA. These include the toxicity of the paint materials and the distance between the object being painted and the spray gun. Baturin[49] reports that a control velocity of 150 fpm is sufficient to offer protection from paint or solvent vapors, but that it is not sufficient when spraying lead-containing paint or primers. He recommends a control velocity of approximately 220 to 260 fpm when spraying lead-containing paints. Hama and Bonkowski[13] cite a German study that lists control velocities for compressed air spray painting. Air velocities suggested are: 69 fpm for a distance between the spray gun and object of 59 inches, 98 fpm for a distance between the spray gun and object of 39 inches, 158 fpm for 32 inches, 296 fpm for 24 inches, and 640 fpm for 20 inches. However, those gun-to-object distances are not consistent with actual practice. The spray gun is generally held 6 to 10 inches from the surface for conventional compressed air spray painting, according to Gaynes.[50]

Table 13. Ventilation requirements, spray booths (cfm/sq ft cross section).

	ACGIH		ANSI/OSHA	
	Air spray	Airless	Air spray	Airless/ electrostatic
Bench-type spray booth	150[a]-200[b]	100[a]-125[b]	150[c]-200[d]	100
Large spray booth				
Walk-in	100[e]	60	100[c]-150[d]	--
Operator outside	100 -150	60 -100	100[c]-150[d]	--
Auto spray paint booth	100	60	--	--

a. Booth cross section less than 4 sq ft
b. Booth cross section more than 4 sq ft
c. Cross drafts up to 50 fpm
d. Cross drafts up to 100 fpm
e. 75 for very large, deep booth; (operator may require approved respirator)

Air cleaning

The air cleaning section of the spray booth not only removes paint mist from the exhaust air, but acts as a means of air distribution within the booth. An arrangement of metal baffles is the simplest form of air cleaner. Specific design criteria for baffle-type booths are listed in Industrial Ventilation: A Manual of Recommended Practice.[45] The baffle-type booth provides a constant flow of air. Mist removal and clean-up difficulties limit its use to low production applications. Dry filter booths combine low cost with highly efficient paint mist removal, but have the disadvantage of a variable airflow. The airflow is at a maximum when the filters are clean, but continuously decreases to a point where the filters require replacement. Like baffle-type booths, the dry filter booth is best suited for low production operations. Water wash booths incorporate various combinations of water curtains and sprays to scrub the paint mist from the exhaust air. They have the advantage of constant airflow, inherent fire protection, and high mist removal efficiency, but at a greater cost than dry-type booths. Maintenance is necessary to retain the high rate of mist removal. Cost of maintenance may equal or exceed that of the dry-type booths.

WORK PRACTICES

Inadequate training and supervision in the techniques of spray finishing can result in a poor work environment as well as a faulty finish and a waste of paint. The basic objective in spraying is to apply the finish with a minimum of fog and overspray loss. The correct balance of air and fluid supply to the gun is crucial; the painter must use the lowest possible air pressure that will give the necessary degree of atomization. Muirhead[51] notes that excessively high air pressure is a prime factor contributing to poor quality work.

Because spray booths function by directing clean air past the worker towards the process, the operator must not position himself between the object being painted and the point of exhaust. Some typical examples of situations where this occurs are illustrated in Figure 4.

In Figure 4-a, four sides of an object are sprayed in a side draft booth. By incorporating a turntable, all four sides can be painted without the operator being covered with his own overspray. A similar situation occurs when internal cavities are sprayed as in Figure 4-b. The painter's breathing zone can be removed from the area of active mist generation if an extension or pole gun is used. Airless spray equipment is useful for such cases because of its inherent low mist generation and its superior coverage of deep recesses. In the last illustration (Figure 4-c), an operator is spraying a tall object in a downdraft booth. Stepladders, platforms, or manlifts can be employed to avoid exposure to the spray backwash.

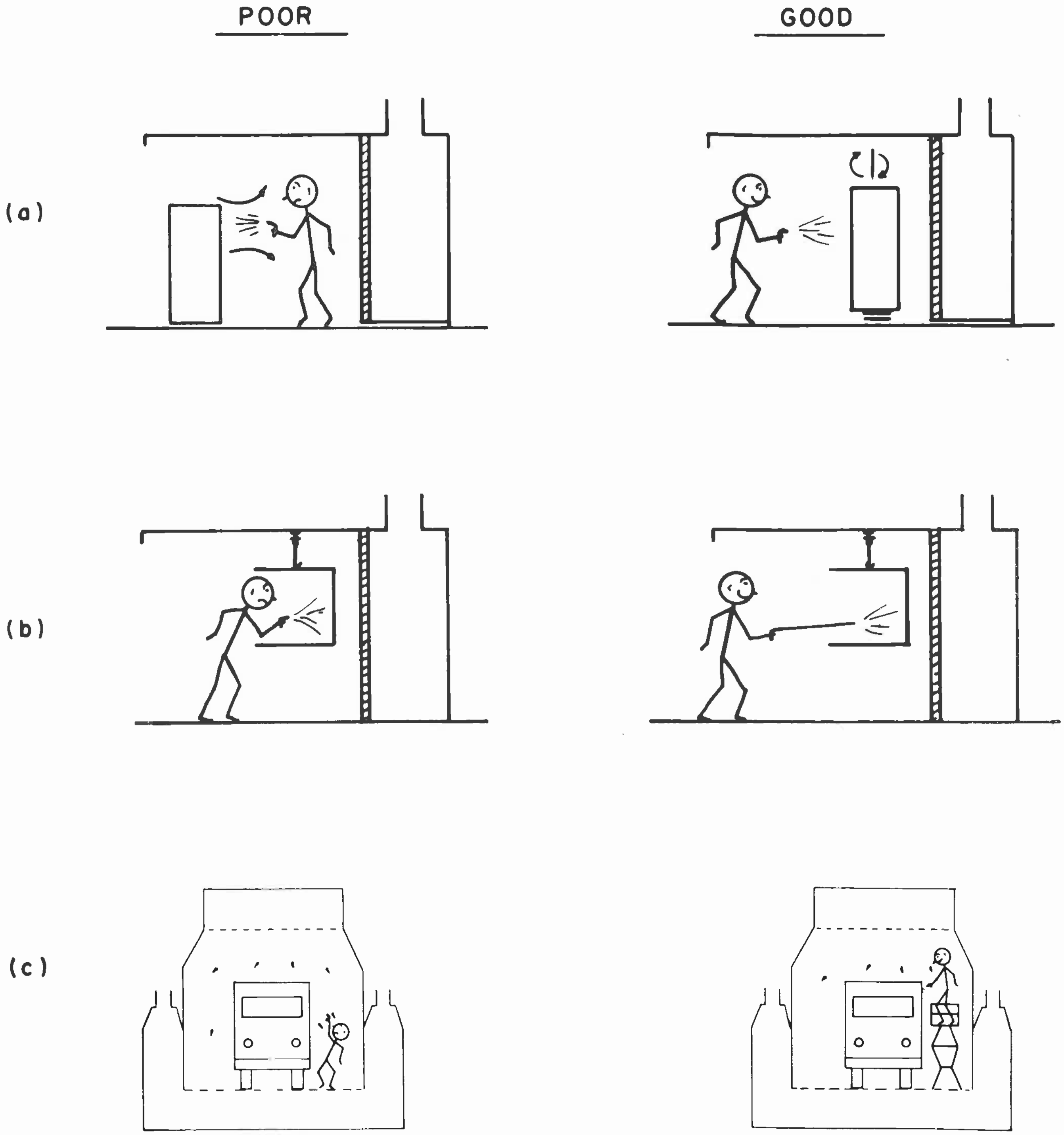


Figure 4. Spray booth work practices.

SECTION VII. EVALUATION PROCEDURES

INTRODUCTION

This section presents the methods for sampling, analysis, and engineering evaluation that were used during the course of this study to measure workplace levels of airborne contaminants and to evaluate the effectiveness of control measures.

AIR SAMPLING AND ANALYSIS

General Principles

Air samples were collected in order to determine the effectiveness of a control measure based on the environmental levels achieved, and to lend support to the observations made during the study. Prior to sampling, a study of the particular finishing process and the associated control measures was made in order to provide an understanding of the variables which could effect sampling results.

Basically, three different types of samples were taken, each for a specific purpose:

1. Personal air samples--This type of sample permitted an evaluation of the potential exposure of the spray painters to various airborne hazards. Where respiratory protection was used, samples were collected outside of the respirator. The results of these samples were directly compared to allowable limits. By themselves, however, these samples did not always give a direct indication of the functioning of a particular control measure.

2. Short duration breathing zone samples--In several finishing processes, the preliminary observations indicated that a specific operation contributed heavily to the overall contaminant levels. To determine this contribution, breathing zone air samples were collected for the duration of the suspect operation. These short duration measurements were made by using either direct reading instruments or conventional personal sampling equipment.

3. Bulk air samples--These fixed area samples were collected in the spray booth and analyzed qualitatively to determine the contaminants present. Bulk air samples were collected where material safety data sheets were either unavailable or judged to be inadequate, or where many types of paints were used in a single workshift.

Sampling rates and duration were based on the applicable permissible exposure limit, the sensitivity of the analytical procedure, the estimated airborne concentration of the contaminant to be sampled, and the length of the actual painting operation. In general, continuous (conveyorized) painting operations were sampled for two consecutive periods of about 4 hours each. For intermittent operations, such as heavy equipment painting or automobile refinishing, separate air samples were taken for the duration of each painting activity. Measurements that were taken to determine exposure to ceiling standard substances were taken during periods of maximum expected concentrations; each measurement consisted of approximately a 15 minute sample. When possible, three days of sampling were performed. The extent of sampling was limited by the necessity to restrict all of the evaluations within a particular plant to a period of several days.

Non-Volatile Paint Components

Air samples for the aerosols of the non-volatile components of paint (total mist, lead, and so forth) were collected using closed face cassettes with preweighed 37 mm membrane filters and personal sampling pumps operated at 2.0 lpm. Total mist was determined by weighing the samples plus the filters on an electrobalance and subtracting the previously determined tare weights of the filters. The tare and gross weighings were performed in duplicate. For analysis of metals, the filters were subsequently wet-ashed with both nitric and perchloric acids to insure their complete dissolution. The ashed samples were diluted to a final volume of 25 ml and aspirated into an atomic absorption spectrophotometer, as described in NIOSH method P&CAM 173.[52]

Three types of filter media were employed in these samples. The majority of samples were collected on 0.8u polyvinyl chloride/acrylonitrile membrane filters. These filters showed high resistance to the common paint solvents, low blank values for lead and chromium, and freedom from blinding at reasonable filter loading. NIOSH detected significant weight loss in some lots of these filters; therefore use of these filters was discontinued. The remaining filter samples were collected on 5u polyvinyl chloride or matched weight 0.8u cellulose ester membrane filters. The PVC filters did not exhibit the same degree of solvent resistance as the other filters.

Volatile Paint Components

Air samples for the organic solvents employed in paints were collected on 150 mg charcoal tubes, with personal pumps operated at either 50 cc/min or 100 cc/min. The lower sampling rate was used for continuous painting operations where samples were collected for the duration of one-half a shift. The higher rate was used for non-continuous finishing operations where sampling (and painting) times were typically 1 hour. A lower total sample volume was collected for these operations because of anticipated higher concentrations. The A and B sections of each sample were separately desorbed and analyzed by gas chromatography as outlined in a modified version of NIOSH P&CAM 127[52] or in P&CAM S56[52]. Chromatographic conditions are reported in Table 14. Except as noted, all desorptions were performed with carbon disulfide.

Table 14. Chromatographic conditions for various solvent mixtures.

Solvent mixture	Gas chromatograph conditions
MEK, toluene, ethanol, isopropanol*	9'x 1/8" SS column with 80/100 mesh Chromosorb 108; temperature programmed from 130 to 160°C; flame ionization detector
Ethyl acetate, ethoxyethyl acetate, aliphatic hydrocarbons	20' x 1/8" nickel alloy column with 10% SP-1000 on 80/100 mesh Supelcoport; temperature programmed from 100 to 160°C at 8°C/min; flame ionization detector
Toluene, xylene, other aromatics, aliphatic hydrocarbons	20' x 1/8" nickel alloy column with 10% SP-1000 on 80/100 mesh Supelcoport; temperature programmed from 80 to 170°C at 8°C/min; flame ionization detector
Toluene, xylene, butyl acetate, diisobutyl ketone, ethoxyethyl acetate, aliphatic hydrocarbons	20' x 1/8" nickel alloy column with 10% SP-1000 on 80/100 mesh Supelcoport; temperature programmed from 85 to 160°C at 8°C/min; flame ionization detector
Xylene, toluene, n-butanol, isobutyl acetate, isopropanol ethanol, aliphatic hydrocarbons	20' x 1/8" nickel alloy column with 10% SP-1000 on 80/100 mesh Supelcoport; temperature programmed from 85 to 150°C at 8°C/min and 150°C for 4 min
Isophorone, isobutyl acetate, n-butanol, toluene, xylene, EGME, ethanol, MEK, petroleum	20' x 1/8" nickel alloy column with 10% SP-1000 on 80/100 mesh Supelcoport; temperature programmed 85°C, 8 min; 8°C/min; finally 190°C, 8 min
MEK, isopropyl acetate, xylene, isopropanol, MIBK, toluene, isobutyl isobutyrate, petroleum distillates	20' x 1/8" SS column with 20% SP-2100/ 0.1% Carbowax 1500 on 100/120 mesh Supelcoport; temperature programmed 110°C, 8 min; 32°C/min; finally 170°C, 16 min
Xylene, toluene	20' x 1/8" SS column with 10% SP-1000 80/100 mesh Supelcoport; 130°C; flame ionization detector
Toluene, xylene, butyl acetate, MEK, MIBK, ethyl acetate, ethoxyethyl acetate, petroleum distillates	20' x 1/8" nickel alloy column with 10% SP-1000 on 80/100 mesh Supelcoport; temperature programmed from 100 to 160°C at 8°C/min

*Desorbed by CS_2 with 1% sec-butanol

Other Materials

Where two component polyurethane enamels were used, consecutive short term samples were collected in the breathing zone of the spray painter to determine ceiling concentrations of hexamethylene diisocyanate. These samples were collected using 2 midget impingers connected in series to a personal pump that was operated at 2.0 lpm. Each impinger contained 15 ml of a nitro reagent solution, which was subsequently analyzed for the HDI/nitro reagent derivative by high pressure liquid chromatography. The solvent was removed from each impinger solution using a rotary evaporator and the residue taken up in 2 ml of methylene chloride. Aliquots of each resulting solution were injected onto a u Porasil column. The mobile phase was an isooctane-methanol-isopropanol solvent gradient. Detection was accomplished by UV absorbance at 254 nm. Although the nitro reagent will react with any reactive isocyanate group, the present method allows quantification of the monomer only.

Analyses of other components and bulk materials were performed on an as-needed basis. Sampling and analytical procedures for these materials are presented in the individual case studies.

AIRFLOW MEASUREMENTS

The effectiveness of spray booths was determined in part by the measurement of air velocities and flow patterns within the booth. These measurements included as a minimum the total quantity of air supplied to and exhausted from the spray booth and the air velocity within the booth. Total exhaust and supply volume were determined by either a pitot tube traverse of the exhaust or supply ducts, or, if duct access was limited, by measurement of face velocities at supply or exhaust grilles. The air velocity in the booth was measured in an imaginary plane occupied by the painter, a vertical plane in the case of a side draft booth. For downdraft booths, an imaginary horizontal plane at face level was used. Velocities were measured at a minimum of 12 points in these planes. The results were averaged and reported as "control velocity." Where appropriate, the standard deviation of the air velocity measurements was reported as an index of the variability of the air velocity within the booth.

SECTION VIII. CONCLUSIONS AND RECOMMENDATIONS

In this section a summary of the conclusions and recommendations based upon the case studies is presented. The level of control of selected hazards is discussed; available control options are evaluated; and recommendations are presented.

CONTROL OF HEALTH HAZARDS

Paint Mist

Paint mist refers to the non-volatile component of the coating aerosol. Its concentration in the breathing zone of spray painters was determined gravimetrically as an index of overspray control. Geometric mean paint mist concentrations for selected finishing operations are reported in Table 15. The concentrations reported for continuous painting operations are 8-hour time-weighted averages. Results from intermittent painting operations are reported for the duration of the specific painting operation.

The level of airborne paint mist is a more reliable indicator of the degree of control in manual spray finishing than the concentration of solvent vapors. Solvent concentrations were well below the recommended maximums even when paint mist levels exceeded the maximum concentration permitted for nuisance dusts. In no case was the reverse true. If the paint composition is known, the concentration of paint mist can also be used as a guide in estimating the potential exposure to specific non-volatile paint components. For example, if the concentration of paint mist is 5 mg/m^3, and lead represents 1 percent by weight of the paint solids, then the airborne concentration of lead could be estimated at 50 ug/m^3.

Continuous operations include both manual and automatic application processes where the painter remains in one location as the workpiece passes by on a conveyor. The concentration of total paint mist for the majority of continuous spray finishing operations did not exceed 5 mg/m^3 provided that spray booth ventilation rates met minimum OSHA requirements (specified in 29 CFR 1910.94) and good spray painting practices were observed. The continuous painting operations (listed in Table 15) that exceeded this concentration involved either the spraying of internal cavities (case study 6) or faulty ventilation and work practices (case study 3). With the corrections suggested in these case studies, paint mist levels could be controlled to below 5 mg/m^3.

Intermittent operations are non-conveyorized processes where a relatively large workpiece is positioned in a booth; after finishing operations are completed by a mobile painter, the workpiece is removed and replaced by the next unit. The concentrations of paint mist reported in Table 15 for intermittent painting operations range from 2.0 to 43.3 mg/m^3. Differences were due to the relative

tive success in maintaining proper airflow orientation as the painter changes position and the degree of sophistication of the paint application equipment. The paint mist concentration for the majority of these operations could be controlled to below 10 mg/m^3 if ventilation and/or application techniques were improved. An exception would be the finishing of relatively enclosed spaces, such as vehicle interiors.

Table 15. Summary of paint mist concentrations in selected finishing operations.

Operation	Paint mist (mg/m^3)
I. Mean time-weighted average concentrations of paint mist in continuous painting operations	
Powder coating small parts (electrostatic)	1.3
Wood furniture (airless and compressed air)	0.1 - 2.5
File cabinets and panels (compressed air)	4.2
Metal furniture (compressed air)	3.7 - 27.6
Appliances (compressed air/electrostatic)	21.7 - 39.2
II. Mean concentrations of paint mist during spraying of internal cavities	
Freezer liners (compressed air)	320.0
File cabinet interiors (airless)	2.9
Walk-in spraying of large vehicles (airless)	36.5
III. Mean concentrations of paint mist in intermittent painting operations	
Heavy equipment exteriors (airless electrostatic with heated paint)	2.0
Automotive refinishing (compressed air)	8.7
Light aircraft (compressed air)	23.3
Railroad freight cars (airless)	43.3

Lead

Lead is used in paints as both a pigment and as a catalyst to accelerate the drying of alkyd and oleoresinous paints. Chrome green, chrome yellow, and molybdate orange were the principle lead pigments found in this study. The amount of lead, by weight, in the dried film of paints using these pigments may reach 15 percent. In no case where the lead content approached this figure was the 50 ug/m^3 limit for lead met. Alkyd resin enamels employing lead only as soaps for paint drying did not exceed the 50 ug/m^3 standard when minimum ventilation requirements were met (case study 5).

Based on the maximum paint mist concentration of 5 mg/m^3 found in well-controlled finishing operations, up to 1 percent lead could be tolerated in the dried film and the OSHA standard for airborne lead would still be met. This is not a practical concentration for the pigments typically used. However, where a variety of colors are painted, the "average" paint for the workshift may be well below this figure and the subsequent average exposure for the shift below 50 ug/m^3.

The lead pigments provide durability to exposure, and thus find greatest use on transportation and heavy equipment. Of the operations in these categories, the heavy equipment finishing operation described in case study 8 comes closest to meeting the 50 ug/m^3 standard, with an 8-hour time-weighted average concentration of about 100 ug/m^3 during painting of equipment exteriors.

While lead should be eliminated where possible, suitable substitutes are not always available, and lead pigments will continue to be used. Safe usage of these materials dictates the use of respiratory protective equipment and the biological monitoring of the painter in addition to engineering controls.

Chromium

Chromium is used in both trivalent and hexavalent forms in paint pigments. Trivalent chromium occurs primarily in the pigment chromium oxide green. Hexavalent chromium most frequently appears as lead chromate in chrome green, chrome yellow, and molybdate orange pigments, and in the corrosion inhibiting pigments zinc and strontium chromate.

All of the spray painting operations studied meet the 1 mg/m^3 OSHA standard for chromium metal and insoluble salts. Conversely, nearly all that employ chromium pigments exceed the OSHA ceiling level of 0.1 mg/m^3 for chromic acid and chromates. The applicable standard is unclear, as these pigments are both insoluble salts and chromates. The OSHA ceiling standard of 0.1 mg/m^3 was adopted from the American National Standard Z37.7-(1971), which was a time-weighted average limit for chromic acid and chromates of alkali and alkaline earth metals. The situation is further complicated by the state-of-the-art of analytical methods. Presently available methods do not allow an unambiguous determination of which chromium species are present. For the purposes of this study, analytical results are reported as total chromium.

The ACGIH has suggested a limit of 50 ug/m^3 (time-weighted average) for the chromates of lead and zinc. NIOSH has proposed a time-weighted average limit of 15 ug/m^3 for non-carcinogenic hexavalent chromium, and a 1 ug/m^3 ceiling concentration for those compounds considered carcinogenic. Most hexavalent chromium compounds used in paint fall in the latter category. The levels recommended by NIOSH can only be met by eliminating hexavalent chromium from the coating formulation, or by automating the process and removing the painter.

As is the case for lead, hexavalent chromium-containing pigments should be eliminated where possible. However, suitable substitutes are not always available. Safe usage of these materials dictates the use of respiratory protection in conjunction with engineering controls.

Other Toxic Metals

Besides lead and chromium, other toxic metals like antimony, arsenic, cadimum, and mercury are used in some paints. These materials were not encountered in any of the field studies.

Silica and Silicates

Talc, diatomaceous earth, and silica (both crystalline and amorphous) are used in paints as extender pigments. These materials may represent up to 20 percent of the non-volatile coating components in certain formulations. Except for crystalline silica, all of these components would be controlled to safe levels in typical spray booth installations, based on the total paint mist concentrations measured.

Organic Solvents

When spray booth ventilation rates meet the minimum requirements set forth by OSHA, exposure to organic solvents is readily controlled to less than 25 percent of currently allowable levels. NIOSH recommendations for lower exposure limits for alkanes, refined petroleum solvents, and toluene are also met in most instances. Except for painting in enclosed spaces (such as vehicle interiors), the operations studied that did not meet the above limits could be brought into conformance by a change in application techniques (case study 6) or increased ventilation (case studies 3 and 4).

No benzene was indicated in any bulk air samples collected and analyzed by gas chromatography/mass spectroscopy. Bulk air samples were collected where refined petroleum solvents were included in the paint formulation or employed as reducers, and in cases where many paints were used during a single workshift.

Organic solvent levels were noticeably higher in paint mixing and storage rooms. These rooms can generally be characterized as small and inadequately ventilated with poor housekeeping. Solvent levels are high because of poor equipment and bad work practices, with open containers of paint and solvents in abundance. Solvent exposures can be controlled by use of paint mixers with loose fitting covers, elimination of solvent leaks and drips, good housekeeping, and general ventilation. A model paint mix room is described and evaluated in case study 10.

Isocyanates

Breathing zone concentrations of hexamethylene diisocyanate (HDI) were determined in automobile refinishing (case study 5) and in light aircraft finishing (case study 7). Except for a single sample, all concentrations of monomeric isocyanate were below the ceiling level for HDI (140 ug/m^3) recommended by NIOSH. The single sample exceeding this value occurred when ventilation was compromised during the painting of aircraft underbodies.

The aerosols of these paints contain a substantial quantity of isocyanate prepolymer with unreacted isocyanate groups. The potential of these prepolymers to cause respiratory impairment and/or sensitization is unknown; however, the prepolymer of HDI possesses approximately the same acute inhalation toxicity as the monomer. If the polymeric material poses the same sensitization potential as the monomer, a paint mist level of about 1 mg/m^3 would be required to maintain the prepolymer concentration below 140 ug/m^3. This mist concentration approaches the lowest mist levels measured in this study, and is quite a bit lower than mist concentrations measured in auto refinishing and aircraft painting. Respiratory protection is therefore recommended wherever reactive urethane coatings are applied. The use of these materials should be restricted in enclosed spaces or other areas where ventilation may be compromised.

Epoxies

Most reports of health problems associated with epoxy paints have been related to the amine curing agents used rather than the epoxy resins themselves. Many of these curing agents are of low volatility and therefore the hazard is associated with the inhalation of the paint aerosol. Present analytical techniques do not permit the evaluation of the presence of these amines in a curing agent/paint aerosol. As is the case with urethane coatings, development of suitable analytical techniques is essential for any future research. It is recommended that, when possible, the less toxic polyamide resins be used in place of the more aggressive amine curing agents.

CONTROL OPTIONS

In the following paragraphs, some observations about the various available control options described in Section VI are noted.

Spray Booths

Spray booths that meet OSHA design requirements are capable of controlling total paint mist and organic solvent vapors to within recommended maximums. Spray booths are partially effective in the control of toxic metals and other dangerous materials, insofar as they contain the hazard within the booth.

Several factors not addressed by the OSHA standard have a significant bearing on the effectiveness of a booth in protecting the health of the painter.

The distribution of air within the spray booth is apparently at least as significant as the average air velocity. It was noted that supply and exhaust air chambers were often built without regard to accepted criteria for plenum design. Particular problems were noted where fresh air was supplied at a velocity that was too great, introduced in a direction other than what was being exhausted, or introduced between the painter and the point of exhaust. The spray booths of case studies 1 and 8 are examples of booth design for proper air distribution.

In order for protection to be maintained, the spray painter must not position himself between the object being painted and the point of exhaust. Where all sides of an object require painting, the operator can maintain proper position if the object is rotated, or if a downdraft booth is employed. Case study 8 describes a unique technique used to ventilate underbody painting operations, and special lifts to allow proper operator position during other operations.

The air velocities recommended in the standard are useful guides in determining air volume requirements, but may be either too restrictive or inadequate, depending on the toxicity of the paint material, and the method and rate of paint application. Higher airflow rates should be considered for highly toxic materials in order to minimize exposure although even at these higher rates control may not be complete. Baturin[49] recommends an air velocity of 220 to 260 fpm when lead-containing paints are sprayed. However, this recommendation was not evaluated in this study because no spray booths with design air velocities greater than 150 fpm were encountered. Such high velocities substantially interfere with most spray processes, inhibiting the deposit of sprayed material onto the intended surface. Lower airflow rates have been suggested for airless spray finishing operations. Even with airless spraying, highly toxic paints or high application rates might warrant higher velocities.

In spray booths equipped with dry filters, airflow must be monitored because it decreases with the build-up of overspray on the filters. Manometers are frequently used to monitor the pressure loss across the filter media. Filters are changed when resistance reaches a predetermined level. Too often these manometers are broken, low on fluid, mounted where they can't be seen, or no change point has been determined. A more positive means to ensure that the filters are changed is the use of a pressure switch and interlock that prohibits activation of the spray gun when the filter is fully loaded.

Application Methods

The working environment of the spray finisher can be improved by the use of paint application methods that minimize the energy expended in the atomization process. Electrostatic discs and bells atomize paint primarily by electrostatic forces and produce very little stray paint mist. An electrostatic bell system was evaluated in case study 6. With minimal air movement in the automated spray room (for the purpose of diluting the evaporating solvents), the mean concentration of paint mist was only 0.1 mg/m^3.

Both airless and airless electrostatic methods, when they are used with heated paint, can produce low levels of overspray, even when relatively large and complex shapes are painted. In case study 8, paint mist concentrations of 2.0 mg/m^3 were measured when these methods were used to finish the exteriors of heavy equipment.

Airless techniques appear to be particularly useful in painting recesses or internal cavities. Not only do they provide a cleaner work environment, but they apply paint faster and cover inside corners better. The benefits of airless were demonstrated in case study 9, in which an airless gun was used to finish the interiors of file cabinets. In a similar operation (case study 6) using conventional spray guns, paint mist concentrations were over 10 times as high. This higher level of paint mist was noted in spite the fact that the total number of units requiring internal painting was significantly less.

There is some reluctance to accept high technology application equipment, especially where appearance is a critical factor. This is due either to the greater versatility of conventional air-atomized spray equipment or to some inherent limitations combined with higher costs for the more sophisticated techniques. However, in many operations, ventilation is impractical, and efficient application techniques are the only logical choice.

Respiratory Protection

Respiratory protection is required in those spray finishing operations that employ significant quantities of highly toxic materials, such as lead, chromium, or reactive compounds (isocyanates and epoxy curing agents). It is also necessary for protection against paint mist and organic solvents in painting enclosed spaces or other areas where ventilation is compromised.

A conventional half facepiece respirator, with mist-removing prefilters and organic vapor-removing cartridges, should provide adequate respiratory protection in cases where the hazards can be identified and quantified. In many instances, the variety of paints employed on a given workshift make quantification of the hazard impractical. In other cases, painting may be done in an enclosed area. These situations warrant the use of a supplied-air respirator.

Many paint constituents can be injurious to the eyes and the skin as well as to the respiratory system. Full facepiece or hood-type respirators are recommended where these constituents are present. In addition, the full facepiece is more comfortable than a half-mask because the pressure of the attaching straps is distributed over a larger facial area and no goggles are required to protect the eyes. Case study 4 describes a railroad car painting operation that successfully employs a respirator program using full facepiece, supplied-air respirators.

RECOMMENDATIONS

Paints and Coatings

Paint formulations should be selected for use that contain relatively non-toxic materials and a minimum amount of solvent. Lead and other toxic metal pigments should be eliminated where possible.

Paint users should establish a file of material safety data sheets for all coatings. Material safety data sheets should be reviewed by the purchaser and rejected if incomplete or found to be inaccurate. The paint and coatings industry should establish strict material safety data sheet guidelines and labeling requirements.

Spray Booths

Spray booths should be selected to provide the maximum enclosure of the painting operation in order to contain the spray mist with a minimum volume of air and to avoid disruptions from stray room air currents. The choice of a downdraft or sidedraft booth depends largely on the configuration of the object that is to be painted. Airflow must be in a direction which will carry contaminated air away from the breathing zone of the painter. If necessary, work platforms, product rotators, or other means must be provided in order that the proper orientation of airflow can be maintained.

Air velocities of approximately 100 fpm are adequate to control most spray painting operations. Lower air velocities (60 fpm) are appropriate where airless spray equipment is used, paint delivery rates are low, and the paint is formulated with relatively safe ingredients. Higher air velocities (150 fpm) should be considered where substantial quantities of highly toxic materials are sprayed. It is preferable to supply make-up air directly to the spray booth to avoid disruptions from stray room air currents and for reasons of product quality control. Make-up air should be supplied from behind (or in the case of a downdraft booth, above) the painter and in the same direction as it is being exhausted. Make-up air velocity should be no greater than twice the control velocity.

Fan noise in the spray booth should be minimized by use of a centrifugal fan rather than a propellor type, and by locating the fan on an isolated surface rather than the spray booth roof.

Application Equipment

Application equipment should be selected that minimizes the energy expended in the atomization process, thus reducing the amount of stray mist that is generated. The recommendations of the paint formulator concerning the method of application and the atomization parameters should be strictly followed.

Certain operations, such as painting deep recesses or internal cavities, can not be effectively controlled by ventilation. Airless application methods are suggested for these operations.

Health Studies

Respiratory problems have been reported among users of two-component urethane coatings. The potential for the isocyanate prepolymers used in these coatings to cause respiratory impairment or sensitization is unknown. In order to define safe levels of exposure to polymeric isocyanates, further development of analytical techniques for the determination of these materials is necessary, followed by environmental and medical investigations of respiratory impairment in exposed individuals.

Health problems have also been associated with amine curing agents used in some two-component epoxy coatings. As is the case with urethane coatings, development of suitable analytical techniques is essential for any future research.

The extensive use of talc, diatomaceous earth, and silica (both crystalline and amorphous) in paints and coatings suggests the possibility of fibrogenic lung disease among painters using these materials. In light of the potential exposure in spraying, epidemiological studies of lung disease in spray painters may be warranted.

Respiratory Protection

Further evaluation of the effectiveness of half facepiece respirators is needed. NIOSH certification tests for spray paint respirators need significant review to reflect current coating technology.

Material Safety Data Sheets

The quality of material safety data sheets was found to vary considerably among suppliers. In one case even lead was omitted from the safety data sheet although the lead content was significant. The number of coating types and suppliers employed by some users make the establishment of a file of material safety data sheets a formidable task. Improved labeling requirements could ease this burden for the purchaser of industrial coatings.

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APPENDIX

CASE STUDY 1

POWDER COATING - SMALL PARTS

The formed steel panels used to mount control hardware for washing machines and clothes dryers are coated with a thermosetting acrylic powder in an operation that recycles both spray booth air and powder overspray. Low total dust levels are maintained through careful attention to air distribution in the design of the spray booths, dust-tight construction of the powder recovery equipment, and good housekeeping.

PROCESS

Operations

Before entering the powder coating room, the steel panels undergo a seven-stage pretreatment process: a chemical wash followed by two water rinses, an iron phosphate bath, a water rinse, a chromic acid bath, and a final water rinse.

The powder coating room (Figure 1-1) contains two separate powder coating systems, one for each color--dark brown and cream. This room is isolated from other plant operations so that the powder will be contained; it is air conditioned to prevent the powder from agglomerating.

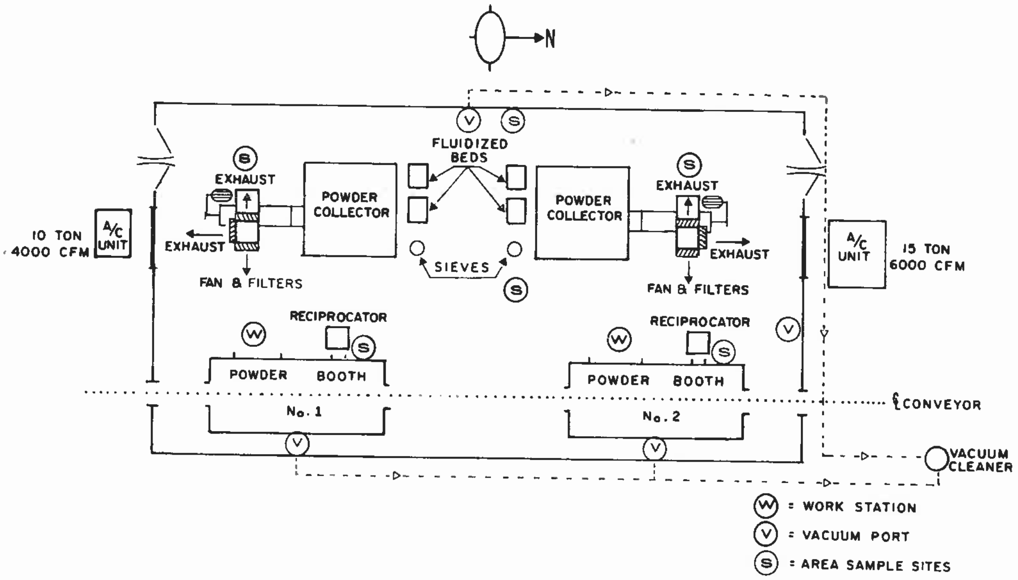

Figure 1-1. Layout of powder coating room.

The operator of the pretreatment process brings 100-pound drums of powder paint to the powder unit. The powder unit operator opens the drums, attaches a vibrator to the drum, and transfers the powder to the first of two fluidized beds (Figure 1-2). An aspirator connected to this fluidized bed transfers the virgin powder to a sieve that removes oversize particles. The powder passing through the seive is discharged directly into a second fluidized bed, which serves as a powder reservoir for the spray guns.

In the first section of the powder booth, the spray operator applies powder to the panel edges that are not accessible to the automatic equipment. In the next section, three reciprocating guns apply a 2-mil coat to the appearance side, the panel rotates, and two guns attached to the same reciprocating assembly apply a 0.5-mil coat to the back half. All guns are electrostatic and operate at 90 kV. Powder delivery to the three guns that coat the appearance side is 22 lb/hr. Each of the two guns coating the opposite side is supplied at 11 lb/hr. All guns are rated at a maximum of 40 lb/hr.

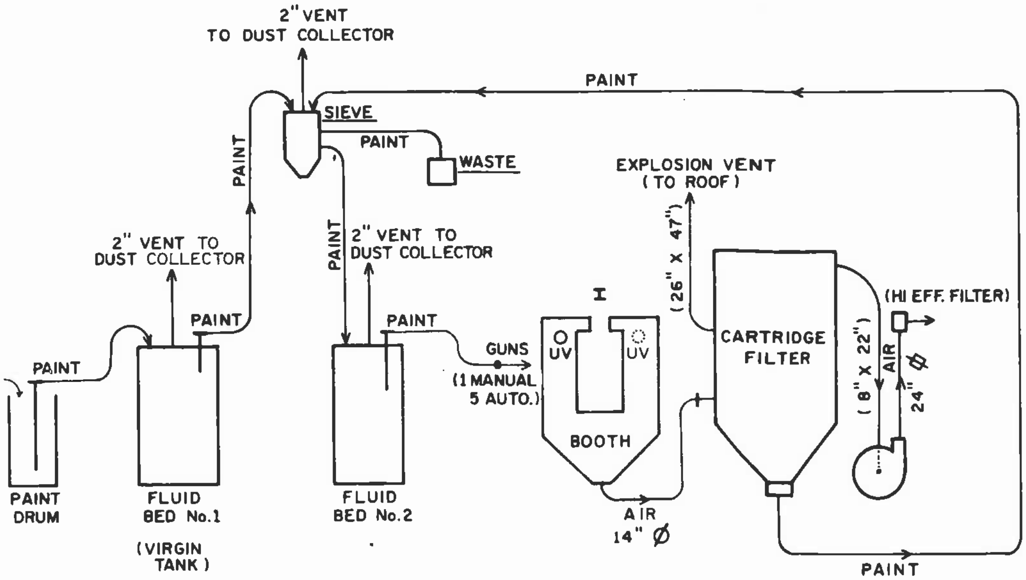

Figure 1-2. Schematic of powder flow.

The excess powder (powder overspray) collected in the powder booth is separated from the air stream by a cartridge-filter-type dust collector. Powder from the dust collector hopper is returned to the sieve via an aspirator, and then discharged to the powder reservoir (second fluidized bed) for reuse.

After receiving the coat of powder, panels are conveyed from the powder painting unit to a baking oven. A temperature of 360°F, maintained for 12 minutes, fuses the powder and activates the cross-linking agent.

Coatings

Both colors are pigmented acrylic resin powders. Approximately 50 percent, by weight, of the powder is a hydroxyl modified acrylic resin. The hydroxyl groups are incorporated into the acrylic polymer during manufacture to provide reaction sites for an isocyanate cross-linking agent. This cross-linking agent is a polymeric isocyanate whose active isocyanate groups are chemically blocked by caprolactam. At baking temperatures, the caprolactam is released and the active isocyanate is regenerated.

In this operation, lead- and chromium-free pigments (titanium dioxide, iron oxide, and carbon black) are used. Filler materials (amorphous silica, non-asbestiform talc, and calcium carbonate) represent less than 10 percent of the formulation.

HAZARD ANALYSIS

Powder paint eliminates the hazard of inhaling the solvent vapors associated with the spray application of conventional coatings. It does not eliminate the danger of fire and explosion but, rather, presents special problems in this regard.

The hazards associated with pigments, filler materials, and resinous binders are similar to the hazards of conventional liquid paints with like composition. The use of lead- and chromium-free pigments minimizes the risk posed by these materials. Trace quantities of lead and chromium may still be found in heavy metal-free formulations because of contaminants in the raw materials or as contaminants introduced in manufacture. In the absence of toxic metals, the filler materials are the most dangerous constituents, but their relatively low concentration in the formulation precludes any serious hazard as long as airborne powder levels are kept below recommended maximums for nuisance materials.

Respiratory irritation, or sensitization, or both, resulting from the polymeric isocyanate should not occur because the active isocyanate groups have been blocked by their reaction with caprolactam. The caprolactam released in the curing oven presents no hazard to the painters. However, there is a possibility that when inhaled, the caprolactam-isocyanate complex could hydrolyze and regenerate caprolactam, a respiratory irritant. However, the isocyanate would not be regenerated because the hydrolysis yields a carbamate.

POWDER BOOTH

The configuration of the powder booth is shown in Figure 1-3. Panels enter and exit through openings that are 5 square feet in size and located on both ends of the booth. The conveyor does not enter the booth, but panel hangers pass through a 6 1/2 inch wide slot running the length of the booth. The spray operator works through an 11 square foot opening with his head and body outside the booth. A 16 square foot opening is provided for removing the reciprocator assembly. Hinged doors reduce this opening to an 8 inch width during spraying.

No powder losses are visible from any booth opening. Average indraft velocities vary from 120 to 135 fpm, depending on the loading of the filter media, based on measurements of total airflow that ranged from 3400 to 3700 cfm. Indraft airflow is well distributed, with the velocity exceeding 100 fpm at all points. A good distribution of flow is obtained by the large horizontal cross section (68 square feet). When compared with the total open area, this cross section results in low internal hood air currents in relation to the indraft velocity. Distribution is further enhanced by placing the exhaust takeoff at the hopper bottoms and incorporating turning vanes at those points.

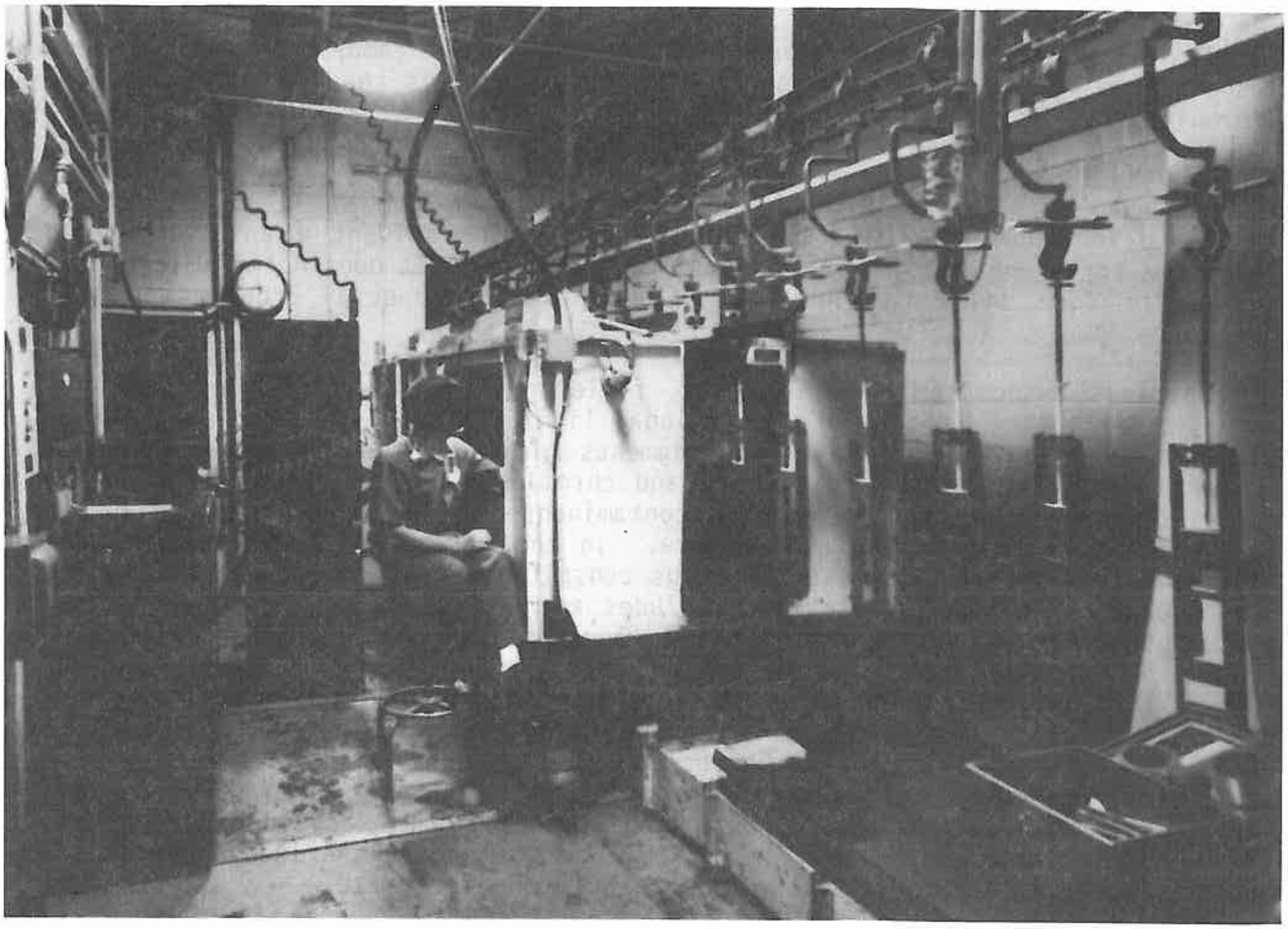

Figure 1-3. Powder coating booth.

DUST COLLECTOR AND FINAL FILTERS

Powder-laden air from each of the powder booths is routed to a combination powder-recovery/air-recirculation system. A cartridge-type dust collector separates the powder from the air stream. Each dust collector contains 16 pleated paper elements, cleaned by a pulse of compressed air. A 10-hp centrifugal fan is located on the clean air side of the collector. The final discharge is at an elevation of 12 feet, through a set of three high efficiency final filters mounted in parallel. Each filter is rated at an efficiency of 90 percent, (as determined by American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) test procedures). Outlet filters are periodically removed and cleaned by compressed air. Clean filter resistance is 0.75 inch water gauge at 1700 cfm. Both dust-collector and final-filter resistance are monitored. Observations of final-filter pressure losses (2 to 3 inches wg) and light dusting from the filter indicate less than complete powder removal. Noise from the fan outlet is reduced by an acoustical silencer located on the fan outlet.

PREVENTION OF FIRE AND EXPLOSION

Although the measured total exhaust rate is approximately 20 percent less than the design value of 4500 cfm, fire and explosion hazards are minimal; the maximum duct powder concentration (0.014 ounces/cubic foot) is less than 30 percent of the lower explosive limit (0.05 ounces/cubic foot). Each booth is equipped with two ultraviolet fire detectors that, if activated, shut off the entire system and close a guillotine damper isolating the booth from the dust collector. Fire detector windows are purged with 100 cubic feet/hour of air to prevent fouling. Each dust collector is provided with an 8 square foot explosion relief, vented to the roof.

GENERAL VENTILATION

Process humidity requirements necessitate that the powder unit area be air conditioned. The room is equipped with two units, a 15-ton, 6,000-cfm unit, located just outside the north wall, and a 10-ton, 4,000-cfm unit, located just outside the south wall. Return air inlets are located above the doors on the respective walls. Supply air from the larger unit is well distributed with six outlets just below ceiling level. The smaller unit supplies air through a single outlet next to the first powder booths. Louvers are adjusted to direct air away from the booth so the air does not adversely affect control. A single, fresh (outside) air outlet located in the northeast corner supplies 250 cfm or approximately one air change per hour.

HOUSEKEEPING

Accumulation of powder on equipment or accidental spillage is inevitable, and prompt removal is necessary in order to prevent entrainment into the shop air. The powder department is equipped with a high capacity, turbine-type vacuum system, with a filter bag separator. The vacuum unit is located outside the enclosed area and has four vacuum outlets in the powder unit. This system permits immediate cleanup of spills and periodic vacuuming of walls and equipment (Figure 1-4).

SAFETY

The danger of electrical shock from the 90-kV equipment is minimized by limiting the available current and by grounding both equipment and personnel. The current is restricted by limiting resistors located in the spray guns and cables. All equipment is interconnected with grounding cables to prevent static buildup and subsequent sparking. Likewise, personnel are grounded by contact between bare hands and the metal gun handle to prevent static buildup.

EVALUATION

As an index of control, the 8-hour, time-weighted average exposure (TWA) to total dust was determined for the spray operator and the equipment operator (Table 1-1). Both individuals spend their entire workshift in the powder-unit area, excluding two 10-minute, scheduled breaks and a 30-minute lunch period. Area samples were taken in the vicinity of the potential exposure sources to determine their relative impact on worker exposure. Total dust measurements

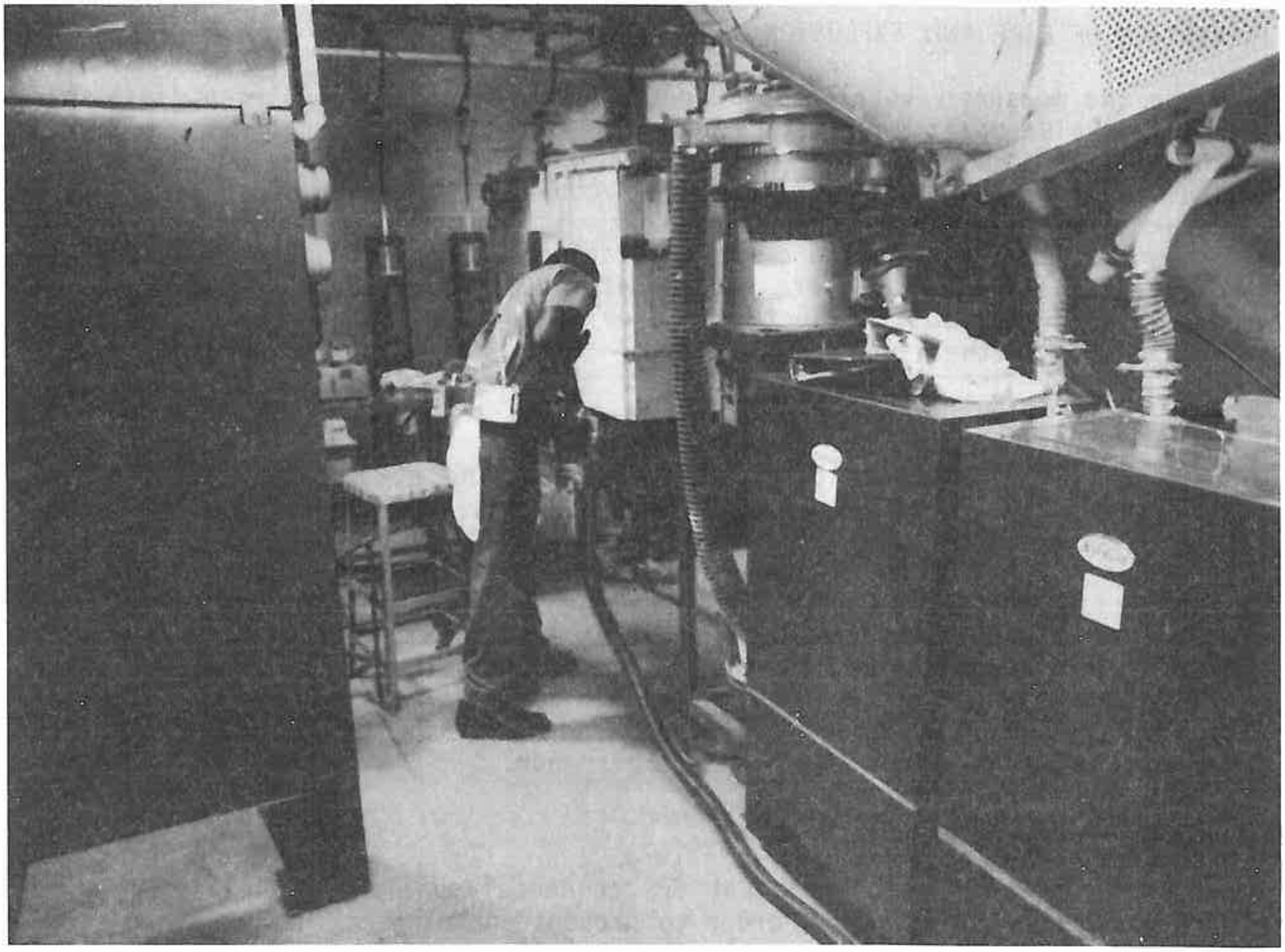

Figure 1-4. Cleanup with central vacuum system.

were made, using preweighed 0.8 u PVC/AN membrane filters in closed cassettes and portable pumps operated at 2.0 lpm. Results of these measurements are reported in Table 1-2.

Table 1-1. Job descriptions.

Position	Duties
Spray operator	--manually sprays the edges of the part not accessible to the automatic unit
Equipment operator	--start up and shutdown of equipment for color changes --loading of new paint --cleaning of paint lines --monitoring of equipment
Utility man	--start up and shutdown of equipment at shift beginning and end --minor repair --relief man for spray operator (approximately 30% of shift in powder unit)
Pretreatment operator	--paint drum delivery from paint storage room (less than 10 percent of shift in powder unit)

Table 1-2. Total dust levels.

Worker or location	Number of days sampled	8-hour time-weighted average (TWA) concentration (mg/m^3)	
		GM	GSD
Sprayer*	3	1.3	1.1
Equipment*	3	1.5	1.4
Reciprocator (brown line$^+$)	3	1.9	1.4
Filter exhaust (brown line$^+$)	3	1.4	1.1
Reciprocator (cream line$^+$)	3	1.0	1.1
Filter exhaust (cream line$^+$)	2	0.5	2.2
Control panel (general area)	3	1.3	1.9
West wall (in AC airstream)	3	0.8	1.1

GM: Geometric mean
GSD: Geometric standard deviation
*Personal samples
$^+$Production approximately 70 percent brown, 30 percent cream

In order to identify trace metals and determine free silica, two bulk samples of the paint were qualitatively analyzed. X-ray diffraction analysis indicated the absence of silica patterns. Although both samples did show patterns indicative of crystalline material, the diffraction patterns were not identified.

The x-ray fluorescence analysis of both samples of bulk material are reported in Table 1-3. An inductively coupled plasma, atomic emission spectrometer (ICP-AES) was used to further examine the ash of the two powder samples. This procedure identified the presence of lead and selenium in trace quantities; no chromium was detected. Air samples were subsequently analyzed by atomic absorption spectroscopy for lead and selenium. All analyses were below the limits of detection for these metals, corresponding to concentrations in air of less than 2 ug /m^3 for lead and 10 ug /m^3 for selenium.

To evaluate the potential for hydrolysis in the lung of the caprolactam isocyanate group, regenerating caprolactam, a bulk sample of the powder was extracted with an isotonic saline solution (1 g/5 ml) over a period of time, taking 1-ml aliquots at intervals of 0, 2, 8, 24, and 48 hours. To determine the caprolactam recovered, the aliquots were then extracted with methylene chloride before analysis by gas chromatography The bulk material yielded very little caprolactam in the recovery procedure. The 24- and 48-hour aliquots displayed an irregularity in the baseline output of the flame ionization detector. If the irregularity represents caprolactam, it could be concluded that perhaps a milligram of caprolactam per gram of bulk powder may go into saline solution. Note that the irregularity may have been because a small amount of the bulk material contaminated the saline aliquot. In this case no conclusion could be drawn. In either case, no hazard from caprolactam should exist at airborne powder paint levels below the limits for nuisance materials.

RESULTS

The total dust exposure of both the sprayer and the equipment operator are low, approximately equal to the dust concentration in the general area (Table 1-2).

Dust concentrations at the brown line are nearly double those of the cream line, which reflects the approximate production ratio of 70/30 for these colors. The concentration of dust in the discharge of the final filters is higher than might be expected, especially when compared with dust levels at the west wall.

Dust levels at the west wall are strongly influenced by the quality of air that is returned by the air conditioning system, a unit that recirculates 100 persent of the powder department air through only a rough fiberglass filter. The higher-than-expected concentrations could be a result of mechanical damage to the filter from a periodic manual cleaning with compressed air.

Table 1-3. X-ray fluoresence analysis of powder paint.

Element	Brown powder	Cream powder
Fluorine	?	?
Aluminum	X	?
Silicon	X	X
Sulfur	XX	X
Chlorine	X	X
Calcium	X	X
Titanium	-	XX
Chromium	?	?
Iron	XX	X
Copper	X	X
Zinc	-	X
Lead	X	X
Strontium	X	X
Barium	XX	XX

X = element present
XX = element present in large amounts
- = element was not detected
? = instrument not sensitive enough to detect the element or interference present

DISCUSSION

Total dust levels could be further reduced by several modifications. These include the use of absolute filters for final filtration and the use of vestibules at the entrance/exit of the conveyor to the booth. The vestibules should be added because present design permits the spraying of powder directly out of the conveyor entrance if an operator works ahead of the conveyor.

The aspiration of the powder paint from the 100 pound drums caused a visible release of dust. Because the drum is lined with a plastic bag, this dust source could be easily eliminated by loosely wrapping the bag around the aspirator tube.

CASE STUDY 2

WOOD FURNITURE FINISHING

Stereo cabinets of polystyrene and wood are finished with a base coat, a glaze, and a clear lacquer in a multi-step, conveyorized operation. The application equipment includes both conventional compressed-air and airless spray guns, although the latter predominates. All finishing operations are performed in sidedraft spray booths, with either dry filters or sheet metal baffles. Make-up air is supplied externally to the spray booths. The operations at this facility are characterized by good housekeeping and a high rate of exhaust ventilation; this result is that employee exposure to solvent vapors and spray mist is low.

The glaze operation features a robot applicator, which was installed to remedy an employee morale problem resulting from the messiness of the glaze application.

PROCESS

Operations

The stereo cabinets are made in a variety of designs, but all are of basically the same configuration; they open from the top with hinges at the rear. The cabinet interiors contain a composition board shelf that receives the record changer and radio amplifier. The cabinets are roughly the same height and depth (approximately 30 in x 20 in), with widths ranging from 30 to 60 inches. The walls and lids are made of thin polystyrene sheets, reinforced with back-up panels of composition board. Rims and bases are natural wood moldings.

The cabinets enter the finishing department on a steel mesh conveyor travelling at 10 feet per minute, with an interval of 2 to 3 feet between cabinets. Because the conveyor cannot rotate the cabinet, spray booths are paired on opposite sides of the conveyor to allow better coverage of product sides and edges. Not all product designs nor all of the finishing steps require the use of a second booth.

The finishing process begins with the application of a barrier coat, followed by successive coats of glaze and clear lacquer. The entire process can involve up to 15 spray painters and 16 glaze wipers. The layout of the finishing department is shown in Figure 2-1. The finishing sequence follows:

1. Dust--Dust and wood chips from the assembly operation are removed from the cabinet with a compressed air jet.
2. Barrier coat (Booths 1 and 2)--The acrylic base coat is applied to the entire cabinet surface.
3. Sand--The wooden rim molding is lightly sanded.
4. Top barrier coat (Booth 3)--Both sides of the cabinet lid receive a second application of barrier coat with a compressed air gun.

5. Dry--The finish is dried for four minutes in a 160°F oven.

6. Glaze (Booths 4 and 5)--A spray painter applies a coat of glaze to the top, sides, interior, and rear edges of the cabinet. In the next booth, a robot sprays a heavy coat of stain to the underside of the lid, and the cabinet sides and front.

7. Wipe, Rub, Brush--The freshly stained surface is wiped with clean rags, rubbed with steel wool, and brushed to produce grain highlights and promote adhesion of the stain. Unlike natural wood, the plastic surface does not absorb the glaze. Thirteen wipers are engaged in this operation.

8. Dry--The glaze is dried for four minutes in a 165°F oven.

9. Lacquer (Booths 6 and 7)--The entire surface of the cabinet is sprayed with a clear lacquer. In the first booth, engravings may receive black or gold highlights.

10. Dry--The cabinets enter a short flash-off tunnel followed by a four minute dry in a 160°F oven.

11. Second glaze (Booths 8 and 9)--A second coat of glaze is applied followed by a wiping operation (three wipers).

12. Fly specking (Booth 10)--An operator scatters dark paint droplets over exterior surfaces using a special air gun.

13. Lid lacquer (Booth 11)--Models with a smooth top receive a second coat of lacquer on the top only.

14. Dry--The finish is dried for four minutes in a 160°F oven.

15. Interior barrier coat (Booth 12)--Cabinet interiors receive a second application of the barrier coating. A coat of black "veiling lacquer" is applied with a compressed air gun to the interior corners.

16. Veiling lacquer (Booth 13)--All visible interior surfaces receive a decorative treatment with black lacquer using a compressed air spray gun.

17. Final lacquer (Booths 14 and 15)--A heavy coat of clear lacquer is applied to the entire cabinet surface.

18. Dry--The cabinets enter a short flash off tunnel followed by a four minute dry in a 160°F oven.

19. Inspection--The finish is inspected for imperfections and rerouted for correction if it is necessary.

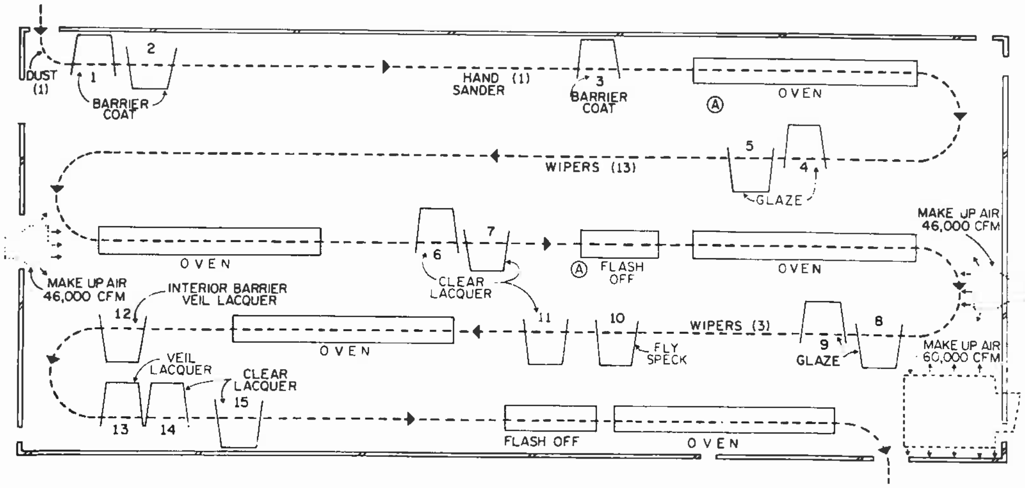

Figure 2-1. Wood furniture finishing room layout.

In step 6 of the above finishing sequence, a heavy coat of glaze is applied to the cabinet exterior and lid underside by a robot spray painter. The robot was installed because of high employee turnover in this messy operation. In addition to eliminating the operator from an unpleasant function, using the robot reduced waste from overspray and increased material utilization by 15 percent. The company expects that the robot should pay for itself in 5 years. Robots are being examined for other spraying operations where visual feedback about the finish appearance is not required.

Coatings

Three types of coatings constitute the bulk of the finishing materials used: an acrylic barrier coat, an oil-based glaze, and a clear lacquer. The barrier or base coat provides color, promotes topcoat adhesion, and protects the plastic furniture substrate from attack by the subsequent coats. The barrier coating is a pigmented acrylic lacquer that has been plasticized with dioctyl phthalate. Iron oxide, lampblack, and burnt sienna provide color. Prior to use, the barrier coat is mixed with equal parts of a reducer. Like all lacquers, the barrier coat cures through the evaporation of its solvent fraction. An oil-based glaze or stain is used to highlight the natural features of the wood surfaces and the molded-in grain of the plastic panels. This oil-based material requires oxidation of the drying oils to complete a cure. A clear nitrocellulose lacquer topcoat is used to provide a protective seal and a semi-gloss finish.

Constituents of the three major coatings are identified in Table 2-1. All three of these coatings are stored and/or reduced as necessary in a building separate from the main plant and finishing department. High pressure pumps located in this building circulate these coatings at 1400 psi to the airless guns. For the compressed-air guns, limited quantities of these coatings are hand delivered to the pressure pots in 5 gallon pails.

Smaller quantities of other coatings are also used. A black lacquer is applied to the record changer compartment in a net or "veil" pattern, in order to produce a decorative effect. Black or gold lacquers are used on some product lines to highlight engravings or other details.

HAZARD ANALYSIS

The principal hazard associated with the coatings in use in these operations is because of the volatile organic materials employed as solvents. These materials fall into the different categories of alcohols, aromatics, esters, ketones, and naphthas, but all exhibit similar physiological effects. These manifestations include irritation of the skin, the conjunctiva, and the mucous membranes of the upper respiratory tract. At high concentrations, these materials can produce the symptoms of headache, nausea, and drowsiness, followed by loss of consciousness and death. Dermal contact with these finishes should be avoided, because toluene and the ketones are known to be absorbed through the skin. Benzene is a potential hazard as a contaminant in formulations containing toluene, xylene, or refined petroleum solvents.

No federal standard exists for isobutyl isobutyrate, a minor constituent of both the clear lacquer and the reducer for the barrier coating. Acute inhalation studies on animals indicate that this material is slightly more toxic than isobutyl alcohol; these results suggest a working limit of 25 to 50 ppm for an 8-hour exposure.

The non-volatile coating components include resins, plasticizers, and pigments. The oleoresins, nitrocellulose, and the thermoplastic acrylics are all nonreactive components which are relatively inert physiologically. Dioctyl phthalate, used to plasticize the acrylic resin, possesses low toxicity. The pigment materials (natural and synthetic iron oxide, lampblack, and amorphous silica) are either of low toxicity or they represent such a minor constitutent of the coating solids that they do not present a hazard under normal conditions of use. Crystalline silica, a highly toxic mineral, is a possible contaminant in the amorphous silica material.

Table 2-1. Coating composition.

Clear Lacquer		
15% solids:		
Resin:	nitrocellulose modified with natural resins and oils	11%
Pigment:	amorphous silica	4%
85% volatile:		
Isopropanol		11%
Isobutyl acetate		18%
n-Butanol		12%
VM&P naphtha		22%
Toluene		12%
Ethylene glycol monobutyl ether		2%
Isobutyl isobutyrate		3%
Aromatic 100		3%
Isopropyl acetate		2%
Barrier Coat		
23% solids:		
Resin:	thermoplastic acrylic plasticized with dioctyl phthalate	
Pigments:	synthetic iron oxide, lampblack, burnt sienna	
77% volatile:		
Methyl ethyl ketone		40%
Isopropyl acetate		55%
Xylene		5%
Barrier coat mixed 1:1 with following reducer:		
Isopropanol		32%
Methyl ethyl ketone		40%
Methyl isobutyl ketone		6%
Toluene		12%
Isobutyl isobutyrate		10%
GLAZE		
21% solids:		
Resin:	oil-based	
Pigments:	iron oxide, lampblack, burnt sienna	
77% volatile:		
VM&P naphtha		50%
Mineral spirits		35%
Toluene		10%
Ethylene glycol monobutyl ether		5%
Xylene		5%

SPRAY BOOTHS

Design

Eight spray booths were included in the original design of the finishing department. These booths consist of a water pan extending from the conveyor edge into a dry plenum chamber. Air is exhausted into a 9-inch slot at mid-level and a 4-inch opening above the water pan. A change of air direction in the plenum is intended to drop particulate matter into the water pan for collection. Air is moved with an axial flow fan and discharged through a "coolie" style weather cap a few feet above roof level. The fan is rated at 15,900 cfm. To improve airflow, five booths were modified by removing the steel spray curtain, slots, and internal baffles, and installing a 5 x 5 array of disposable 20-inch square filters and turning vanes in the plenum. Each of these five booths has a smaller booth paired with it, situated on the opposite side of the conveyor to allow better paint application to the sides and back of the stereo cabinet. These booths are also of a dry filter design, with a 3 x 5 array of disposable filter pads. Fans for the smaller booths are rated for 10,930 cfm. Filters on all booths were changed at the end of the 8-hour shift. A typical booth is shown in Figure 2-2.

With the exception of two dry filter booths used for glaze application, all the booths are open on three sides. The two booths used for glaze application have sheet metal side curtains with openings for the conveyor and cabinet passage. It was necessary to close the sides on these booths because of the proximity of the finish wipers to these operations.

Airflow Measurements

Total airflow was measured on each of the booths that were in use. The airflow in the dry filter booths was recorded with both clean and dirty filters. Control velocity was measured with a hot wire anemometer at 12 points in the vertical plane occupied by the paint sprayer and the measurements were averaged. Results of these measurements are presented in Table 2-2.

Total airflow for the slot-type booths was 10 to 20 percent below the design value of 15,900 cfm. Airflow for the slot booths that had been reworked with filters was 1.5 to 2 times the design value. A maximum decrease in airflow of about 25 percent was observed for the large (5 x 5) dry filter booths with heavy loadings. The smaller (3 x 5) booths experienced larger decreases in flow. While airflow with clean filters was 150 percent of design, it dropped over one half when the filters loaded.

Average air velocities ranged from 130 to 230 fpm in the larger dry filter booths, from 60 to 110 fpm in the smaller filter booths, and from 40 to 150 fpm in the slot booths. The glaze booths, which were partially enclosed, exhibited a higher velocity than the more open booths with the same total airflow. In most cases, increased airflow meant increased air velocity at the operator's platform, but other factors (including location of doors, walls, process equipment, and airflow patterns established by the make-up air units) affected the control velocity.

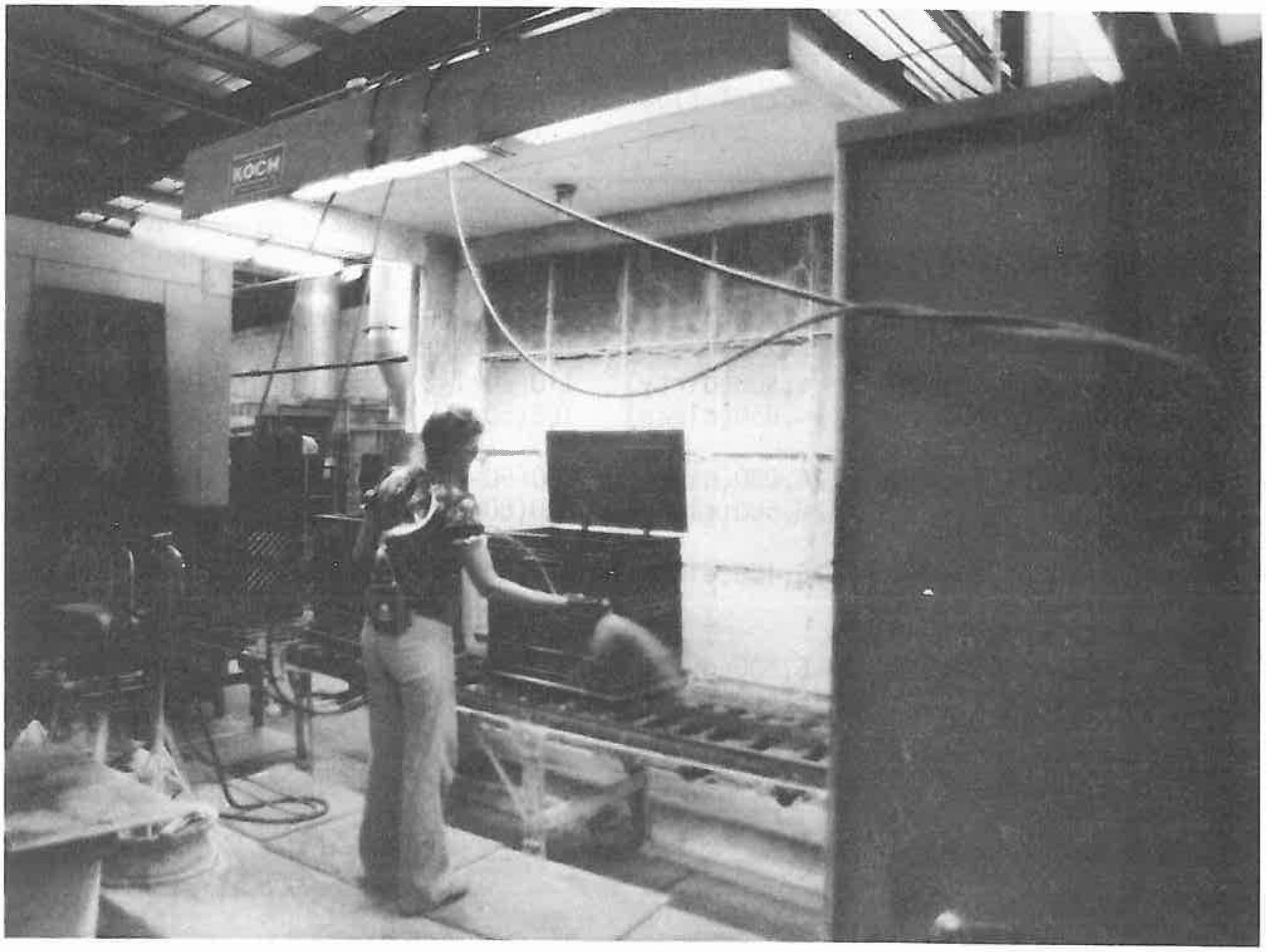

Figure 2-2. Dry filter booth used in cabinet lacquering.

GENERAL VENTILATION

Make-up air is provided to the finishing department by two 46,000 cfm make-up air heaters that are direct fired with natural gas and a third 60,000 cfm unit. Fresh air inlets for the make-up air heaters are located at ground level, far removed from booth exhaust stacks. Tempered air is introduced into the finishing department through three grille boxes. The volume and high discharge velocity of these distribution points, together with 20 percent deficiency in the volume of supply air, produce substantial crossdrafts in areas near doors and supply air points.

Because all air exhausted from the booths must be supplied from the finishing department, the booth exhausts have the effect of providing dilution ventilation for any solvents that are evaporated from the open conveyor lines.

A fan supplies room air to a plenum running underneath the conveyor in order to provide cooling for the finish wipers during the summer months (Figure 2-3). The system was not in operation during this survey.

Table 2-2. Spray booth airflow.

Booth*	Type	Rated flow(cfm)	Actual flow (cfm)	Average Velocity (range)	Coating	Comments
1	5 x 5 filter	15,900	23,400(dirty) 28,700(clean)	130(40-250) 160(100-200)	Barrier	Heavy paint application
3	Slot	15,900	12,200	95(40-200)	Barrier	Air gun
4	3 x 5 filter	10,930	6,900(dirty) 14,650(clean)	110(60-140) 105(60-150)	Glaze	Heavy paint application;
5	5 x 5 filter	15,900	26,000(dirty) 28,600(clean)	230(90-300) 220(80-350)	Glaze	Heavy paint application;
6	5 x 5 filter	15,900	28,100(dirty)	210(100-350)	Lacquer	Heavy paint application
7	3 x 5 filter	10,930	6,500(dirty) 15,400(clean)	60(10-90) 100(60-170)	Lacquer	Heavy paint application
8	5 x 5 filter	15,900	26,500(dirty)	230(70-400)	Glaze	Booth closed on 3 sides
10	4 x 6 filter	11,120	--	--	Fly speck	Very light paint application
12	Slot	15,900	14,100	70(30-140)	Barrier; veil lacquer	Airless: barrier coat air gun: veil lacquer
13	Slot	15,900	12,100	40(15-65)	Veil lacquer	Air gun
14	5 x 5 filter	15,900	27,000(dirty)	150(100-200)	Lacquer	Heavy application

*Booths 2, 9, 11, 15 not in use.

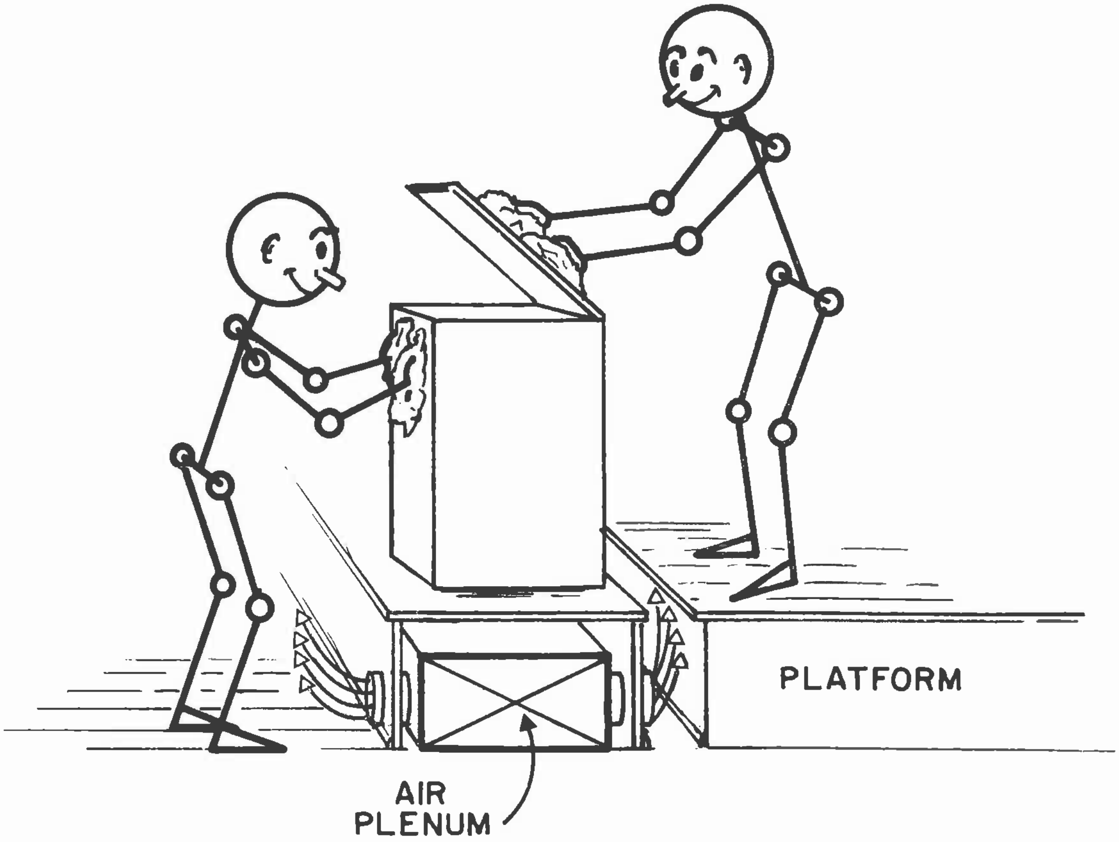

Figure 2-3. Ventilation heat relief for glaze wipers.

PROTECTIVE EQUIPMENT

Protective equipment is limited to the optional use of aprons or shop coats and gloves. No respiratory protection is required at the environmental levels measured. For cleanup, waterless hand cleaner is available at the work stations.

EVALUATION

At this facility, twenty-seven employees are potentially exposed to paint solvents or spray mist. This number includes 10 spray painters, 16 finish wipers, and a crew chief/relief person. Potential sources of exposure include spray mist and solvent vapors from spraying, solvent vapors evaporating from finished cabinets, and (for the crew chief only) solvent vapors from paint system cutting or mixing operations.

As an index of control, the 8-hour time-weighted average (TWA) exposures to total spray mist and selected organic solvents were determined for the paint sprayers. Area samples for total mist and selected solvents were taken at the booth face of the robot spray painter to evaluate the performance of that system. The 8-hour time-weighted average exposures to selected organic solvents were determined for the finish wipers. Area samples for organic solvents were taken in solvent flash-off and drying oven areas to determine the impact of these sources on employee exposure.

The 8-hour TWA exposures were calculated from separate morning and afternoon samples. With the exception of the crew chief, all employees spend their entire workshift in the finishing department, excluding 2 scheduled 15-minute breaks and a 30-minute lunch.

Total mist samples were collected using closed-face cassettes with preweighed 37 mm polyvinyl chloride/acrylonitrile copolymer membrane filters and personal pumps operated at 2.0 lpm. Organic solvent samples were collected on 150 mg charcoal tubes with personal pumps operated at 50 cc/min. Tubes were subsequently desorbed and analyzed by gas chromatography.

Solvents for analyses were selected based on the stated composition of the finishing materials and qualitative analysis of selected charcoal tube samples by mass spectroscopy. No benzene was detected in any samples. The effects of the solvents were assumed to be additive, and a combined exposure factor calculated.

To determine the presence of crystalline silica as a contaminant in the amorphous silica present in the clear lacquer, dried lacquer residue was obtained from the booth filters and analyzed qualitatively by x-ray diffraction. The sample yielded no crystalline diffraction patterns, indicating a crystalline silica concentration of less than 0.25 percent of the paint solids.

RESULTS

Air sampling results are reported in Tables 2-3 through 2-7. In all cases the exposure of workers to total paint mist and to organic solvents was less than 25 percent of allowable levels.

DISCUSSION

The low concentrations of paint mist and organic solvents can be attributed to adequate ventilation of the spraying operation, proper orientation of the worker with respect to the booth and the workpiece, and the inherent low bounce back of the airless spray guns. Because no makeup air is supplied directly to the spray booth, solvent exposures cannot be reduced below the concentration of solvents present in the background air. On the other hand, the spray booths act as a source of general exhaust ventilation, keeping the background levels to a minimum. No attempt was made to correlate mist and solvent levels to spray booth airflow because of significant differences in paint characteristics, paint usage, and cabinet areas finished in each work station. In addition, only those spray booths in operations that had proven to be troublesome had been modified to increase airflow.

The glaze wipers had the highest exposure to petroleum distillates, but still far below hazardous levels. A supply air duct running underneath the conveyor at the wiping station circulates room air to provide relief during warm weather months (Figure 2-3). This system was not in use at the time of the study but might prove to be useful in the further reduction of solvent exposure to the glaze wipers.

Table 2-3. Airborne levels of paint spray mist in wood furniture finishing.

Booth	Operation	Paint mist (mg/m^3)* GM	GSD
1	Heavy coat of barrier finish	0.8	1.4
3	Second coat of barrier finish to top and sides	0.4	1.6
4	Manual coat of glaze to top and sides	1.0	1.2
5	Robot application of heavy coat of glaze (area sample)	0.1	2.0
6	Heavy coat of lacquer	0.5	1.2
7	Second coat of lacquer to top and sides	0.4	1.8
8	Light coat of glaze	0.1	5.0
12	Barrier coating of interior surfaces	0.5	1.1
13	Veil lacquer applied to interior	0.1	1.5
14	Final heavy coat of lacquer	2.5	1.0

GM: Geometric mean
GSD:Geometric standard deviation
*8-hour time-weighted average (TWA)

Table 2-4. Airborne solvent levels in barrier coat operations

		8-hour time-weighted average (TWA) concentration (mg/m^3)							
Booth	Date	MEK	Isopropyl Acetate	Xylene	Isopropanol	MIBK	Toluene	Isobutyl isobutyrate	C_E*
1	9/10	6	13	1	3	<6	9	<7	0.11
1	9/11	4	11	2	2	<4	8	<6	0.09
3	9/12	<3	3	1	1	3	3	<5	0.06
3	9/13	<3	4	1	1	<3	4	<4	0.05
OSHA PEL		590	950	435	980	410	750	150*	1.0
ACGIH TLV		--	--	--	--	--	375	--	--
NIOSH		590	--	--	980	200	375	--	--

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the exposure limit.

**No OSHA standard for isobutyl isobutyrate exists; 150 mg/m^3 is used by analogy with n-butanol; see text.

Table 2-5. Airborne solvent levels in glaze operations.

		8-hour time-weighted average (mg/m^3)				
Booth	Date	Toluene	Xylene	Ethylene glycol monobutyl ether	Petroleum distillates	C_E*
4	9/10	3	1	19	20	0.10
4	9/11	2	2	12	12	0.06
Robot	9/12	3	2	19	13	0.10
Robot	9/13	1	1	11	20	0.06
8	9/12	4	1	14	6	0.07
8	9/13	5	1	15	6	0.08
Glaze wipers**		5	4	18	33	0.10
Background**		4	2	14	15	0.08
OSHA PEL		750	435	240	2950	1.0
ACGIH TLV (1979)		375	435	120	-	1.0
NIOSH		375	435	-	350	1.0

*Combined Exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the exposure limit.

**Geometric mean

Table 2-6. Airborne solvent levels in lacquer operations.

		8-hour time-weighted average (mg/m^3)								
Booth	Date	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	C_E*
6	9/10	2	6	10	6	<12	2	2	12	0.12
6	9/11	2	6	7	6	<7	3	1	9	0.10
7	9/12	2	5	<6	4	<8	3	1	9	0.08
7	9/13	<1	3	5	4	<7	4	3	27	0.09
14	9/12	8	24	15	14	11	5	4	23	0.21
14	9/13	10	25	18	15	11	7	5	27	0.23
Background(GM)**		1	2	<3	1	4	1	1	<4	--
OSHA PEL+		980	700	300	750	240	150+	950	2950	1.0
ACGIH TLV (1979)		980	700	150	375	120	-	950	-	1.0
NIOSH		-	-	-	375	-	-	-	350	-

(a) Isopropanol; (b) Isobutyl acetate; (c) n-Butanol; (d) Toluene; (e) Ethylene glycol monobutyl ether; (f) Isobutyl isobutyrate; (g) Isopropyl acetate; (h) Petroleum distillates.

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the exposure limit.

**Geometric mean

+No OSHA standard for isobutyl isobutyrate exists; 150 mg/m^3 is used by analogy with n-butanol; see text.

Table 2-7. Airborne solvent levels in veil lacquer operations.

Booth	Date	8-hour time-weighted average (mg/m^3)									
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	C_{E*}
12	9/10	<1	25	13	12	3	<26	<23	3	<14	0.24
12	9/11	<1	23	9	12	3	<16	<14	4	10	0.18
13	9/12	<1	3	<5	5	1	12	<11	<1	<7	0.10
13	9/13	<1	4	<4	6	1	10	<9	<1	<5	0.09
OSHA PEL		140	700	300	750	435	240	1900	590	2950	1.0
ACGIH TLV (1979)		25	700	150	375	435	120	1900	590	--	1.0
NIOSH		23	--	--	375	435	--	--	590	350	--

(a) Isophorone; (b) Isobutyl acetate; (c) n-Butanol; (d) Toluene; (e) Xylene; (f) Ethylene glycol monobutyl ether; (g) Ethanol; (h) MEK; (i) Petroleum distillates.

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the exposure limit.

CASE STUDY 3

METAL FURNITURE: SOLVENT AND WATERBORNE COATINGS

This modern sheet metal job shop manufactures custom cabinetry for office equipment, automatic data systems, and electronic products. In this shop, base and finish coatings are applied in over 700 different colors and various textures. Both solvent and waterborne coating systems are used. The application equipment includes conventional spray guns, air-atomized electrostatic handguns, and electrostatic guns mounted on reciprocators. All of the coating operations are performed in sidedraft, dry filter spray booths that are enclosed on all sides. Make-up air is introduced into the booths through a distribution plenum in the back wall and into conveyor entry and exit vestibules. The high levels of paint mist that were measured at this facility are attributable to infrequent replacement of paint filters, improper distribution of supply air, and relatively high atomizing-air pressures.

PROCESS

Operations

Prior to finishing, semi-assembled sheet metal fabrications are hung on an overhead conveyor in the "load area" (Figure 3-1). They then receive an automatic seven-stage metal pretreatment. This process consists of a detergent wash followed by two water rinses, an iron phosphate bath, a third water rinse, a chromic acid rinse, and a final rinse with deionized water. The workpieces are then routed to an elevated multi-zone oven for drying.

Following this, they are transported through a sidedraft spray booth designated "Special booth" in Figure 3-1. In this booth, speciality paints, such as contrasting colors for the insides of cabinets, are applied. Because not every production run requires the application of contrasting colors, this subprocess is not always in operation during a regular shift. After a 10-minute air flash-off period, the workpieces enter two in-line sidedraft spray booths (designated "Prime Booths A" and "B" in Figure 3-1). Both sides of each workpiece receive a base or prime coat. This can be applied either manually with hand-held spray equipment or by equipment mounted on a reciprocator. The selection of an application method is influenced primarily by the physical configuration of the production-run workpieces.

Electrostatic equipment is used only for conventional solvent-type paints. Following a second 10-minute air flash-off period the workpieces enter an identical set of in-line spray booths. These booths are designated "Finish Booths A" and "B" in Figure 3-1. In these booths, a finish coat is manually applied over the wet prime coat using hand-held equipment Textured and wrinkled finishes, when they are required by customer order, are applied in these booths. As an alternative, the workpieces from the prime booths can be routed to the elevated baking ovens before they receive the finish coat. The majority of workpieces receive both prime and finish coats before baking.

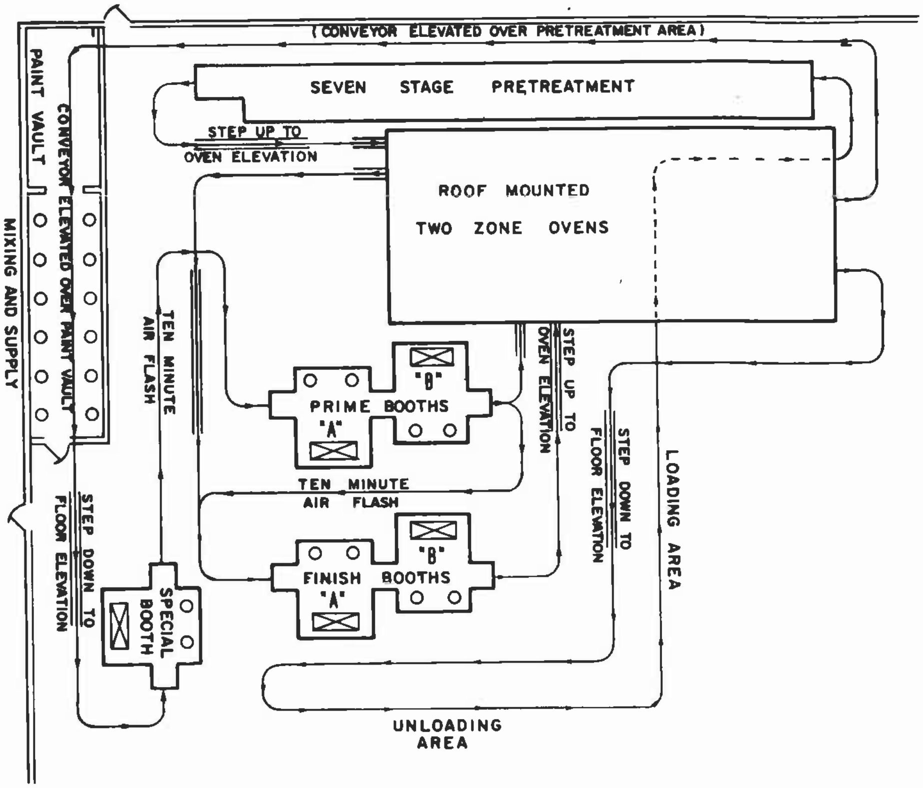

Figure 3-1. Process layout - metal furniture finishing.

Coatings

Coating formulations are specified by customer order. These orders can generate runs of as few as several pieces to runs that require several shifts. The largest single type of paint consumed at the facility is an alkyd baking enamel. This conventional solvent-type paint is supplied by several vendors, in an array of formulations that conform to customer requirements. These coatings cure when they are baked in an oven for approximately 25 minutes at 300°F.

The second most significant type of paint consumed is a waterborne acrylic emulsion, which comprises 30 to 40 percent of the total paint consumption at this facility. A move to substantially increase this percentage is anticipated. This shift in the type of paint consumed was initiated principally to meet environmental regulations. Other advantages of this waterborne paint cited by plant personnel are excellent adhesion to the metal substrate and reduced solvent exposure to the paint sprayer. The increased adhesion properties present special problems in stripping this material from defective parts; the cost of stripping can often exceed the cost of the part itself. This type of coating system requires baking for approximately 25 minutes at 350°F.

A central paint supply system delivers and recirculates a total of 25 colors$^+$ to the booths. With this system, color changes can be accomplished in less than 30 seconds. All the waterborne coatings and small runs of other paints are delivered to the booths in portable pressure pots.

HAZARD ANALYSIS

With more than 700 different coating formulations in use, employees are potentially exposed to a wide variety of paint materials. The organic solvents that are used produce similar physiological effects. In general, they are irritants to the conjunctiva and to the mucous membranes of the upper respiratory tract. They all produce depression of the central nervous system and, at high concentrations, produce symptoms of headache, nausea, and drowsiness followed by unconsciousness.

The hazards of organic solvents are drastically reduced when waterborne coatings are employed, because these substitute materials typically contain less than two percent organic co-solvents. Dimethylethanolamine is used in the waterborne formulation as an emulsion-stablizer, surface active agent, producing a slight fishy odor noticeable in the flash-off areas. Dimethylethanolamine has been demonstrated to induce asthma and/or rhinitis. No standard exists for exposure to dimethylethanolamine, however, animal studies indicate that it is of the same order of acute toxicity as monoethanolamine which has a Permissable Exposure Limit (PEL) of 3 ppm. Because of the low vapor pressure of dimethylethanolamine, the chief hazard would be associated with inhaling the paint aerosol rather than the vapors of dimethylethanolamine.

The non-volatile components of the coating formulations that are utilized are, for the most part, physiologically inert. Exceptions are the lead- and chromium-containing pigments that are present in certain color formulations. The reactive resins, polyurethane and epoxy, and their associated catalysts, are only used to a limited extent but are potential irritants or sensitizing agents to the skin and/or respiratory system. Their limited use did not permit evaluation during this survey.

SPRAY BOOTHS

Design

The five spray booths that are in operation at this facility are of nearly identical design. The only difference is the in-line configuration of the prime and finish booths as opposed to the detached "special" booth. The booths were originally installed as sidedraft booths with an oil-flooded sheet and wash section. However, most paints would not float on the oil, which created severe problems in removing paint sludge from the oil reservoirs. The oil also caused slippery conditions in and around the booth. A switch to a water wash design would have required replacement of both pumps and reservoirs. Because of the problems associated with such a change, the oil-flooded sheet and air-wash section was replaced with an 8 foot by 20 foot filter bank for collection of the paint solids. This modified design is shown in Figure 3-2. Note that make-up air is supplied through 5 air inlets located on the wall opposite the exhaust filter bank, and through two filtered-air inlets in each conveyor inlet and supply exit vestibule. Design specifications called for an exhaust flow rate of 27,800 cfm and a make-up air flow rate of 31,600 cfm. The excess make-up air was to be supplied to the vestibules, in effect sealing out dust and dirt from the spray booth.

One common fault of filter type spray booths that is shared by these booths is that the air velocity in the immediate vicinity of the painter is often the lowest in the booth. This is because the heaviest accumulation of paint on the filters is in this area. In general, there is only one painter stationed in each spray booth (but this can vary with the size and shape of a particular product run during any given workshift). Stationing a single painter per booth eliminates the possibility of the painter being exposed to another painter's overspray.

There are certain product runs where the painter is stationed in the booth with reciprocator-mounted equipment. The increased overspray generated by this type of equipment can create excessive solids buildup on the exhaust filter, reducing the exhaust air volume of the booth, and causing the entire booth to fill with spray mist.

In order to stay ahead of the conveyor line, most painters prefer to work near the conveyor entrance to the booth, as opposed to working near the center of the spraying section. However, spraying from the end of the booth may cause spray mist to escape through the entrance vestibule into the plant.

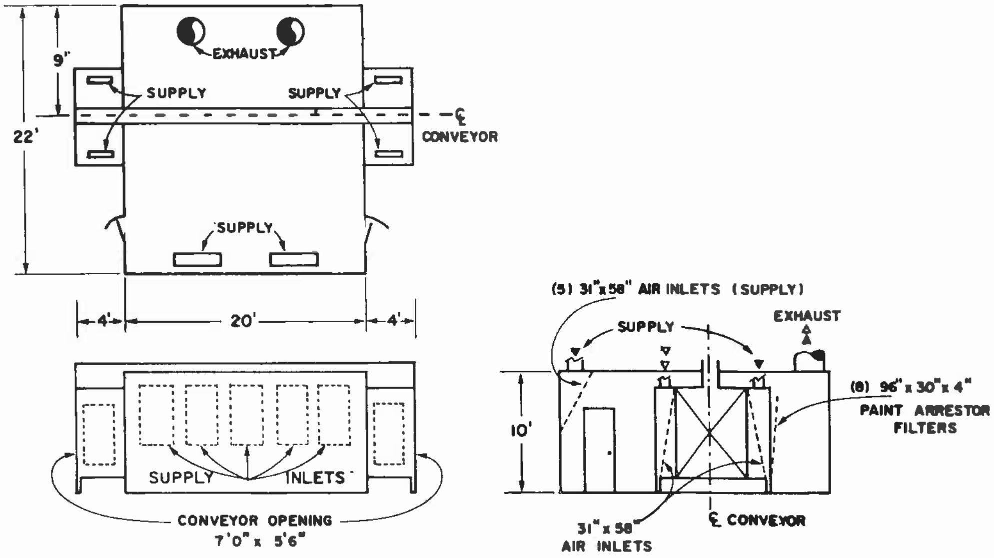

Figure 3-2. Spray booth configuration.

Airflow Measurements

A hot wire anemometer was used to measure air velocities within the spray booth, and the total volume of supply and exhaust air. Results of these measurements are reported in Table 3-1.

Table 3-1. Spray booth airflow rates.

Booth	Exhaust (cfm)	Supply (cfm) Total	Supply (cfm) Behind painter	Supply (cfm) Vestibules	Control velocity (fpm)
Prime A	9,000	33,000	16,000	17,000	60
Prime B	14,000	25,000	10,000	15,000	50
Finish A	44,000	32,000	14,000	18,000	140
Finish B	25,000	27,000	13,000	14,000	80
Special	20,000	35,000	11,000	24,000	60
Design	27,800	31,600	NA	NA	118

The heavy paint buildup on the exhaust filters in both prime booths caused the exhaust flow to drop off considerably. The exhaust flow for Prime Booth A was only one-third the design value. The heavy paint buildup in this booth could be attributed to the operation of reciprocator-mounted spray guns. Exhaust filters on both this booth and the others were replaced every three to six workshifts. Based on the low exhaust flow, this service period is considered too long. Measured total supply rates presented in Table 3-1 were within ± 10 percent of design specifications.

The proportioning of make-up air between the vestibules and booth supply air inlets varied considerably. Increased quantities of fresh air supplied to the vestibules resulted in a net decrease in air movement in the painters' breathing zone, as shown in Table 3-1 and Figure 3-3. Spray mist was observed escaping from booths which had a severe imbalance of supply and exhaust air.

PROTECTIVE EQUIPMENT

At the start of each workshift, painters don clean coveralls and either rubber or cloth gloves (at their option). During the painting operations, they wear a supplied-air respirator (not NIOSH-approved) that has a replaceable plastic viewing window, cloth cap, and loose fitting cloth hood. In an earlier survey by the company's insurance carrier, reported solvent levels inside the hood were slightly higher than in the breathing zone outside the hood. This was probably because the respirator hood fabric was permeated by liquid paint or solvent. The respirator did appear to offer protection from the paint over spray. Volumes and pressures of the respirator supply air were regulated, within certain limits, by the individual painters.

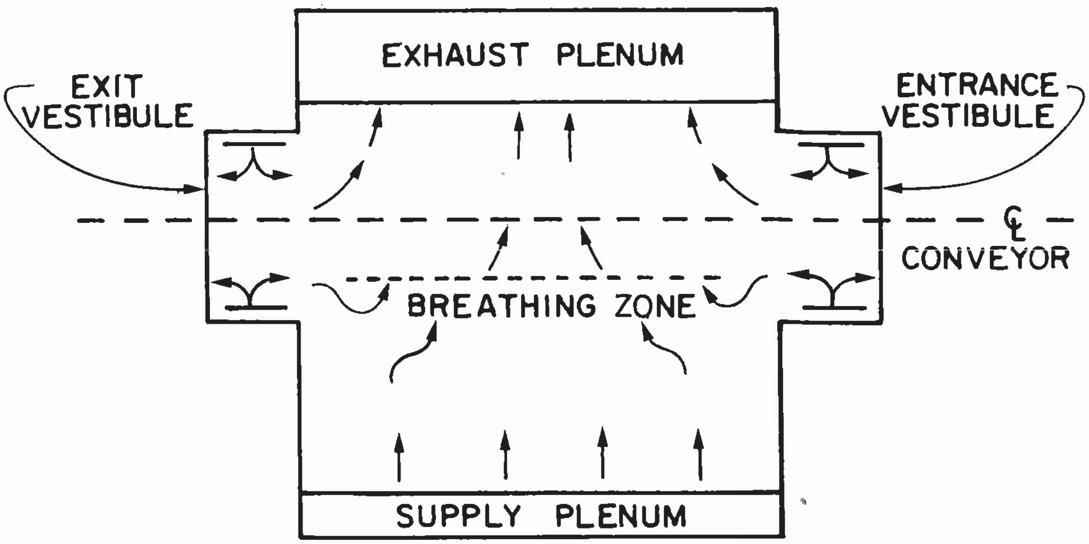

Figure 3-3. Booth airflow.

WORK PRACTICES

The opposed painting sections of the in-line booths eliminate the need to turn the workpiece during the painting process. However, painters often spray both sides of a workpiece on short production runs. The worker paints the back side of each workpiece by positioning himself between the object being painted and the exhaust filter. This practice caused the painter to be engulfed in his own spray mist. With longer production runs, the painters were stationed in opposing booths, which obviated the need for this practice.

EVALUATION

Up to 12 employees are potentially exposed to paint solvents or spray mists at this facility. The employees are identified as one paint vault attendant, one relief painter, and up to 10 spray painters/workshift. Potential sources of exposure include spray mist and solvent vapors from spraying, solvent vapors evaporating from finished pieces, and paint system cutting or mixing operations.

As an index of control, the 8-hour time-weighted average (TWA) concentrations of total spray mist, lead, and organic solvents were determined for the paint sprayers. All sprayers spend their entire workshift in the finishing department, excluding scheduled breaks and lunch. Conventional solvent-reduced paints were in use during the first day of the survey. An acrylic emulsion paint was used exclusively during the second day of the survey. On the last day of the survey, both solvent and emulsion paints were used.

The 8-hour TWA concentrations were calculated from separate morning and afternoon samples collected outside the respirator. Samples of total spray mist were collected using closed-face cassettes with preweighed 37 mm polyvinyl chloride/acrylonitrile copolymer membrane filters and personal pumps operated at 2.0 lpm. Because of the variety of paints used and the lack of material safety data sheets for specific coatings, all filters were subsequently ashed and analyzed for lead by atomic absorption spectroscopy. Solvents for analyses were selected based on a limited number of available material safety data sheets and on the qualitative analysis of selected charcoal tube samples by mass spectroscopy. Major compounds on these samples were toluene, xylene, aliphatic hydrocarbons in the C8-11 range, n-butyl acetate, diisobutyl ketone, and 2-ethoxyethyl acetate. Other compounds that were identified but present in lesser quantities included methyl amyl ketone, isobutyl alcohol, isobutyl acetate, isopropanol, and trimethyl-and tetramethyl benzenes.

RESULTS

Airborne concentrations of organic solvents are reported in Table 3-2. In all cases the concentration to organic solvents was less than 50 percent of allowable levels. Airborne concentrations of paint mist are reported in Table 3-3. One-half of the samples exceeded the 15 mg/m^3 limit set by OSHA for total dust. This can be attributed to high atomizing-air pressures, the presence of a second painter in the booth, or low spray booth airflow. Painters U and Y showed the highest mist levels. Both these painters sprayed using an atomizing-air pressure of approximately 80 psi and frequently shared the same booth. The mist levels of painter W were somewhat lower, even though air pressure exceeded 90 psi. This painter most frequently worked alone. Painters X and Z showed the lowest mist levels. Both these painters worked alone and consistently sprayed at an air pressure of 60 psi or less.

The majority of the samples that were analyzed for lead were below detectable limits, corresponding to airborne lead concentrations less than 7 ug/m^3. However, all samples that were taken on the afternoon shift of the first day of the survey showed hygienically significant amounts of lead. The specific paint and the exact percentage of lead in the paint that was responsible for these levels were not identified. These lead concentrations are reported in Table 3-4. The range of colors used and the variety of workpieces painted did not allow an accurate estimate of the time-weighted average concentration of lead.

DISCUSSION

The use of excessively high air pressure is a prime contributing factor to poor quality work, excess spray mist, and paint waste. Improved supervision of spraying practices, with a goal of reducing-atomizing air pressures, could reduce paint mist levels substantially while improving paint mileage.

Paint mist levels could also be reduced by assigning only one painter to each booth whenever that is possible. In no case should a spray painter occupy the same booth with automatic, reciprocator-mounted equipment.

Spray booth efficiency could be markedly improved by replacing exhaust filters at the end of every shift, or by monitoring the pressure drop across the filter bank and changing filters when a given pressure drop is exceeded. Equally large gains in booth efficiency could be achieved by properly proportioning the fresh air supplied to the booth and the vestibules, reducing vestibule air to no more than one third of the total quantity of makeup air.

Because the paint wets the respirator hood fabric, consideration should be given to switching to a respirator with a hood made of an impervious material. A respirator that is certified by NIOSH should be used. In any event, continued use of respiratory protection is warranted, as long as any lead-containing paints are used, or when two-component urethane or epoxy paints are applied.

Table 3-2. Airborne levels of organic solvents in metal furniture finishing.

	8-hour time-weighted average (mg/m^3)						
Painter	Toluene	Xylene	n-Butyl acetate	Diisobutyl ketone	2-Ethoxy-ethyl acetate	Aliphatic hydrocarbons	C_E*
U	61	30	109	23	14	180	0.46
V	57	36	56	<1	1	170	0.34
W	59	48	82	6	10	120	0.44
X	12	7	22	3	4	33	0.10
Y	52	48	56	3	1	170	0.37
OSHA PEL	750	435	710	290	540	1800	1.0
ACGIH TLV (1979)	375	435	710	150	270	--	1.0
NIOSH	375	435	--	--	--	--	--

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \dots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the exposure limit.

Table 3-3. Airborne levels of paint spray mist in metal furniture finishing.

Painter	8-hour TWA (mg/m^3) GM	GSD
U	27.6	1.9
V	<12.9	2.0
W	<18.9	2.0
X	3.7	1.8
Y	23.5	1.4
Z	7.0	1.1

GM: Geometric mean
GSD: Geometric standard deviation

Table 3-4. Airborne levels of lead in metal furniture finishing

Painter	Sample duration (minutes)	Lead ($\mu g/m^3$)
U	152	1050
W	156	660
X	150	30
Y	154	250

CASE STUDY 4

RAILROAD CAR FINISHING

Hopper cars are finished in the paint shop of a manufacturer and rehabilitator of railroad freight cars. Exterior surfaces are finished with air drying alkyd enamels by two painters using airless spraying equipment. All painting is performed in a semi-downdraft, water-wash spray booth, equipped with a longitudinal pit to facilitate underbody painting. Full-facepiece, supplied-air respirators are worn during all spraying operations. The respirator is prevented from fogging with spray paint mist by covering the viewing window with layers of clear plastic food wrap.

PROCESS

Operations

This plant is engaged in the manufacture and rehabilitation of railroad freight cars, primarily hopper cars. These cars are painted chiefly to protect them against corrosion; aesthetic considerations are secondary. Therefore, application techniques are geared to providing a high film build in a minimum time.

The steel surface of these cars is prepared for finishing by blasting with commercial grit or steel shot. After cleaning, the cars are moved from the blasting area into the spray booth shown in Figure 4-1. Prior to painting, the car's trucks and couplers are wrapped and access platforms are dropped into position at each end of the car. The booth doors are closed when painting begins.

Two painters apply the finish, using airless spray equipment operated at 3,600 to 4,000 psi. Light colors require both a prime and a finish coat; darker colors require only a single coat. A typical car requires about 45 minutes of actual spraying time, and 40 to 50 gallons of paint.

The painters begin by descending into the pit and painting the underbody. They start in the middle and work toward opposite ends of the car. After completing the underbody, painters proceed to the main level and access platforms to paint the sides and ends of the car. The interiors of the hopper cars are not finished.

After spraying, the rail cars are moved to an enclosed drying area where markings and manufacturer's identification numbers are added. The process layout allows one car to be prepared while a second is being painted, and a third is curing in the dry-off area. About 3 cars are painted per shift. During the survey, 3 types of cars were painted: a wood chip car, a coal hopper, and an aggregate car. All 3 have the same basic configuration, except that the wood chip car has a 50 percent larger volume.

Coatings

Color, coating type, and film thickness are specified by customer order; alkyd enamels are used most frequently. Light color topcoats are preceded by a zinc

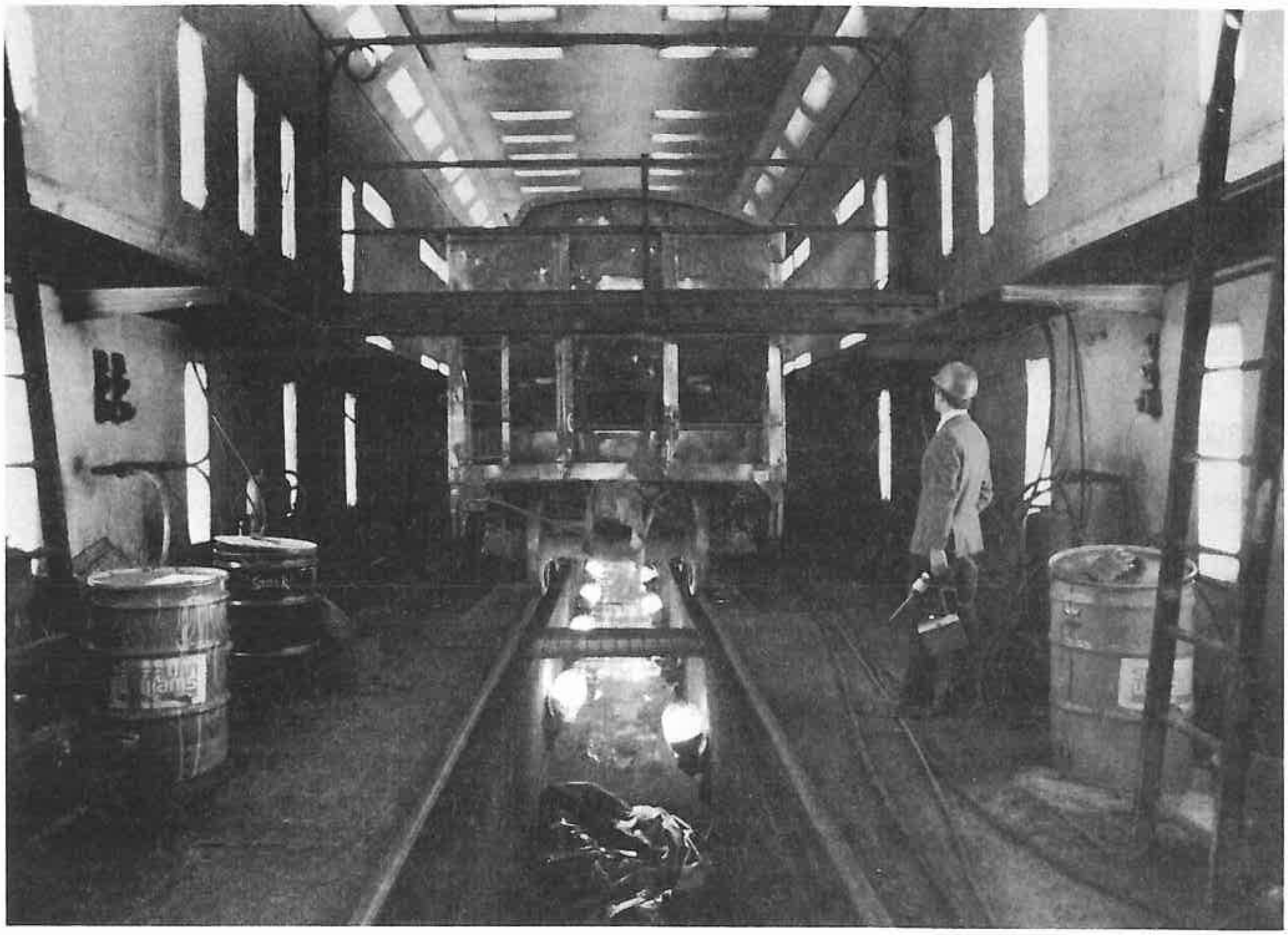

Figure 4-1. Railroad car in booth ready for painting.

chromate primer. Darker colors are generally applied directly to the metal substrate.

The compositions of the coatings used during this survey are presented in Table 4-1. Although these coatings are supplied by different manufacturers, composition varies only slightly. All are approximately 50 percent solvent by weight. Metallic soaps employed as driers allow a tack-free surface in 3 to 5 hours. As with all alkyd resin paints, the film cures by the oxidation and subsequent polymerization of the resin. The principal solvent used is mineral spirits, along with lesser quantities of toluene and xylene. Up to 5 gallons of additional mineral spirits may be added to each 50-gallon drum of paint to reduce it to application viscosity.

HAZARD ANALYSIS

Lead compounds are the main hazard associated with the coatings in use at this facility. These compounds include both inorganic lead (lead chromate, lead monoxide) used as pigments and lead soaps employed as driers. In addition to

Table 4-1. Paint composition.

Paint "A": Blue alkyd enamel

0.25	% CrVI (in pigment)
0.19	% Pb (in drier)
40	% mineral spirits
10	% aliphatic hydrocarbons
5	% toluene
5	% aromatic naptha

Paint "B": Zinc chromate primer

3.7	% CrVI (in pigment)
4.7	% Zn (in pigment)
25	% mineral spirits
5	% toluene

Paint "C": Brown alkyd enamel

0.24	% Pb (as litharge)
0.2	% Pb (in drier)
40	% mineral spirits
5	% toluene
5	% xylene

Paint "D": Zinc chromate primer

0.72	% CrVI (in pigment)
0.91	% Zn (in pigment)
0.22	% Pb (in drier)
45	% mineral spirits
5	% aromatic naphtha

Paint "E". Gold Alkyd Enamel

0.24	% CrVI (in pigment)
0.29	% Pb (in drier)
40	% mineral spirits
5	% aliphatic hydrocarbon
5	% toluene
5	% aromatic naptha
5	% VM&P naphtha

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*All percentages shown are by weight of total paint.

the hazard of lead poisoning, lead chromate (and zinc chromate) has been implicated as a lung carcinogen in workers who produce chromate pigments.

Alkyd resins have been used in paints for some time with no reports of any chronic hazards.

The organic solvents employed in these formulations all exhibit similar physiological effects. In general, they are irritants to the conjunctiva and the mucous membranes of the upper respiratory tract. They all produce irritation of the central nervous system and, at high concentrations, produce symptoms of headache, nausea, and drowsiness, followed by unconsciousness and death. Polyneuropathy, associated with the lower molecular weight alkanes, may occur from chronic inhalation of mineral spirits.

SPRAY BOOTH

Design

The railroad cars are painted in the semi-downdraft spray booth shown in Figures 4-2 and 4-3. The booth measures 20 feet wide, 22 feet high, and 96 feet long, and will accommodate the largest freight cars made in this shop. The booth entrance and exit are equipped with automatic roll up doors. Three emergency doors are located along each side. Two 36,000 cfm, make-up air units supply fresh air to the 4 corners of the booth through banks of filters running from ceiling to floor. Two exhaust grates, each 2.5 feet wide, straddle the track for about 60 percent of the booth's length. Four water-wash sections, each equipped with a 15,000 cfm fan, scrub overspray from the air before it is discharged to the atmosphere.

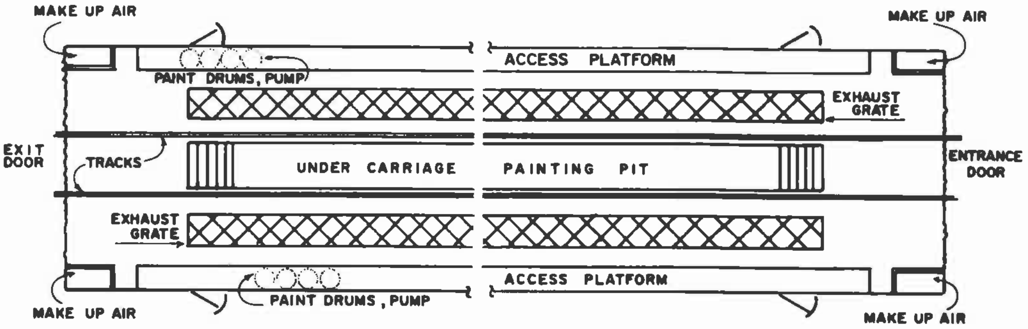


Figure 4-2. Plan view of railway car, semi-downdraft booth.

Each side of the booth has an elevated, open-mesh platform 8 feet above the floor level. Ladders located at both ends of the booth provide access to these platforms. Manually operated, counterbalanced cross platforms are kept at ceiling level until the car is in place. These platforms are lowered in order to provide access to the upper half of the cars at both ends. A pit that is 4 feet deep is provided between the rails in order to facilitate painting the under carriage.

Airflow Measurements

Air velocity was measured at the supply air inlets and exhaust grates using a hot wire anemometer. Velocities were averaged, and the total volume of air that was supplied and exhausted was determined. Results of these measurements are presented in Table 4-2.

Table 4-2. Semi-downdraft booth airflow summary.

Exhaust air		Design	Actual
NE section		15,000 cfm	14,000 cfm
NW section		15,000 cfm	14,600 cfm
SE section		15,000 cfm	12,600 cfm
SW section		15,000 cfm	11,300 cfm
	Total	60,000 cfm	52,500 cfm
Supply air			
North unit		36,000 cfm	39,000 cfm
South unit		36,000 cfm	27,000 cfm
	Total	72,000 cfm	66,000 cfm

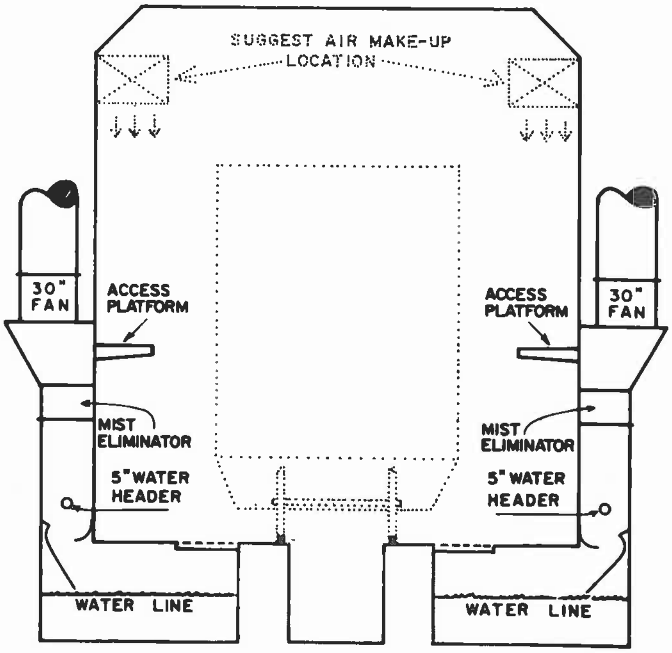


Figure 4-3. Cross-section of railway car, semi-downdraft booth.

Control velocity was determined at an elevation of 5 feet, with the car in the booth, and again on the access platforms, at an elevation of about 12 feet above floor level. Because the make-up air units apparently had an adverse effect on air distribution, the measurements were repeated again with the supply air shut off. Both sets of measurements are presented in Figure 4-4.

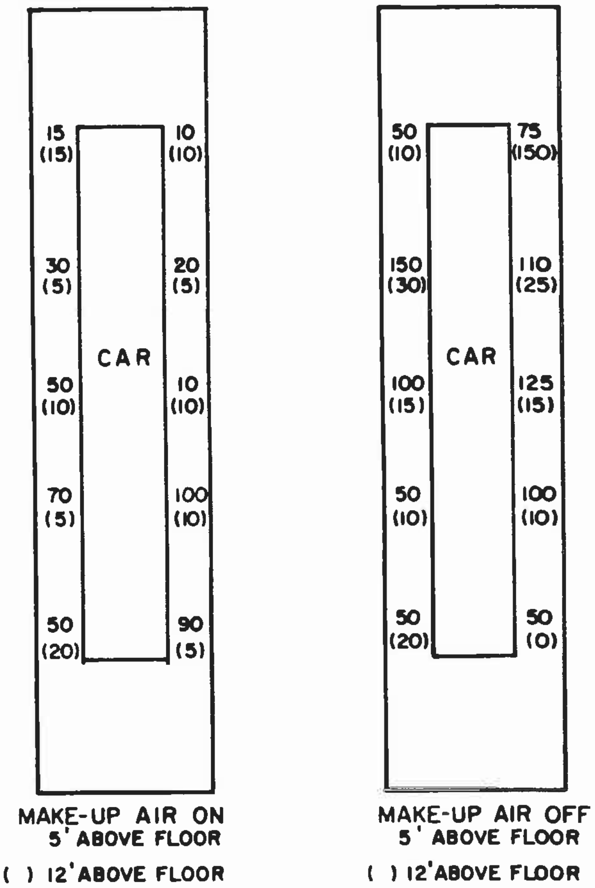


Figure 4-4. Control velocity (fpm) in railroad car, semi-downdraft booth.

The adverse air distribution caused by the make-up air location is depicted in Figure 4-5. With the make-up air units on, air is apparently directed underneath the car, short circuiting the area alongside the car,and resulting in a dead air space in the center of the booth. An alternate location for the make-up air inlets is shown in Figure 4-3. By locating the air inlets above the car sides the dead air space would be eliminated.

PROTECTIVE EQUIPMENT

Before painting each car, the painters don heavy cotton hoods, overpants, and hip-length coats. They wrap masking tape around openings of these suits at the

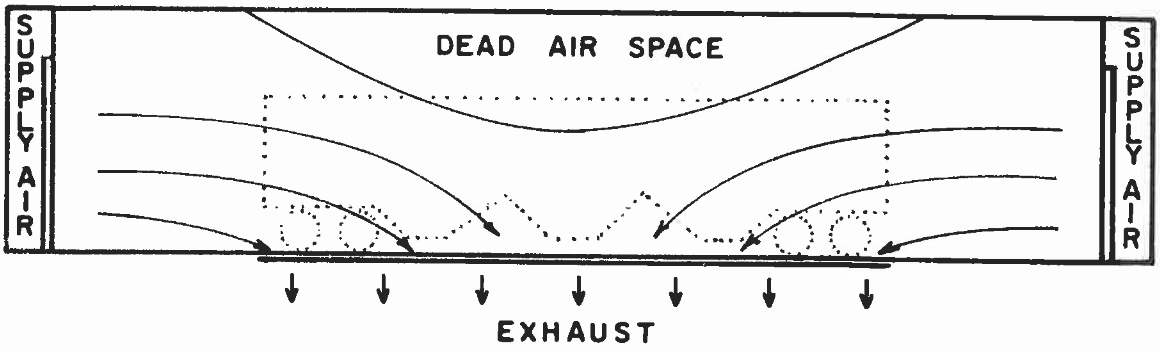


Figure 4-5. Side view of airflow patterns in a semi-downdraft booth.

neck and wrists. A full-facepiece, supplied air respirator, and rubber gloves are worn during painting, so no skin is exposed.

The facepiece of the respirator is kept clear by stretching clear plastic food wrap over the viewing window. Up to 10 sheets of wrap are applied, leaving tabs around the circumference of the facepiece. The tabs allow the sheets to be removed singly, as they are contaminated by overspray. A contaminated sheet is shown alongside a freshly wrapped respirator in Figure 4-6.

The full-facepiece respirator offers maximum protection against air contaminants, with little inconvenience to the painter. The full-facepiece is more comfortable than a half-mask because the pressure of the attaching strips is distributed over a larger facial area. In addition, for the full-facepiece, no goggles are required to protect the eyes from the potentially irritating components of the overspray. The respirator airline does not hinder operations, because the painter must drag the paint line along anyway.

WORK PRACTICES

The painters are careful to work on opposite sides of the railcar, thus minimizing direct contact with the each other's overspray. However, the painters are careless about their own overspray, often painting the upper half of the car from floor level. Access platforms that would permit proper orientation of the painter with respect to the downdraft airflow are provided.

EVALUATION

Two painters are required to finish a railroad car. A third painter rotates assignments with the others. In addition to painting, the painters are responsible for moving the cars in and out of the booth, applying decals, mixing paint, maintaining spray guns, and general housekeeping in the paint area. To determine control effectiveness, breathing zone concentrations (outside respirator) of total spray mist, lead, chromium, and organic solvents were determined by personal air samples taken during the time required to paint each hopper car. Total mist, lead, and chromium were collected using closed-face cassettes with 0.8 u polyvinyl chloride/acrylonitrile membrane filters at a sampling rate of 2.0 lpm. After weighing, the filters were ashed and analyzed

Figure 4-6. Full-facepiece respirator window protected by food wrap.

by atomic absorption spectroscopy for lead and chromium. Organic solvent samples were collected on 150 mg charcoal tubes with personal pumps operated at 100 cc/min. Tubes were subsequently desorbed and analyzed by gas chromatography.

Metals for analysis were selected based on the stated composition of the finishing materials and a qualitative analysis of air samples for each type of paint. Trace metals indicated by these analyses are reported in Table 4-3. The material safety data sheet from one supplier did not indicate the presence of any toxic metals. After the qualitative analysis indicated the presence of lead, the supplier was queried. He admitted that litharge was added to the paint in the amount of 2 pounds per 100 gallons of paint, and that a lead soap drier was used.

Solvents for analysis were selected based on the stated composition of the finishing materials and on a qualitative analysis of area charcoal tube samples by mass spectroscopy. Major peaks identified were aliphatic hydrocarbons, toluene, xylene, and higher molecular weight aromatic hydrocarbons. No benzene was detected.

Table 4-3. Qualitative analysis of bulk air samples for metals.

Element	Paint A	Paint B	Paint C	Paint D	Paint E
Al	Mi*	T	T	T	T
Ca	Mi	Mi	T	Mi	Mi
Co	T	ND	ND	ND	ND
Cr	T	Mi	ND	Mi	T
Cu	T	ND	ND	ND	ND
Fe	T	M	M	M	Mi
Mg	Mi	Mi	T	Mi	T
Mn	T	T	ND	T	ND
Na	Mi	Mi	Mi	Mi	Mi
P	ND	T	ND	T	ND
Pb	T	T	T	T	T
Sn	ND	ND	ND	ND	ND
Ti	T	ND	ND	ND	T
W	ND	T	ND	T	ND
Zn	T	Mi	T	Mi	T

*Key: Mi - minor
T - trace
ND - not detected
M - major

RESULTS

Airborne concentrations of total paint mist, lead, and chromium are reported in Table 4-4. The levels for both paint mist and lead exceeded those that would be allowed for a full shift's exposure. Because actual spraying time does not exceed 2 hours per shift, 8-hour time-weighted average levels of total mist and lead would be below legal limits. It should be noted that while the concentration of chromium does not exceed the legal maximum, it is significantly higher than the levels proposed by NIOSH and the American Conference of Governmental Industrial Hygienists (ACGIH).

There were no major differences observed between mean total mist levels among the painters. Mean concentrations of lead and chromium for the individual painters were not calculated because of variations in the content of these metals in the paints used.

Arrangements had been made to evaluate a heated (160°F), electrostatic (76,000 volt) spray gun during this survey. Time and equipment constraints allowed only one sample for comparison. This sample is identified in Table 4-4. Mist concentration was 33.2 mg/m^3 as compared to a mean concentration of 44.4 mg/m^3 for the other samples. Visible overspray appeared to be less, but the time required for painting was twice as long, in part because of the lower paint delivery rate. It is unclear from this single sample whether improved application techniques would significantly lower exposure.

Airborne concentrations of aliphatic hydrocarbons, toluene, xylene, and other aromatics are reported in Table 4-5. Solvent fractions eluting from the gas chromatograph before toluene are listed as "aliphatic hydrocarbons." Solvents eluting after xylene are reported as "other aromatics." Combined solvent concentrations range from 70 to 200 percent of the maximum allowed for a full shift exposure, based on current legal maximums. Because of the short spraying time, the 8-hour time-weighted average concentrations would be below the legal maximum. However, both NIOSH and the ACGIH have recommended lower exposure limits for toluene, and NIOSH has recommended a 350 mg/m^3 maximum for refined petroleum solvents.

As a rule of thumb guide to the maximum concentration allowed for short periods of time, the ACGIH has established excursion factors. The appropriate 8-hour limit, multiplied by the excursion factor, yields the maximum concentration recommended for exposures of short duration. For the solvents employed, a maximum excursion of 1.25 times the 8-hour limit is permitted. Approximately one-half the solvent samples exceed this recommended maximum excursion.

Table 4-4. Airborne levels of spray mist, lead, and chromium in railroad car finishing.

Car type	Painter	Paint	Sample time (min)	Total mist (mg/m^3)	Lead (ug/m^3)	Chromium (ug/m^3)
Pulp	X	A	50	27.0	120	120
Pulp	X	A	57	42.1	210	180
	Y	A	60	35.0	170	140
Pulp	X	A	24	57.7	250	250
	Z	A	24	33.9	140	160
Coal	Z	B,C	40	66.3	620	910
	Y	B,C	49	47.3	510	750
Gravel (partial)	Y	D,E	23	71.9	280	540
	Z	D,E	22	69.3	270	420
Gravel (sides only)	Z	E	15	28.3	170	100
	Y	E	16	41.3	160	130
Gravel (partial)	X*	E	38	33.2	120	100
	Z	E	17	41.4	140	110
Painter X (geometric mean)				38.4 (1.4)**	--	--
Painter Y (geometric mean)				47.1 (1.4)	--	--
Painter Z (geometric mean)				44.9 (1.5)	--	--
Grand Mean				43.3 (1.4)	211(1.7)	220 (2.2)
OSHA PEL***				15	50	1000****
ACGIH TLV (1979)***				10	150	50
NIOSH***				--	--	1

* Painter used heated electrostatic spray gun

** Number in parentheses are geometric standard deviations

*** For full shift exposures

****Chromium metal and insoluble salts

Table 4-5. Airborne levels of organic solvents in railroad car finishing.

				Concentration (mg/m^3)				
Car type	Painter	Paint	Sample time (min)	Toluene	Xylene	Other aromatics	Aliphatic hydro-carbons	$^*C_E$
Pulp	X	A	50	120	12	160	720	0.96
	Y	A	50	150	<4	190	920	1.16
Pulp	X	A	57	160	30	300	890	1.47
	Y	A	60	130	4	150	770	0.96
Pulp	X	A	24	230	25	330	1400	1.90
	Z	A	24	120	<9	180	730	1.00
Coal	Z	B,C	40	350	90	320	790	1.84
	Y	B,C	49	310	80	350	780	1.84
Gravel	Y	D,E	23	270	<8	250	1200	1.62
	Z	D,E	22	330	<10	300	1500	1.99
Gravel	Z	E	15	110	<14	<140	430	0.74
	Y	E	16	130	<13	<130	500	0.78
Gravel	X	E	31	210	<5	170	890	1.18
	Z	E	17	230	13	250	880	1.40
Geometric mean				188	14	217	840	1.3
Geometric standard deviation				1.5	2.6	1.4	1.4	1.4
OSHA PEL**				750	435	435***	1800****	1.0
ACGIH TLV (1979)**				375	435	--	--	--
NIOSH**				375	--	--	350	--

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the exposure limit

** For full shift exposure

*** Xylene

****Hexane

DISCUSSION

In many paint shops, coating formulations are continually changing to meet the specifications of different customers. The nature and degree of the hazards associated with these coatings varies, and the material safety data sheet, if available, may not be complete. In these shops a full-facepiece, supplied-air respirator, or an air-supplied hood, is a logical choice for a paint spray respirator. They not only afford a high degree of protection, but protect the eyes from the irritating effect of many of the paint constitutents. The full facepiece respirator is more comfortable to the wearer than a cartridge-style half-mask because of the lower breathing resistance and the distribution of the headband pressure over a larger facial area. The major drawback of the full-facepiece respirator for paint spraying is that the viewing window fogs with stray mist; the problem is overcome in this operation by covering the viewing window with food wrap. However, the painter's vision may be impaired by the food wrap, limiting this technique to rough painting operations.

Several opportunities exist to reduce exposure to spray mist without major design changes. Improved application equipment might reduce the overspray, but probably not without an attendent increase in application time. However, the use of a pole-type spray gun could decrease exposure during under carriage painting without slowing the painter by increasing the distance from the spray. Booth design could be markedly improved at minimal cost by relocating the make-up air inlets to above the car sides as shown in Figure 4-3. Lastly, mist concentrations could be reduced while painting car sides, if painters are required to use the access platforms while painting the car sides.

CASE STUDY 5

AUTO REFINISHING

Automobiles and light trucks are refinished in this modern repaint shop. Complete body repainting comprises over 90 percent of this paint shop's output; the remainder consists of spot painting. Conventional air-atomized spray equipment is used, fed by pressure pots. All complete body repainting and spot repainting of areas over two-square feet are performed in a conventional "drive-through" spray booth with an integral oven. Airborne concentrations of lead, hexamethylene diisocyanate (HDI), and organic solvents were within recommended levels. Spraying certain yellow and red colors (not used during this survey) represents a potential for over exposure to lead.

PROCESS

Operations

Unlike shops that specialize in body work, over 90 percent of the painting in this shop is complete body repainting. Although spot painting of body work is also performed, a large percentage of the vehicles that require body work will be completely repainted. Figure 5-1 is a layout of the shop.

Complete body repainting begins with masking and cleaning of the old painted surfaces. First, two technicians wash the vehicle to remove water soluble dirt. Then, painted surfaces are lightly, but carefully, sanded to remove imperfections and provide a smooth surface; they are also solvent-wiped to remove traces of old wax or road gum. Chrome trim and glass areas are masked, and the car is driven into the spray booth.

One painter performs essentially all the paint work, completing 6 to 8 cars per shift. The painter is responsible for mixing all paint, and for matching the finish color to the original for spot repainting. The paint mixture is based on a formula card that specifies the required proportions of 30 stock color paints that are combined with a paint drier, bake converter, and optional isocyanate hardener. Mixing generally takes 5-10 minutes, but additional tinting required to match faded or odd colors will require longer mixing times.

After closing the booth doors and starting the fan, the painter removes any body shop dust from the vehicle with an air nozzle and wipes the vehicle with a tack rag. Next, he applies a light coat of a gray primer/sealer (about 1 quart), starting at the hood and working around the car. Finally, he applies two coats (about 1 gallon) of the enamel finish, starting again with the hood and working back around the vehicle. Both finishes are applied with conventional air-atomizing spray guns fed from pressure pots. Atomizing-air pressure was observed to range from 50 to 65 psig. Air pressure on the paint delivery pot was 15 psig. Overall painting application time was 40 to 45 minutes.

Coatings

Both the primer/sealer and the enamel topcoats are alkyd enamels, which form a cured paint film by the oxidation of double bonds in the resin and subsequent

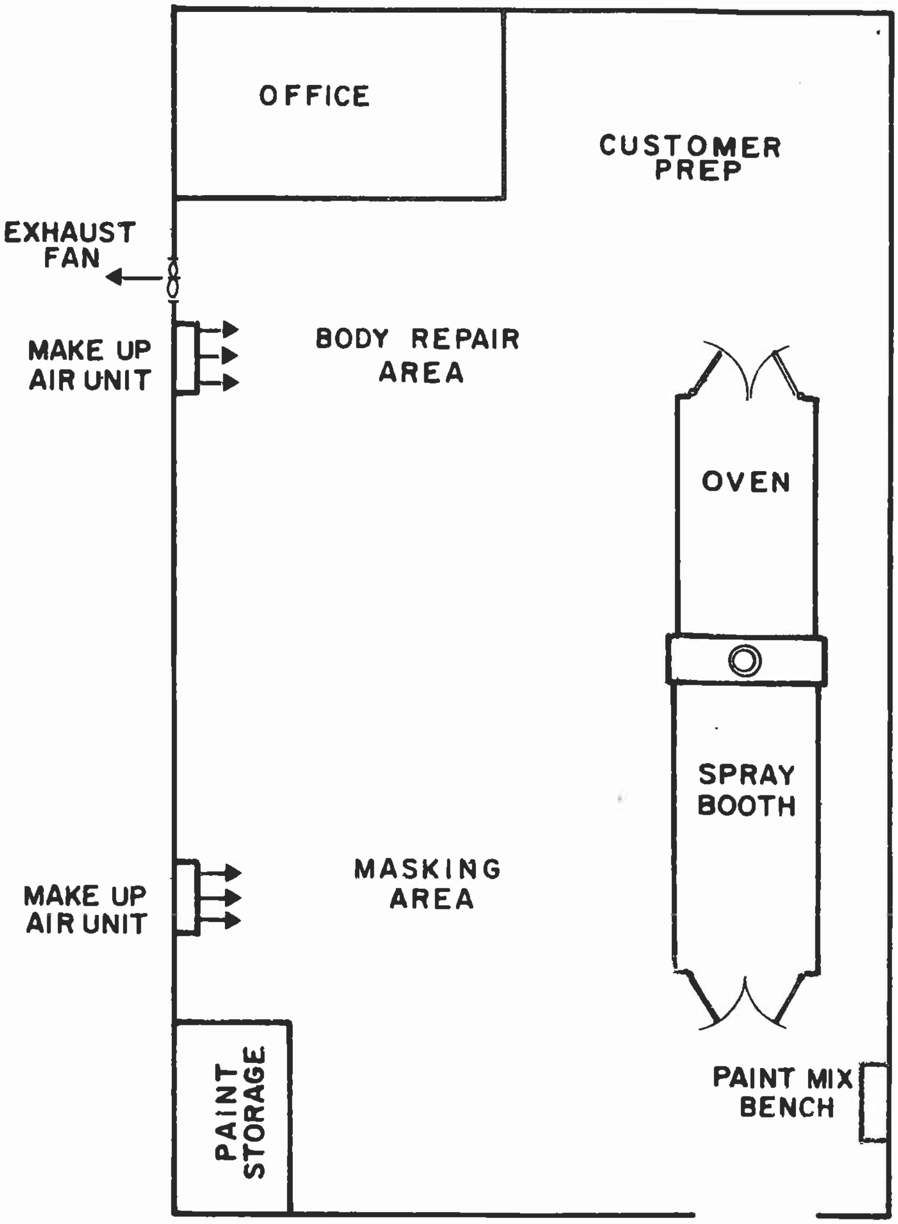


Figure 5-1. Paint shop layout.

polymerization. This oxidation is catalyzed by the presence of a lead soap drier. Several ounces of a baking converter additive are sometimes added by the painter; this material is a mixture of acrylic and urea resins and a wrinkle inhibitor, mixed in a solvent. This additive confers some thermosetting qualities to the finish. Despite the use of the bake converter, the basic function of the oven is to promote rapid evaporation of the solvent rather than providing a true baked finish. The finish continues to cure over several months.

Enamel finishes are used for total body repainting because with them, no hand rubbing is necessary to gain a high gloss surface film; lacquer finishes, on the other hand require hand rubbing. The rapid cure of lacquer finishes permits the painter to blend spot repairs into undamaged areas, which makes this type of finish more popular in body repair shops.

The alkyd resin that is used in the enamel topcoat is modified by the addition of an acrylic resin with hydroxyl groups. This resin not only improves the durability of the finish, but allows the use of a polyisocyanate cross linking agent in order to provide a chemically-cured, urethane paint film. This isocyanate hardener consists of prepolymers of hexamethylene diisocyanate (HDI), mixed in a solution of ethyl acetate, 2-ethoxy ethyl acetate, and xylene. Free isocyanate comprises less than 0.7 percent of the resin fraction at manufacture, but may increase to 1.6 percent with age. Eight to sixteen ounces of this optional isocyanate hardener are added to each gallon of enamel (at extra cost to the customer). Approximately 10 percent of the customers of this facility choose the isocyanate-modified urethane finish. The composition of the finishing materials is listed in Table 5-1.

HAZARD ANALYSIS

The organic solvents employed in these formulations all exhibit similar physiological effects. In general they are irritants to the conjunctiva and to the mucous membranes of the upper respiratory tract. They all produce depression of the central nervous system and, at high concentrations, produce symptoms of headache, nausea, and drowsiness, followed by unconsciousness.

The non-volatile components of the coating formulations are for the most part physiologically inert. Exceptions are lead and chromium, which are present as chrome yellow and molybdate orange pigments that are used in many yellow and red colors, and the lead soaps that are used as driers. According to the coating formulator, lead can account for up to 15 percent of the total paint weight in certain shades of red. Lead is a cumulative poison that affects the red blood cells and produces damaging effects on the tissues it contacts. Lead chromate (chrome yellow) has been implicated as a lung carcinogen in workers who produce chromate pigments.

The isocyanate hardener, used to a limited extent for premium body repainting jobs, is a prepolymer of hexamethylene diisocyanate (HDI), and contains small quantities of residual monomer. The monomeric material is a lacrimator and irritant, and produces respiratory sensitization in certain individuals. The prepolymer and the monomer have an acute inhalation toxicity that is of the same order of magnitude as the monomer, but the prepolymer's capability for producing sensitization is unknown. Because both the monomer and the polymer have low vapor pressure, the main isocyanate hazard is associated with the inhalation of the paint aerosol.

Table 5-1. Composition of finishing materials.

Gray primer sealer	
47% Solids:	
Modified alkyd resins	28%
Pigment	19%
53% Volatile:	
Xylene and mixed aromatic solvents	50%
Ethyl alcohol	1%
2% Additives: wetting agents, driers	
Note: Drier is a lead soap; Total paint is 0.13% lead by weight.	
Enamel topcoat	
43% Solids:	
Acrylic modified alkyd resin	37%
Pigment (variable composition)	6%
57% Volatile:	
Mineral spirits	42%
Toluene	5%
Xylene and other aromatics	3%
n-Butyl acetate	7%
Urethane additive (Mixed 8-16 oz. per gal. of enamel)	
45% Hexamethylene diisocyanate (HDI) prepolymer	
55% Solvent	
Ethylacetate	32%
2-Ethoxy ethyl acetate	16%
Xylene	7%

SPRAY BOOTH

All complete body repainting as well as the spot painting of areas greater than 2 square feet are performed in a standard-make spray booth, similar to that shown in Figure 5-2.

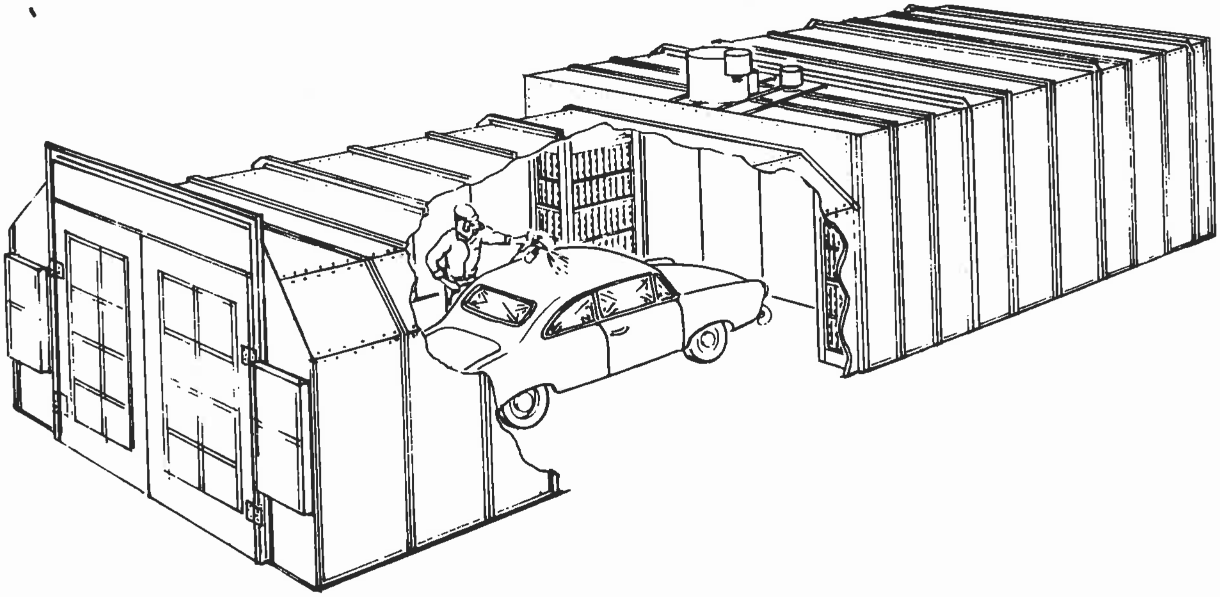


Figure 5-2. Spray booth and oven.

The working area of each booth is approximately 14 feet wide by 26 feet long by 9 feet high. The booth is the "drive-through" variety, with the exit doors connecting directly to a drying oven. Air is supplied to the booth through 20 in x 20 in foam filters mounted in the doors and door bulkhead. Air is exhausted through two exhaust chambers that are located on either side of the exit doors and connected to a single duct fan on the roof of the spray booth. Each exhaust chamber contains six 20 in x 20 in and three 10 in x 20 in paint arrestor filters. Pressure drop is monitored by a manometer and the filters are changed when the pressure drop exceeds a predetermined point. It is estimated that total airflow declines about 10 percent after a set of five to six complete body repaintings.

The booth was designed for a nominal 100 cfm/sq ft of booth cross-sectional area. Measured air velocities are presented in Figure 5-3. The presence of an automobile raises the actual air velocity in the painter's breathing zone. Also, the placement of the exhaust openings at the booth sides tends to increase the air velocity there.

PROTECTIVE EQUIPMENT

Protective equipment is limited to the use of a half-facepiece, air-purifying respirator, with organic vapor-removing cartridges and mist prefilters.

Cartridges are changed when the painter detects a solvent odor. Filters are changed when breathing resistance is affected.

EVALUATION

One full time painter is employed in this shop. Total spraying time for complete body repainting is approximately 45 minutes, and the painter will spray from 6 to 8 cars on a typical workday (8-hour shift).

To determine control effectiveness, the breathing zone levels (outside the respirator) of total spray mist, orangic solvents, and lead and chromium were determined by personal air samples taken during the time required to repaint each car. Total mist samples were collected by using closed-face cassettes, with preweighed 37 mm polyvinyl chloride/acrylonitrile copolymer membrane filters and personal pumps operated at 2.0 lpm. After weighing, the filters were ashed and analyzed for lead and chromium by atomic absorption spectroscopy. Organic solvent samples were collected on 150 mg. charcoal tubes with personal pumps at 100 cc/min. Tubes were subsequently desorbed and analyzed by gas chromatography.

For polyurethane topcoats, consecutive, short-term samples were taken in the painter's breathing zone in order to determine ceiling isocyanate concentrations. Isocyanate samples were collected by using two midget impingers, which were connected in series to a personal pump operated at 2.0 lpm. Each impinger contained 15 ml of a nitro reagent solution, which was subsequently analyzed for the HDI/nitro reagent compound by high pressure liquid chromatography.

RESULTS

Sample results for total mist, lead, and chromium are reported in Table 5-2. Mean paint mist levels are within the recommended maximums for an 8-hour exposure to total particulates. Eight-hour time-weighted average (TWA) exposure to lead was within the 50 ug/m^3 OSHA limit. However, none of the coatings used on the vehicles painted during the survey contained significant quantities of red or yellow pigments. This was not by the study's design, rather, red and yellow colors are relatively unpopular for both new vehicle purchases and repainting. The lead levels that were observed are a result using a lead soap as the paint drier. For these reasons, all but one chromium sample were below the limits of detection for chromium (3 ug per filter). Because the most common chromium pigment is lead chromate, the one detectable chromium sample is probably erronous because the corresponding lead level recorded for the sample was quite low.

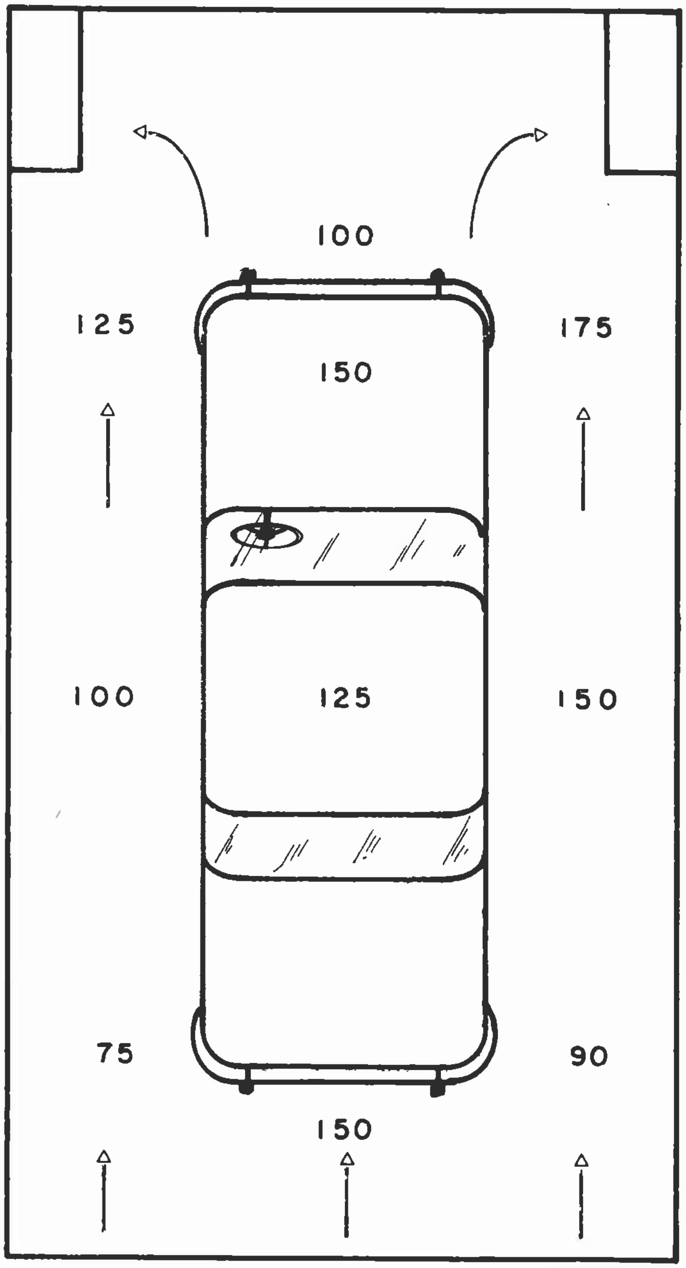


Figure 5-3. Spray booth air velocity.

Table 5-2. Airborne levels of paint mist, lead, and chromium in automobile refinishing.

Car size	Color	Sample duration (min)	Total mist (mg/m^3)	Lead (ug/m^3)	Chromium (ug/m^3)
Subcompact	White	42	8.0	<36	72
Standard	Brown	44	11.3	57	<34
Compact	Green	40	16.1	63	<38
Subcompact	Blue	45	8.8	34	<34
Subcompact	Blue	40	12.4	76	<38
Fender only	Brown	15	6.1	<97	<97
Compact	Blue	43	4.0	<34	<34
Geometric mean			8.7	52	--
Geometric standard deviation			1.6	1.5	--
Estimated 8-hour TWA*			5.0	30	--
OSHA PEL			15	50	100
ACGIH TLV (1979)			10	150	50
NIOSH			--	--	1

*8-hour time-weighted average, based on 7 cars per shift and 40 min per car.

Organic solvent concentrations are reported in Table 5-3. Solvent levels are well below any existing or proposed exposure limit.

Table 5-3. Airborne levels of organic solvents in automobile refinishing.

Car size	Sample duration (min)	Concentration (mg/m^3) (a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	C_E*
Subcompact	42	25	7	2	--	--	--	--	23	0.06
Standard	44	44	7	9	--	--	--	--	27	0.10
Compact	40	67	10	10	--	--	7	5	24	0.15
Subcompact	45	42	10	4	--	--	--	--	21	0.09
Subcompact	40	24	7	7	--	--	--	--	24	0.07
Fender only	15	69	6	6	6	6	--	--	63	0.16
Compact	43	25	5	2	--	--	2	5	23	0.07
Geometric mean		39	10	5	--	--	4	5	--	0.09
Geo standard deviation		1.6	1.0	2.0	--	--	2.4	1.0	--	1.5
OSHA PEL		750	435	710	590	410	1400	540	2950	1.0
ACGIH TLV (1979)		375	435	710	590	410	1400	270	--	1.0
NIOSH		375	--	--	590	200	--	--	350	--

a) toluene, b) xylene, c) n-butyl acetate, d) methyl ethyl ketone, e) methyl isobutyl ketone, f) ethyl acetate, g) 2-ethoxy ethyl acetate, h) petroleum distillates

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the exposure limit.

Sampling results for hexamethylene diisocyanate (HDI) are reported in Table 5-4. All three samples were below the 10-minute ceiling concentration limit for HDI that is recommended by NIOSH. For current levels of usage, 8-hour time-weighted average exposure limits would also be met. An analysis for HDI oligomers was not attempted.

Table 5-4. Airborne levels of hexamethylene diisocyanate in automobile refinishing.

Car size	Sample duration (min)	Hexamethylene diisocyanate (ug/m^3)
Compact	13 (Coats 1 + 2)	<50
Subcompact	7 (Coat 1)	<93
	5 (Coat 2)	<130
NIOSH (10 minute ceiling)		140

DISCUSSION

The spray booth used at this facility is typical of that found in most refinishing shops and automotive dealers. The design appears adequate in keeping solvent and total paint mist concentrations within acceptable maximums. Using the mean total mist concentration of 8.7 mg/m^3 of Table 5-2, the 50 ug/m^3 lead standard can only be met if the lead content of the paint solids is less than about 0.5 percent by weight. Unfortunately, many shades of yellow and red will contain many times this amount of lead. Eliminating lead from these colors is not feasible at this time, because the use of lead-containing pigments is required in order to match factory colors. Only when all vehicle manufacturers, both foreign and domestic, have switched to heavy-metal-free factory finishes, and all the current vehicles are no longer in use, will it be possible to reduce the lead hazard for all paint colors in the automotive finishing trade.

While no respiratory protection would be needed for a majority of the painting operations when they are performed in a effectively functioning spray booth, use of certain colors poses a risk of overexposure to lead and other metals. Good industrial hygiene practice suggests that all painters wear an approved air-purifying respirator while painting. Because the sensitization potential of the polyisocyanate is not well understood, respiratory protection will also minimize this hazard.

CASE STUDY 6

APPLIANCE FINISHING

Refrigerator and chest freezer cabinets are painted with a thermosetting acrylic enamel in an operation that features both manual and automatic paint application. The levels of paint mist and organic solvents when paint is applied by conventional and electrostatic means were compared. Painters who used electrostatic guns for a greater percentage of their work were found to have lower potential exposures, despite lower booth airflow. Greatly elevated paint mist and organic solvent levels were found when the internal surfaces of chest freezer liners were painted.

PROCESS

Operations

Sheet metal components for refrigerator freezers and chest-type freezers are finished in white, gold, almond, avocado, or copper, with a thermosetting acrylic enamel. The finishing process begins with an eight step pretreatment consisting of two alkaline washes, followed by a hot water rinse, a zinc phosphate bath, a cold water rinse, a chromic acid rinse, and two demineralized water rinses. Then the parts are oven dried and transferred manually to the overhead paint line conveyor.

The paint line is shown schematically in Figure 6-1. It consists of two manual spray booths and two automatic electrostatic spray systems. The line first enters a sidedraft, water wash spray booth. In this booth, two painters apply a prime coat of acrylic enamel to the corners, recesses, and interior flanges of the doors, lids, and cases using air-atomized, electrostatic (70,000 volt) spray guns. Embossed steel doors require a slightly heavier coat, which makes a third painter necessary for these runs. The additional painter uses a conventional air-atomizing spray gun.

The first coat is completed in an automated electrostatic system that is contained in a downdraft spray room. Spray units in this system consist of rapidly rotating bells, charged to 100,000 volts, into which paint is introduced and atomized by the action of the electrostatic and inertial forces. The units are grouped into headers of 3 spray units. The system is composed of two opposed sets of three reciprocating headers, for a total of 9 spray units on each side of the conveyor. An additional 3-unit header is mounted on the floor to coat the top of the refrigerator cases (the cases are suspended upside down from the conveyor).

After leaving the spray room, the workpiece travels through a short flash-off tunnel and into a second spray room. This system is identical to the previous one, except that there is one less spray header on each side of the conveyor line. Each of the automated electrostatic spray systems is operated by an attendant who changes paint colors and maintains the equipment as necessary. Two painters in a sidedraft booth that is similar to the first booth apply paint to light areas; one works with a conventional air-atomized, spray gun, and the second works with both conventional and electrostatic guns. After painting, all items are baked in a 365^{O}F oven for 12 minutes.

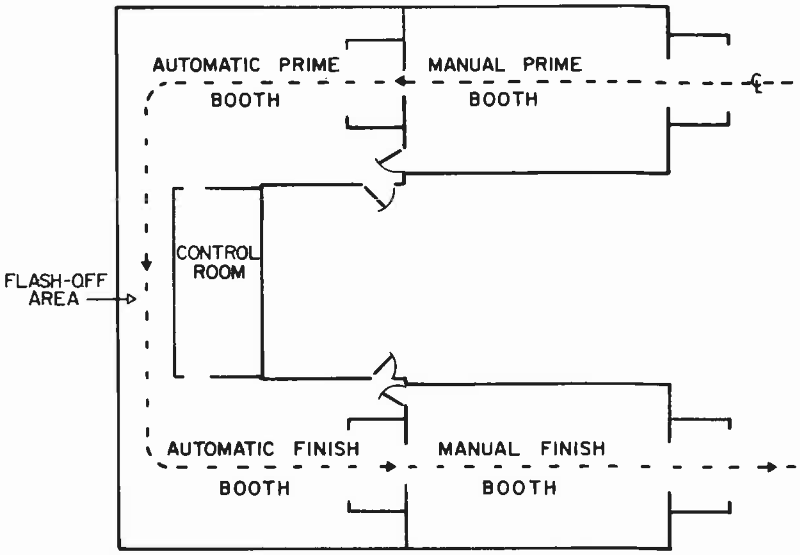


Figure 6-1. Layout of appliance finishing area.

Liners for chest-type freezers are painted with a white acrylic enamel on the same paint line. However, they are manually sprayed by air-atomized guns; the automated systems are not used. The liners represent approximately 10 percent of the units painted, and occur in short runs of about 5 minutes each, interspersed during the day. Air-supplied helmets are worn during the painting of the liners because of the fog generated in this operation.

Coatings

Lids, doors, and cases are coated with a thermosetting acrylic enamel in a choice of five colors. The basic paint consists of a pigmented acrylic resin in a solution of organic solvents. The coating material, as received from the manufacturer, contains approximately 60 percent volatile materials by volume, and is further reduced with toluene and/or xylene. Coatings for the automated system are reduced with toluene and xylene at a ratio of 2 gallons of paint to 1 gallon of thinner; the exact thinner mix varies slightly with color. Coatings for manual spraying are thinned with xylene at a ratio of 3 gallons of paint to 1 gallon of xylene.

A white acrylic enamel from a second supplier is used for the interior surfaces of chest freezer liners. This material is a pigmented acrylic resin mixed with a phenolic resin to confer thermosetting properties. It is thinned at a 3:1 ratio, with a mixture of xylene and other aromatic solvents.

Coating materials are mixed in a separate paint mix room and piped to the spray guns at 20 psig. Each 3-unit electrostatic spray header applies approximately 4 gallons of paint per hour. Each painter applies approximately 3-1/2 gallons per hour with the manual equipment. All the manual guns are operated at an atomizing-air pressure of 60 psig.

HAZARD ANALYSIS

The principal hazard that is associated with the coatings used is a result of the volatile organic materials, chiefly toluene and xylene, employed as solvents. Both these materials can produce irritation of the skin, the conjunctiva, and the mucous membranes of the upper respiratory tract. At high concentrations, they can produce the symptoms of headache, nausea, and drowsiness, followed by loss of consciousness. Dermal contact with these finishes should be avoided because toluene can be absorbed through the skin, producing systemic poisoning. Dermal contact should also be avoided because coatings are not easily removed from the skin, and workers tend to use these solvents in personal cleaning.

Lead is a potential hazard in all colors. Even in white paints, traces may be present in raw materials or as contaminants introduced in manufacture. The other pigment materials are essentially physiologically inert. To date, no evidence of harm has been demonstrated by the thermosetting acrylic resins used. As a minimum, however, these non-volatile materials should be controlled to below the maximum levels recommended for nuisance materials.

SPRAY BOOTHS

Manual Spray Operations

The paint booths for the manual spray application of the prime and finish coats are shown in Figure 6-2. Fresh air is supplied from behind the painters through seventy 20 in x 20 in filters located on the front wall of the booth, and removed at the rear of the booth through a water curtain. The water curtain consists of a water header located above four rows of asbestos-cement board; each sheet is about 2 feet high, forming overlapping sheets of water and providing four horizontal exhaust slots. An additional water header cleans paint mist from the exhaust air stream. A series of metal baffles in the exhaust plenum reduce water carryover into the exhaust fans. Parts enter and exit the booth through short vestibules supplied with make-up air.

Make-up and exhaust airflows were measured in both the prime and finish booths. Control velocity was measured with a hot wire anemometer at 24 points in the vertical plane occupied by the paint sprayer and the measurements were averaged. Results of these measurements are presented in Table 6-1. The average control velocity for the finish booth was double that of the prime booth, in spite of an exhaust rate that was only 20 percent greater. This was because of a lower volume of air supplied behind the painter in the prime booth, resulting in air from outside the booth being short circuited through the vestibules into the waterfall.

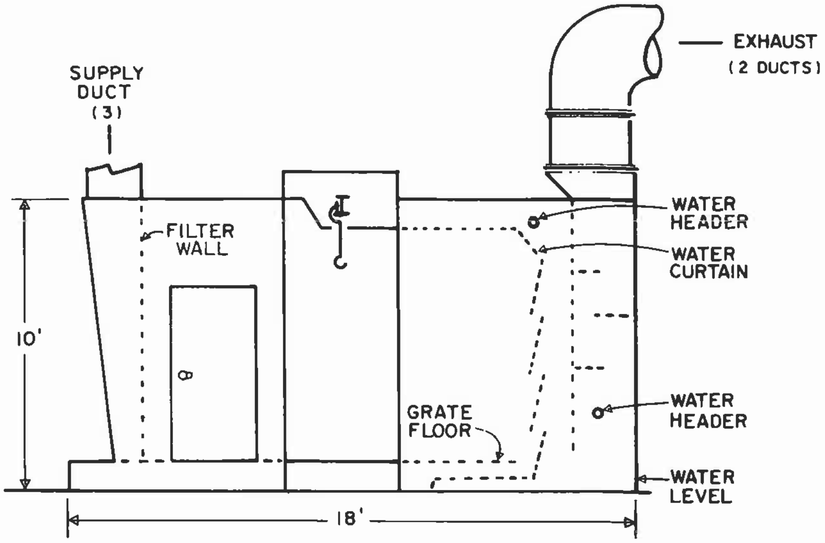


Figure 6-2. Cross-section of manual spray booth.

Table 6-1. Manual spray booth airflow rates.

	Prime booth	Finish booth
Exhaust (cfm)	19,000	25,000
Supply (cfm)	16,000	28,000
Control velocity (fpm)		
Average	70	150
Low	25	75
High	125	250

Automatic Spray Operations

A spray room for the automatic electrostatic paint systems is shown in Figure 6-3.

Fresh air is supplied from a ceiling plenum through two rows of 20 in by 20 in fiberglass filters, located on each side of the overhead conveyor. A 4 foot wide exhaust grate is located in the floor directly beneath the conveyor. The prime and finish spray rooms exhaust 18,000 and 20,000 cfm respectively, for a nominal exhaust rate of 20 cfm per square foot of horizontal area. While an air velocity this low would not be adequate for conventional spray equipment, the extremely high transfer efficiency of the electrostatic bell system produces little or no overspray.

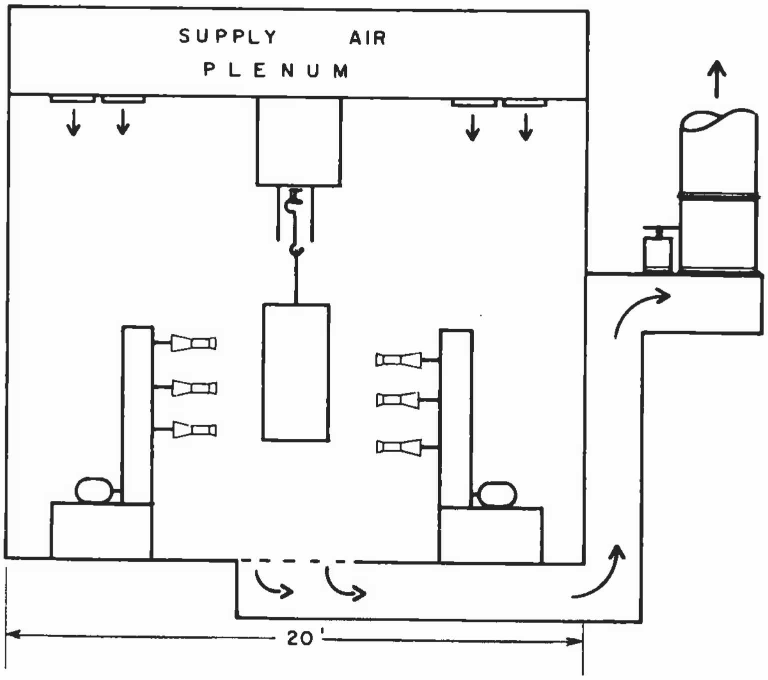


Figure 6-3. Cross-section of automatic electrostatic spray room.

PROTECTIVE EQUIPMENT

At the start of each workshift, painters and system operators don clean coveralls. Respirator usage is limited to liner painting operations. The respirators used in that operation are of the supplied air variety (NIOSH approved), with a replaceable plastic viewing window, cloth cap, and loose-fitting, plastic coated, cloth hood.

EVALUATION

Eight employees are potentially exposed to paint solvents or spray mist in this operation. This number includes 5 spray painters, 2 operators for the automated equipment, and a mix room attendant. Potential sources of exposure include spray mist and solvent vapors from spraying, solvent vapors evaporating from finished cabinets, and (for the mix room attendant) solvent vapors from paint thinning operations.

As an index of control, the 8-hour time-weighted average (TWA) concentrations of total spray mist, lead, toluene, and xylene were determined for the hand sprayers. Four hand sprayers spend their entire workshift in the spray booth except for scheduled breaks and a 30 minute lunch period. The fifth painter serves as a relief and as an additional sprayer for embossed doors. Because of the extended periods spent outside the booth, the exposure of this worker was not evaluated. The 8-hour TWA concentrations were calculated from separate morning and afternoon samples.

Total mist and lead samples were collected using closed-face cassettes with preweighed 37 mm polyvinyl chloride membrane filters and personal pumps operated at 2.0 lpm. After weighing, the filters were wet-ashed and the resulting solution analyzed for lead by atomic absorption. Organic solvents were collected on 150 mg charcoal tubes with personal pumps operated at 50 cc/min. Tubes were subsequently desorbed and analyzed for toluene and xylene by gas chromatography. Toluene and xylene were selected based on qualitative analysis of selected charcoal tube samples by mass spectroscopy. Methyl ethyl ketone, 1,1,1-trichloroethane, and n-butanol were also indicated by the qualitative analysis, but at low concentrations.

It was observed that the liner painting operation engulfed the painter in mist as shown in Figure 6-4. Although it comprised only 10 percent of the painting time (5 minutes each hour), it probably contributed significantly to the average mist concentration. To determine this contribution, solvent levels were compared during cabinet and liner painting with a combustible gas indicator. In addition, 5 short term samples for total mist were taken during the liner painting (outside the respirator). Results of these measurements are reported in Table 6-3.

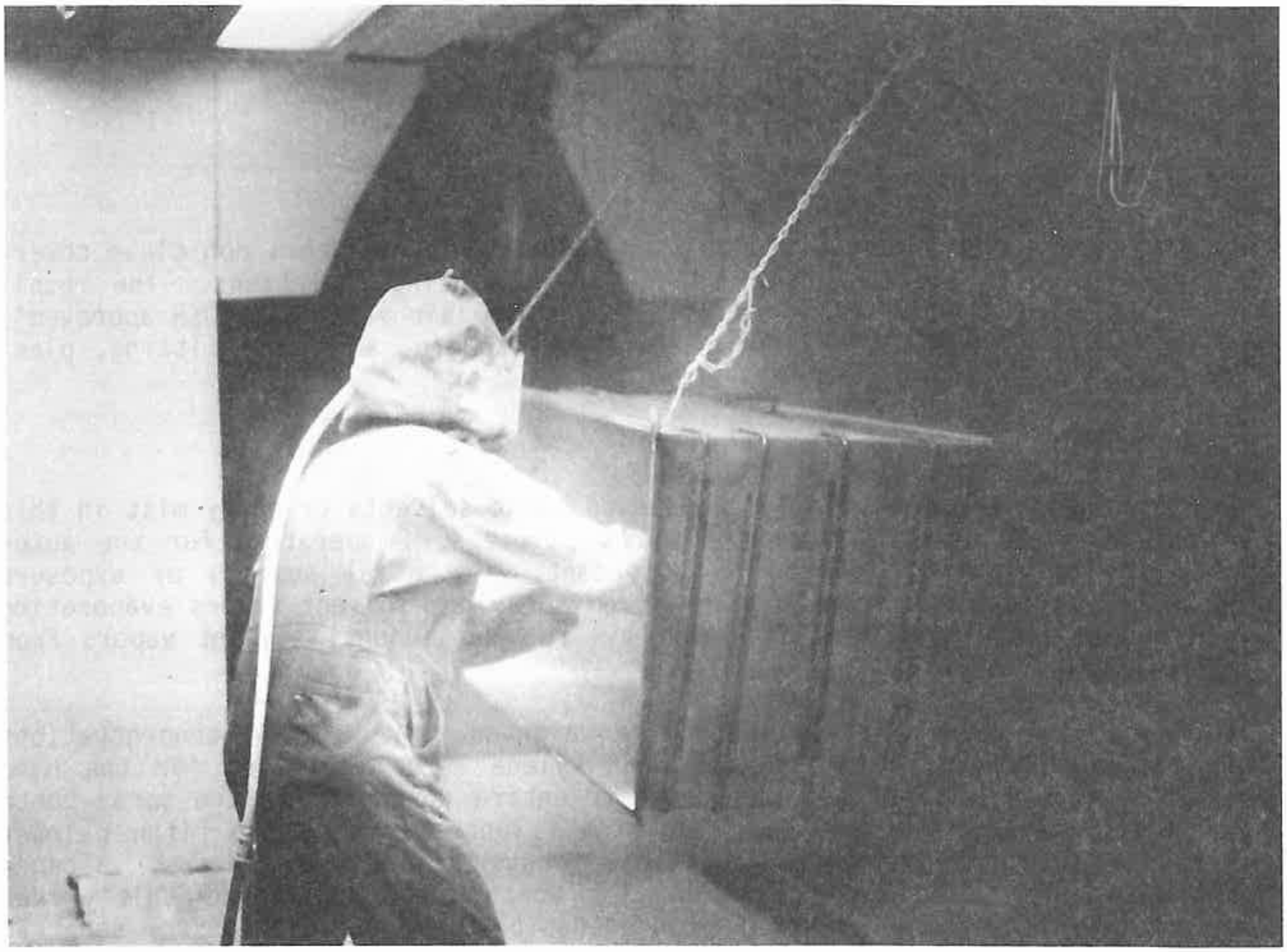


Figure 6-4. Liner painting operations.

RESULTS

As reported in Table 6-2, the mean 8-hour TWA concentrations of organic solvents were less than both legal and current recommended maximums. Individual TWA levels were also all below recommended maximums. The prime contributor to the average solvent level was the liner painting operation. Solvent levels of 300 to 600 ppm were measured with a combustible gas indicator during liner painting, as opposed to 1 to 10 ppm during the painting of refrigerator case exteriors. All measurements were taken in the breathing zone of the spray painter outside the respirator. Supplied-air respirators were worn during liner painting.

Table 6-2. Airborne levels of organic solvents in appliance finishing.

		8-hr time-weighted average concentration (mg/m^3)				
	Number of	Toluene		Xylene		C_E*
Operation	samples	GM	GSD	GM	GSD	
Manual prime booth						
Painter 1**	3	130	1.1	148	1.2	0.52
Painter 2	3	104	1.3	113	1.4	0.40
Manual finish booth						
Painter 3	3	204	1.2	225	1.2	0.79
Painter 4	2	88	1.7	112	1.9	0.38
Automatic prime booth (area sample)	3	262	1.3	76	1.5	0.54
Automatic finish booth (area sample)	3	117	1.1	31	1.6	0.23
OSHA PEL		750		435		1
ACGIH TLV (1979)		375		435		--
NIOSH		375		--		--

GM: Geometric mean
GSD: Geometric standard deviation

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \dots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the exposure limit

**Painters 1 and 2 used electrostatic guns for exterior panels, conventional guns for liners; painter 3 used conventional spray equipment continuously; painter 4 used both electrostatic and conventional guns for exterior panels, conventional guns for liners.

As shown in Table 6-3, the 8-hour TWA concentrations of paint mist exceeded the legal maximum for total dust. Again, the liner operation was a heavy contributor to the average concentration, as is evidenced from the results of the short term mist samples reported in Table 6-4. Based on these results and a mean mist concentration of 35 mg/m^3 for all spray painters, mist concentrations would be less than the 15 mg/m^3 total dust standard during exterior painting operations.

Table 6-3. Airborne levels of spray mist and lead in appliance finishing.

Operation	Number of samples	8-hour time weighted average concentration			
		Paint mist (mg/m^3)		Lead (ug/m^3)	
		GM	GSD	GM	GSD
Manual prime booth					
Painter 1*	3	21.7	1.1	<7	1.0
Painter 2	1(Pb-3)	31.4	--	<6	1.0
Manual finish booth					
Painter 3	3	54.5	1.3	20	1.4
Painter 4	2(Pb-3)	39.2	1.4	13	2.2
Automatic prime booth (area sample)	3	0.1	1.9	<6	1.0
Automatic finish booth (area sample)	3	0.1	1.0	<6	1.0
OSHA PEL		15		50	
ACGIH TLV (1979)		--		150	
NIOSH		--		--	

GM: Geometric mean
GSD: Geometric standard deviation

*Painters 1 and 2 used electrostatic guns for exterior panels, conventional guns for liners; Painter 3 used conventional spray equipment continuously; Painter 4 used both electrostatic and conventional guns for exterior panels, conventional guns for liners.

Only those painters with the highest total mist levels had measureable concentrations of lead in their breathing zones. These results, shown in Table 6-3, along with the corresponding mist levels, were well below the 50 ug/m^3 standard for lead.

Solvent levels in the automatic prime booth were twice the levels in the automatic finish booth. Approximately 40 percent more paint is applied in the prime booth than the finish booth and this, along with 10 percent less exhaust in the prime booth, accounts for the difference in solvent concentration. Because the equipment operators spend one half of their workshift in a control room, their average exposure would be somewhat less than that indicated by these area samples.

Mist levels in both automatic spray rooms were extremely low, because of the high transfer efficiency of the electrostatic bell spray equipment.

Table 6-4. Airborne levels of spray mist during liner painting.

Identification	Sample Duration (min.)	Total Mist (mg/m^3)
5164	6.4	350
5158	6.0	320
5157	6.1	330
5152	4.4	300
5168	6.0	310
Geometric mean	--	322
Geo std deviation	--	1.1

DISCUSSION

During the finishing of freezer liners, the painters are surrounded by a cloud of paint mist. Solvent and paint mist concentrations in this cloud are high enough to require the use of respiratory protection. Supplied-air respirators are provided and used during this operation. Conventional air-atomizing guns produce a mixture of air and paint particles that rebounds from the surface being painted. As is the case with the freezer liner operation, this characteristic is particularly troublesome when internal surfaces or cavities are being painted. Airless spraying could accomplish this task without the overspray currently encountered and with little or no reduction in finish quality. In addition to the reduced overspray, more rapid paint build with less paint waste could be achieved with the airless method.

CASE STUDY 7

LIGHT AIRCRAFT FINISHING

Helicopter exteriors are finished with an epoxy/polyamide primer and a two-component polyurethane topcoat. Conventional air-atomized spray equipment is used in large, downdraft spray booths. Breathing zone levels of organic solvents and dibutyltin dilaurate, a paint accelerator, were well below recommended maximums. Breathing zone levels of lead greatly exceeded allowable levels when certain colors were used. Control of total mist, chromium, and isocyanate was marginal, particularly when helicopter underbodies were painted. Air-purifying respirators were worn during all spraying operations.

PROCESS

Operations

Helicopters are finished in a paint shop adjacent to the manufacturing building. This shop contains 5 spray booths and 3 open bays. A layout of the paint shop is shown in Figure 7-1.

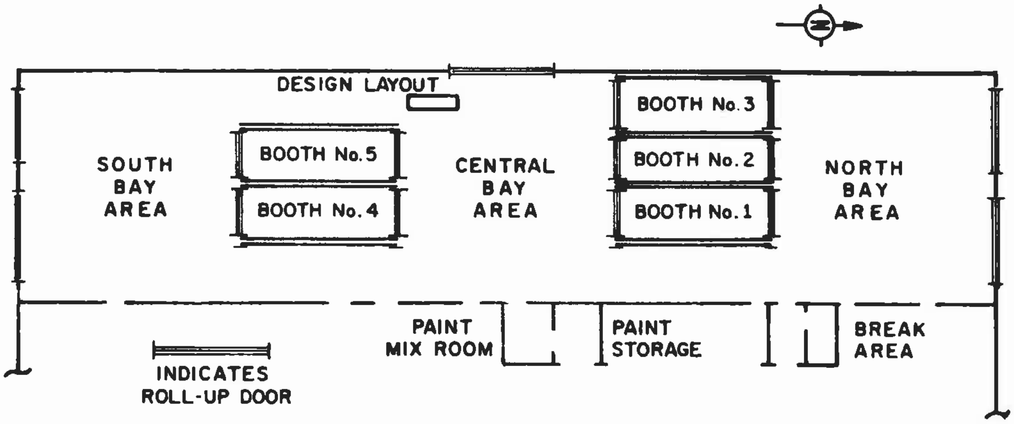


Figure 7-1. Layout of helicopter finishing area.

The North Bay Area of the paint shop is reserved for all pretreatment processes. In this area the ships are cleaned, masked, repaired with body putty, sealed, rinsed with a dilute chromic acid solution, and tested with water for leaks. All doors, cowls, and air foils are removed and hung on portable parts racks. The ships are then manually transported by dolly to one of the three north spray booths. The small parts racks are positioned over the exhaust grates inside the spray booth.

Each spray booth can accommodate 2 to 4 painters and 1 or 2 helicopters, depending on the size of the ship. After tack wiping and black light inspection, all ships and small parts receive a single coat of a yellow-green epoxy primer, which requires approximately 1 hour for application and another hour for curing. The small ships receive 2 to 3 gallons of primer while larger ships require 3 to 4 gallons.

All coating materials are applied with conventional air-atomizing spray guns operating at 50 to 65 psig. Either siphon or pressurized feed (at 15 psig) is used; however, siphon-fed guns are generally restricted to striping or lettering operations. In order to coat the undersides of the helicopter cockpit area, the painter is required to lay on his back on a mechanic's creeper and spray directly upward to the work area. A stepladder is used to gain access to the tail and upper body sections of the helicopter. After the primer has cured, a minimum of 2 coats of white or off-white base color are applied, using the same equipment and application techniques. A 20- to 30- minute drying time is provided between each coat. Base color use is approximately 4 gallons for small ships and 6 gallons for the larger ships.

After application and curing of the base coat, the ships are manually transported to the Central Bay Area where color schemes, striping, and identification markings are laid out and masked. Striping, identification markings, and interior painting is generally performed in Booth 4 or 5 (Figure 1). These spray booths are identical to Booths 1 and 3. Painting time varies with ship size and the complexity of the individual color scheme. The ships are then moved to the South Bay Area where seats and upholstery are installed and general clean-up is performed.

Coatings

A variety of coating systems are available for the helicopters. The selection of a particular system is based primarily upon the end use of the ship and upon the customer's preference.

All ships receive a primer coat for corrosion protection. This coating system can be described as a two-component, epoxy-polyamide resin system that contains strontium chromate pigment. One component consists of a pigmented epoxy resin based on bisphenol A and epichlorohydrin. The other component is a clear polyamide resin, containing a small quantity of the aromatic amine 2,4,6-tris (dimethylaminomethyl) phenol. The two components are manually mixed before application by slowly pouring the polyamide resin solution into the pigmented epoxy component until a one-to-one volumetric ratio has been attained. Composition of the epoxy primer is described in Table 7-1.

Table 7-1. Composition of epoxy-polyamide primer.*

Component A		Component B	
Non-volatiles	Volatiles	Non-volatiles	Volatiles
30% Epoxy resin	35% 2-Butanone	20% Polyamide resin	30% Ethanol
20% Strontium chromate	--	5% Aromatic amide	25% Isopropanol
15% Talc and diatomaceous silica	--		20% Toluene

* Component A and component B are combined in a 1:1 volumetric ratio 30 minutes before use. Composition stated is approximate percentage by weight.

Polyurethane enamels are the standard exterior finish and constitute over 80 percent of the topcoats that are applied. Acrylic lacquers are also available on a special order basis. Epoxy enamels used for cockpit and cabin interiors comprise the balance of paint usage. The polyurethane enamel topcoat system is a two-component, air dry, aliphatic type material. One component of this system consists of a pigmented, hydroxylated, acrylic polyester resin solution, containing a small quantity of an organotin catalyst (dibutyltin dilaurate). The second component, or activator, is a clear isocyanate prepolymer based on hexamethylene diisocyanate (HDI) in a solvent solution. The prepolymer is a mixture of the biuret compound of HDI and other trimers. The two components are mixed before application in a 3 to 1 volumetric ratio. In order to speed the curing time, approximately 4 ounces of a solution containing dibutyltin dilaurate are added to each gallon of the mixture.

The heavy metal content in the exterior finishes varies widely with their color. Lead content of the dried film can range from 8 to 20 percent in oranges, yellows, and reds while other colors are essentially lead-free. There are no cadmium-containing pigments formulated by the manufacturer of this coating system. Composition of the polyurethane enamel is described in Table 7-2.

Table 7-2. Composition of polyurethane enamel.*

Component A		Component B (activator)	
Non-volatiles	Volatiles	Non-volatiles	Volatiles
53% Pigment** in modified polyester resin	29%-Ethoxyethyl acetate	39% Polyisocyanate	5%-Ethoxyethyl acetate
	16%-Ethyl acetate		56%-Ethyl acetate
	2%-Aliphatic hydrocarbons		Accelerator: dibutyltin dilaurate in a solvent

* Component A and component B are combined in a 3:1 volumetric ratio. The accelerator is added at a rate of 4 ounces per gallon. Composition stated is approximate percentage by weight.

**Pigment primarily titanium dioxide; orange, yellow, and red colors may contain from 8 to 20 percent lead in dried film.

HAZARD ANALYSIS

Primer

Solid, uncured epoxy resins found in solvent-based epoxy primers seldom cause any dermal irritation or sensitization. The polyamide resin, present as the major component of the curing agent is also relatively harmless. Amine-cured coatings have been reported to cause asthma-like symptoms and urticaria when applied under conditions of poor ventilation. The use of the polyamide resin should preclude these manifestations. The aromatic amine 2,4,6-tris (dimethylaminomethyl) phenol is a minor constitutent of the curing agent. It has been evaluated for acute toxicity, and, like phenol, is corrosive. It possesses the same order of dermal toxicity as phenol. The long-term effects of exposure are unknown; however, several of the aromatic amines have been shown to be carcinogenic in humans or animals or both.

The pigment portion of the primer contains substantial quantities of the corrosion-resistant pigment, strontium chromate and the extender and filler pigments, talc and diatomaceous silica. Strontium chromate has been determined to induce cancer in animals at the site of implantation and has been implicated as a lung carcinogen in workers who manufacture chromate pigments.

Talc and diatomaceous silica can cause fibrosis of the lung. These materials are at least partially encapsulated in a paint resin matrix, which may act to limit their biological availability. However, in no case would a hazard exist from the extender pigments at paint mist levels of 15 mg/m^3 or less, based on the fraction of the paint solids represented by these materials.

The solvents that are used in the primer pose no unusual hazards that are not associated with other paints.

Topcoat

The polyester resin component of the urethane topcoat is similar to resin systems used in conventional coatings. This resin presents no known toxic hazards. The isocyanate activator, a prepolymer of HDI, contains a small quantity of residual monomer. The level of free monomer may increase during storage. The monomeric material is an irritant to the eyes and respiratory tract, and produces respiratory sensitization in certain individuals.

The prepolymer is of the same acute inhalation toxicity as the monomeric material. Its capability of producing sensitization has not been demonstrated; however, the fact that the monomeric materials have produced sensitization should not be ignored when discussing the polyisocyanates. Because both monomer and polymer are materials of low vapor pressure, the principal isocyanate hazard is associated with the inhalation of the paint aerosol. The polyisocyanate represents about 15 percent of the paint solids in this formulation. If the polymeric material does pose the same sensitization potential as the monomer, then a safe limit for total paint mist would be about 1 mg/m^3. No instances of sensitization have been reported by this plant in five years of use; however, all painters wear respirators.

Pigment hazards vary with the topcoat color. Inorganic pigments are weak colors and require considerable pigment to produce the depth of color desired. The principle hazards are associated with yellow, orange, and red. Lead content ranges from 8 to 20 percent of the dried film.

Current standards for organotin compounds are based on analogy with mercury, thallium, and selenium compounds. Indications are that the dialkyl tin compounds are less toxic than the tri- and tetra-alkyl compounds.

Ethoxyethyl acetate and ethyl acetate are the major solvent hazards associated with the urethane enamel. The chief toxic manifestations of both compounds are eye and nasal irritation. At high concentrations, headache, drowsiness, and unconsciousness may occur.

SPRAY BOOTHS

Design

All spray painting operations are performed in 1 of 5 identical downdraft booths similar to that shown in Figure 7-2 and 7-3.

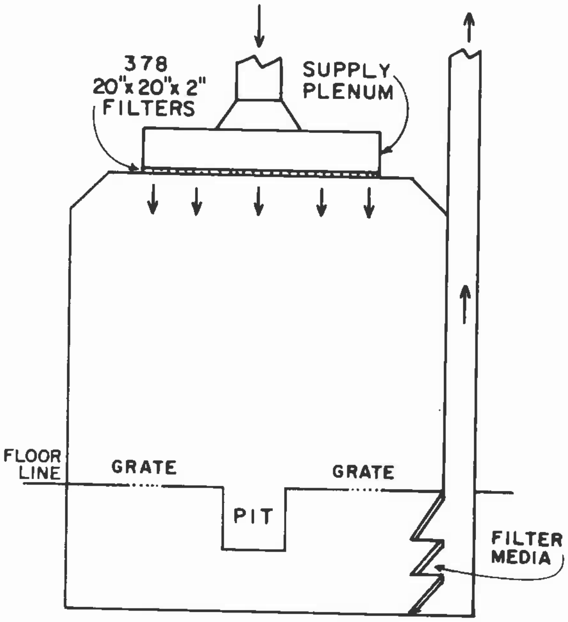


Figure 7-2. Cross-section of helicopter spray booth.

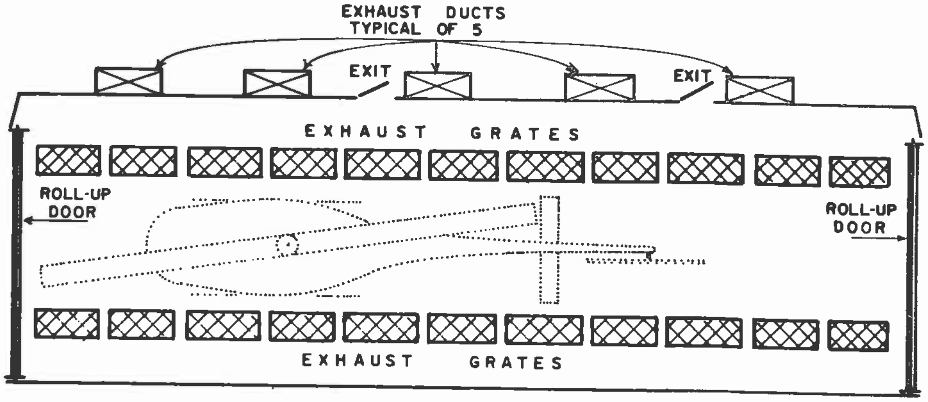


Figure 7-3. Plan of helicopter downdraft spray booth.

The interior dimensions of each booth are 24 feet wide by 70 feet long by 20 feet high. Both ends of the booth are equipped with full height, roll-up doors with access doors at the side. The top of the booth consists of a supply air plenum containing polyester filters. The plenum chamber measures 3-1/2 feet high by 15 feet wide and runs the length of the booth. Air is supplied to the plenum through 4 supply air ducts. The floor of the booth contains 2 parallel exhaust grates, each 2-1/2 feet wide and running the length of the booth. A pit, covered by removable plates, is available to facilitate painting of helicopter underbodies, but is not used. An under the floor exhaust plenum aids in air distribution and houses the overspray filters. These filters consist of a non fire-supporting paper folded into accordian style pleats with staggered air holes. The filter media is arranged in 3 rows along the wall of the plenum.

Both inlet and exhaust filters are changed at 5 week intervals. Five ducts per booth route exhaust to roof-mounted, vane axial fans. Exhaust fans are rated at 34,000 cfm each, for a booth exhaust rate of 170,000 cfm. This exhaust rate corresponds to a nominal downdraft velocity of 100 fpm within the booth. Fourteen make-up air heaters with evaporative coolers, can supply a total of 588,000 cfm of tempered air to the spray booths. The make-up air that is available limits the total number of booths in use at one time. Five of the make-up air heaters are capable of producing a 120°F temperature rise, allowing the booths to serve as curing chambers. During the curing cycle, the booth airflow is reduced to 56,000 cfm.

Airflow Measurements

Ventilation measurements were performed in 2 of the spray booths and reported in Table 7-3. Total exhaust was within ± 10 percent of the design rate for both booths. Air velocities at the exhaust grates showed little variation as a result of good air distribution by the exhaust plenum (grate velocity was twice the theoretical plenum velocity). Air velocity within the booths varied considerably with both time and position, from a low of 10 fpm near the walls to 300 fpm near the fresh air plenum. Figure 7-4 illustrates booth airflow patterns.

Table 7-3. Ventilation mesurements for light aircraft finishing.

Booth No. 1		Booth No. 2	
Exhaust:		Exhaust:	
West grate	92,000 cfm	West grate	92,000 cfm
East grate	88,000 cfm	East grate	67,000 cfm
Total	180,000 cfm	Total	159,000 cfm
Control velocity:		Control velocity:	
Average	110 fpm	Average	95 fpm
Range	50 to 300 fpm	Range	10 to 250 fpm

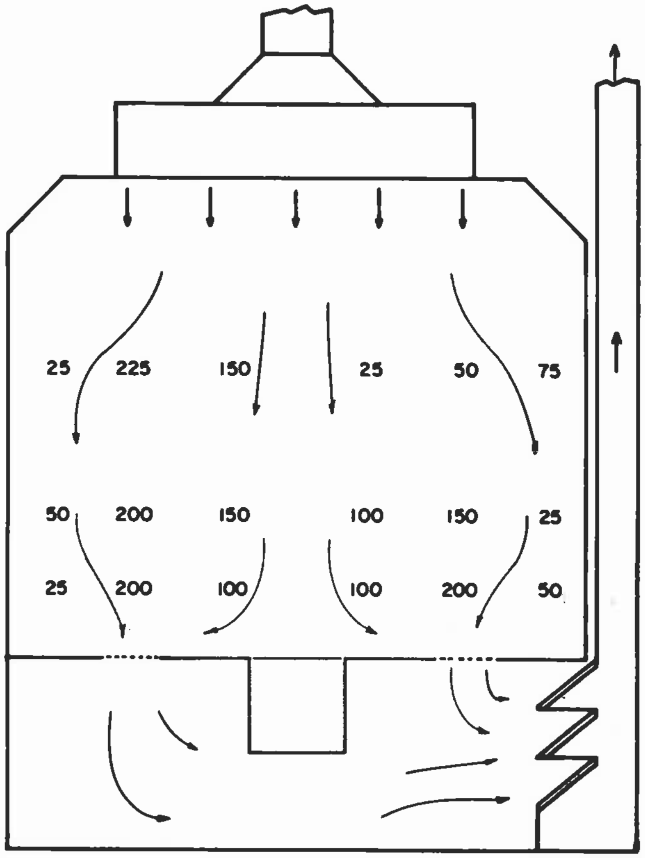


Figure 7-4. Spray booth airflow (ft/min).

Two factors influence this variation. First, the relatively small grate size in proportion to the booth width induces a region of higher airflow above the grate area. Second, supply air velocity appeared to vary because of poor distribution in the supply plenum.

Overspray control was facilitated by positioning the ship between the exhaust grates as shown in Figure 7-5. The regions of highest air velocity thus coincided with the cabin sides. Control was similarly aided by placing racks holding doors, cowls, and other small parts directly over the exhaust grates. Observations indicated that control of overspray was compromised when helicopter underbodies were finished.

PERSONAL PROTECTIVE EQUIPMENT

Before entering the spray booth, all painters don a set of disposable coveralls and a loose-fitting hood made of Tyvek ^{R}. During painting operations, they wear a NIOSH-approved, half-facepiece respirator, with organic vapor-removing cannisters and mist prefilters. Rubber gloves are available but not used by all workers.

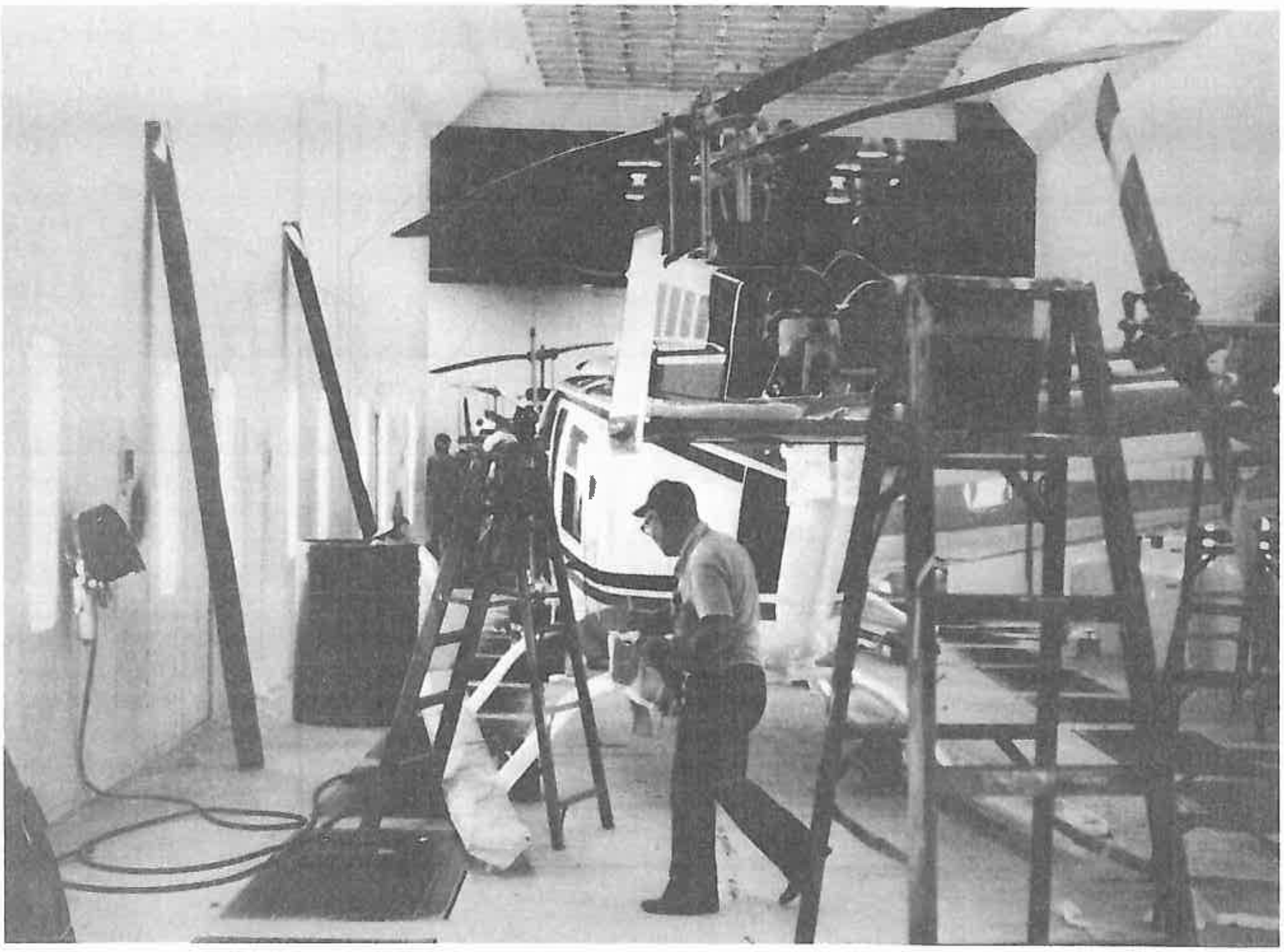


Figure 7-5. Helicopter in booth after striping.

While providing excellent protection, the coverall material does not readily breathe, which causes complaints from the painters during hot weather. However, because few painting operations at this plant require more than one hour, use of this type of clothing should not produce undue thermal stress.

The size and shape of the helicopter and the toxicity of the paint materials require the use of respiratory protective equipment. Again, the short duration of actual spraying make respirators more acceptable to the employees. At this facility line supervisors have the responsibility for enforcing and training in the use of respirators. Several employees noted respirator leakage. These same employees were found to be wearing respirators with one headband either missing or improperly adjusted, which underscores the need for training as a function of the safety or hygiene management.

EVALUATION

Approximately 130 people are employed in the finishing department, with the majority working the day and afternoon shifts. Many have no exposure to paint spraying. Of those individuals employed as spray painters, a maximum of 6 paint at any time. The actual time that these workers paint varies with the size of the helicopter and the complexity of the color scheme, but a daily exposure of 2 hours or less is an estimate. This exposure time is low because of the slow pace of finishing necessary to attain a virtually flawless finish, the extensive preparation of the ship for priming, and the time-consuming layout of the custom color schemes.

To determine control effectiveness, the airborne levels of total spray mist, toxic metals, and organic solvents were determined by personal air samples taken during the time it took to paint each aircraft.

Total mist, lead, strontium, and chromium were collected using closed-face cassettes with preweighed, 0.8 u pore size, 37 mm polyvinyl chloride/acrylonitrile membrane filters and personal pumps operated at 2.0 lpm. After weighing, the filters were ashed and analyzed by atomic absorption spectroscopy for metals. Air samples taken during ship priming were analyzed for strontium and chromium. Samples taken during topcoat application were analyzed for lead.

Organic solvent samples were collected on 150 mg charcoal tubes with personal pumps operated at 100 cc/min. Tubes were subsequently desorbed and analyzed by gas chromatography.

For polyurethane topcoats, consecutive short term samples were taken in the painter's breathing zone to determine ceiling concentrations of HDI. These samples were collected using 2 midget impingers connected in series to a personal pump operated at 2.0 lpm. Each impinger contained 15 ml of a nitro reagent solution, which was subsequently analyzed for the HDI/nitro reagent derivative by high pressure liquid chromatography.

Dibutyltin dilaurate, used as an accelerator in the urethane enamel, was collected using closed-face cassettes with 37 mm glass fiber filters and personal pumps operated at 2.0 lpm. Because of the anticipated low airborne concentration of tin, sampling times were increased to encompass the finishing of 2 aircraft. Following collection, the samples were analyzed by x-ray fluorescence for total tin content.

RESULTS

Prime Application

Breathing zone (outside respirator) levels of paint mist, strontium, and chromium (strontium chromate) are reported in Table 7-4. (NOTE: Ship numbers are included in tables so that samples for mist, solvents, and so forth, can be compared). Both concentrations of total mist and total chromium exceed allowable limits for a full shift's exposure. On a 8-hour, time weighted average basis, however, levels of total mist and chromium are below legal limits. It should be noted that both NIOSH and the American Conference of Governmental Industrial Hygienists (ACGIH) have recommended exposure limits well below the current OSHA standard for chromium.

Table 7-4. Airborne levels of paint mist, strontium, and chromium in light aircraft finishing: primer application.

Ship number	Operation	Sample duration (min)	Total mist (mg/m^3)	Strontium (mg/m^3)	Chromium (mg/m^3)
1	Prime	25	17.9	1.7	1.2
2	Prime	40	40.6	4.4	2.7
2	Prime	41	17.5	1.9	1.3
GM (GSD)			23.3(1.6)	2.4(1.7)	1.6(1.6)
OSHA PEL*			15	--	1.0
ACGIH TLV (1979)*			10	--	0.05
NIOSH*			--	--	0.001

GM: Geometric mean
GSD: Geometric standard deviation
*For full shift exposures.

The exposures to organic solvents reported in Table 7-5 are well below any existing or proposed standards for the materials used.

Table 7-5. Airborne levels of organic solvents in light aircraft finishing: primer application.

Ship number	Operation	Sample duration (min)	Concentration (mg/m^3) 2-Butanone	Toluene	Ethanol	Ispropanol	C_E*
1	Prime	25	21	54	21	17	0.14
2	Prime	40	92	72	46	33	0.31
2	Prime	41	37	55	18	13	0.16
GM (GSD)			42(2.1)	60(1.2)	26(1.6)	19(1.6)	.19(1.5)
OSHA PEL**			590	750	1900	980	1.0
ACGIH TLV (1979)**			390	375	1900	980	1.0
NIOSH**			590	375	--	980	--

GM: Geometric mean
GSD: Geometric standard deviation

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \dots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the exposure limit

**Full shift exposures.

Topcoat Application

Breathing zone (outside respirator) levels of paint mist and lead are reported in Table 7-6. As might be expected, the mean concentrations of total mist in applying the base coat to the whole ship are equal to those in ship priming. As base coats are primarily white or off-white colors, all lead-in-air measurements for whole-ship painting were below the limits of detection. For the sampling conditions used, this corresponds to an airborne concentration of less than 50 ug/m^3. Paint mist levels varied more greatly in striping operations than in whole ship painting. Ventilation was compromised in underbody painting, with mist exposures far greater than those experienced in striping the ship's sides. Only one ship was painted with a lead-containing pigment. This paint, a red hue, contained 11.3 percent lead by weight (dried film). It was used to paint an underbody, resulting in a lead concentration several times the current 8-hour limit for lead. Other colors may contain up to 20 percent lead. Variations in the lead content of the paint and the quantity sprayed make realistic estimates of 8-hour averages difficult.

Table 7-6. Airborne levels of paint mist and lead in light aircraft finishing: topcoat application.

Ship number	Operation	Color	Sample duration (min)	Total mist (mg/m^3)	Lead (mg/m^3)
3	Base coat, whole ship	White	27	28.2	--
5	Base coat, whole ship	White	35	24.7	--
6a	Base coat, whole ship	White	41	34.5	--
7a	Base coat, whole ship	White	45	41.2	--
6b	Base coat, whole ship	White	62	16.5	--
7b	Base coat, whole ship	White	31	9.8	--
	Whole ship painting GM (GSD)			23.3 (1.7)	--
8	Striping, painter's helper	Brown	25	8.5	--
8	Stripe, first coat, tail and cowl	Brown	31	16.5	--
8	Stripe, second coat, tail and cowl	Brown	19	9.8	--
9	Stripe, first coat, underbody and tail	Red*	26	23.3	2.9
9	Stripe, second, third coats, underbody and tail	Red*	35	38.8	5.0
10	Stripe, side, three coats	Cream	29	6.4	--
	Striping operations GM (GSD)			14.1 (2.0)	--
OSHA PEL**				15.0	0.05
ACGIH TLV (1979)**				10.0	0.15
NIOSH **				--	0.10

GM: Geometric Mean
GSD: Geometric Standard Deviation
* Molybdate orange pigment; 11.3 percent lead in dried film
**For full shift exposure

As was the case in ship priming, the airborne concentrations of organic solvents in topcoat application are well below any existing or proposed standards. These measurements are shown in Table 7-7.

Table 7-7. Airborne levels of organic solvents in light aircraft finishing: topcoat application.

Ship number	Operation	Sample duration (min)	Concentration (mg/m^3)			C_E*
			Ethyl acetate	Ethoxyethyl acetate	Aliphatic hydrocarbons	
3	Base coat, whole ship	27	92	54	<40	0.19
4	Base coat, whole ship	34	74	38	<30	0.14
5	Base coat, whole ship	35	76	41	<30	0.15
6a	Base coat, whole ship	41	78	50	30	0.16
7a	Base coat, whole ship	45	120	70	50	0.24
6b	Base coat, whole ship	62	49	27	30	0.10
7b	Base coat, whole ship	31	66	38	30	0.13
	Whole ship painting GM (GSD)		77 (1.3)	44 (1.4)	34(1.2)	0.15 (1.3)
8	Striping, painter's helper	25	69	21	80	0.13
8	Stripe, first coat, tail and cowl	31	70	33	70	0.15
8	Stripe, second coat, tail and cowl	19	21	11	100	0.09
9	Stripe, first coat, underbody and tail	26	85	65	100	0.23
9	Stripe, second, third coats, underbody and tail	35	160	94	80	0.33
10	Stripe, side, three coats	29	19	11	37	0.03
	Striping GM (GSD)		52 (2.5)	30 (2.7)	73 (1.5)	0.13 (2.5)
OSHA PEL**			1400	540	2000	1.0
ACGIH TLV (1979)**			1400	270	1800	1.0
NIOSH**			--	--	350	--

GM: Geometric mean
GSD: Geometric standard deviation

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \dots \frac{C_n}{L_n}$

Where: C is the concentration of the individual contaminant, and
L is the exposure limit.

**For full shift exposure.

Sampling results for hexamethylene diisocyanate are reported in Table 7-8. All but one sample are below the 10 minute ceiling concentration limit for HDI recommended by NIOSH. The single value in excess of this limit was for the final coat to the underbody and tail. As was noted before, ventilation is compromised in this operation.

The first two samples reported in Table 7-8 were taken in parallel, with the second sample preceded by a filter. This was done to determine if the isocyanate was present as a vapor, or as a constituent of the paint aerosol. Insufficient material was collected to enable a judgement to be made.

Table 7-8. Airborne levels of hexamethylene diisocyanate in light aircraft finishing.

Ship number	Operation	Sample duration (min)	Hexamethylene diisocyanate (ug/m^3)
5	Base coat, whole ship	15	27
5*	Base coat, whole ship	15	<26
5	Base coat, whole ship	21	19
9	Stripe, first coat, underbody and tail	13	<30
9	Stripe, first coat, underbody and tail	7	<57
9	Stripe, second coat, underbody and tail	10	67
9	Stripe, second coat, underbody and tail	8	<47
9	Stripe, third coat, underbody and tail	11	250
NIOSH Recommendation			
Ceiling (10 Minutes)			140
8-hour time-weighted average			35

*Sample taken parallel to preceding sample, but with prefilter.

As shown in Table 7-9, airborne concentrations of tin were sufficiently low to preclude any hazard from its application.

Table 7-9. Airborne levels of dibutyltin dilaurate in light aircraft finishing.

Ship number	Operation	Sample duration (min)	Tin (ug/m^3)
4,5	Base coat	69	4
6a,7a	Base coat	83	7
6b,7b	Base coat	93	2
OSHA PEL*			100
ACGIH TLV (1979)*			100
NIOSH*			100

*For full shift exposure

DISCUSSION

The exterior finishing of helicopters is not unlike that done in an automobile repair shop or in a factory that produces bus or truck bodies in low volume. (Application techniques, coating materials, and spray booth design are all similar.) While the sheer volume of air exhausted provides more than adequate control of the solvent hazard, the size and shape of the helicopter does not permit the same degree of control of the stray mist in the immediate vicinity of the painter, particularly during underbody painting. A comparison of total mist concentrations in Table 7-6 lends credence to this observation. Mist concentrations are highest for underbody painting operations, and lowest for side striping.

Ventilation is compromised in underbody painting. In order to improve overspray control during this task fresh air should be supplied to the painting pit (not currently used). Because only a small section of the pit should be open at any time, additional fresh air requirements would be minimal. A sidedraft-style booth, similar to that used in auto body shops, might be a better choice for finishing helicopters and other light aircraft, if the painting required on the downstream side is minimal. In this type of booth, a flow of air away from the painter could be maintained at nearly all points of the aircraft, with a possible decrease in total exhaust volume. Sidedraft ventilation might be all that is possible with fixed-wing aircraft, when under-wing, as well as underbodies may require painting.

Improvements in paint application techniques are limited. The conventional air-atomized spray equipment is operated within the pressure recommendations of the coating suppliers. Portions of the ship are made of fiberglass, limiting the utility of electrostatic techniques. Many of the striping colors are metallic finishes, ruling out the use of airless equipment. Lastly, the cost of the paint consumed is so small when it is compared to the total labor involved that paint savings from the improved techniques would not justify the expenditure.

Many components of the coatings in use have not been evaluated for chronic toxicity, or serious questions have been raised about the adequacy of current legal maximums. Unfortunately, suitable substitutes have not been found for all of these materials, and even improved ventilation controls may be incapable of reducing these hazards to an acceptable level. Until solutions are found, a good program of protective equipment and medical supervision is essential. Because the greatest hazard is associated with the inhalation of the paint aerosol, respiratory protection is the foundation of such a program. Because of the improved fit and the better protection against eye irritation, a full face piece respirator is recommended. A supplied-air respirator is preferable not only for its high degree of protection, but for its increased comfort in hot weather.

CASE STUDY 8

FINISHING OF HEAVY EQUIPMENT

Hay stack wagons receive a single coat of an alkyd resin enamel in a three-step finishing process. The enamel is applied using hot airless and hot airless electrostatic equipment in a large downdraft spray booth. The booth features a pit for underbody painting which incorporates a supply of fresh air. Powered manlifts within the booth provide access to high areas of the wagon and allow the painter to maintain proper orientation with respect to the airflow. The sophistication of the application equipment and the excellence of the spray booth design result in low levels of spray mist when the exterior of the wagon is painted. When wagon interiors are painted, mist levels increase approximately tenfold.

PROCESS

A hay stack wagon is a two-wheeled agricultural trailer designed to be pulled behind a tractor. Powered by the tractor's engine through a power take-off system, it gathers hay and compresses it into a high density stack. The wagon is box-like in shape, and fabricated from sheet steel and steel members; it measures approximately 15 feet high, 12 feet wide, and 24 feet long.

Operations

The finishing process consists of a detergent wash, followed by paint application and oven drying. The finishing department is shown in Figure 8-1. Finishing begins in a 30 by 50 foot wash booth, where two operators remove soil and manufacturing debris by spraying the wagons with a detergent solution. After washing, the wagons are towed to a staging area, oven-dried, then towed to the spray booth for painting.

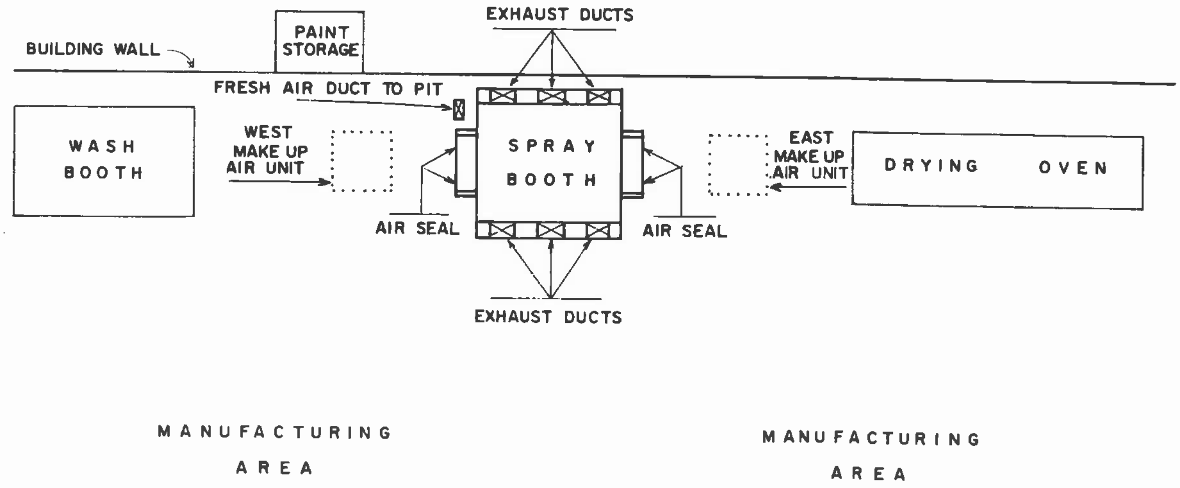


Figure 8-1. Finishing department layout.

Two painters apply a single coat of an alkyd enamel in a 32 by 40 foot downdraft spray booth. The booth is equipped with five airless electrostatic hand spray guns and two airless pole guns. The pole guns are used to allow the operator access to hard-to-reach areas. All guns are operated at a paint pressure of 1000 to 1200 psi and the electrostatic guns operate at a charging potential of 60,000 volts. The paint is heated to 100 to 130°F, which allows paint formulation at a lower solvent content, and application at a lower pressure than would be possible with a cold airless system. The paint is distributed with a loop-type system, from an adjacent paint storage room.

The two painters require one hour to apply the 10 to 12 gallons of paint that are necessary to cover the product. Both painters begin coating the bottom frame and lower edges with the pole guns. Painter A enters the pit for about 5 minutes to spray the remaining members with an electrostatic gun (Figure 8-2). He returns to the floor, sprays the front of the wagon, then raises the manlift to paint the top with a pole gun. Then he works his way down the side

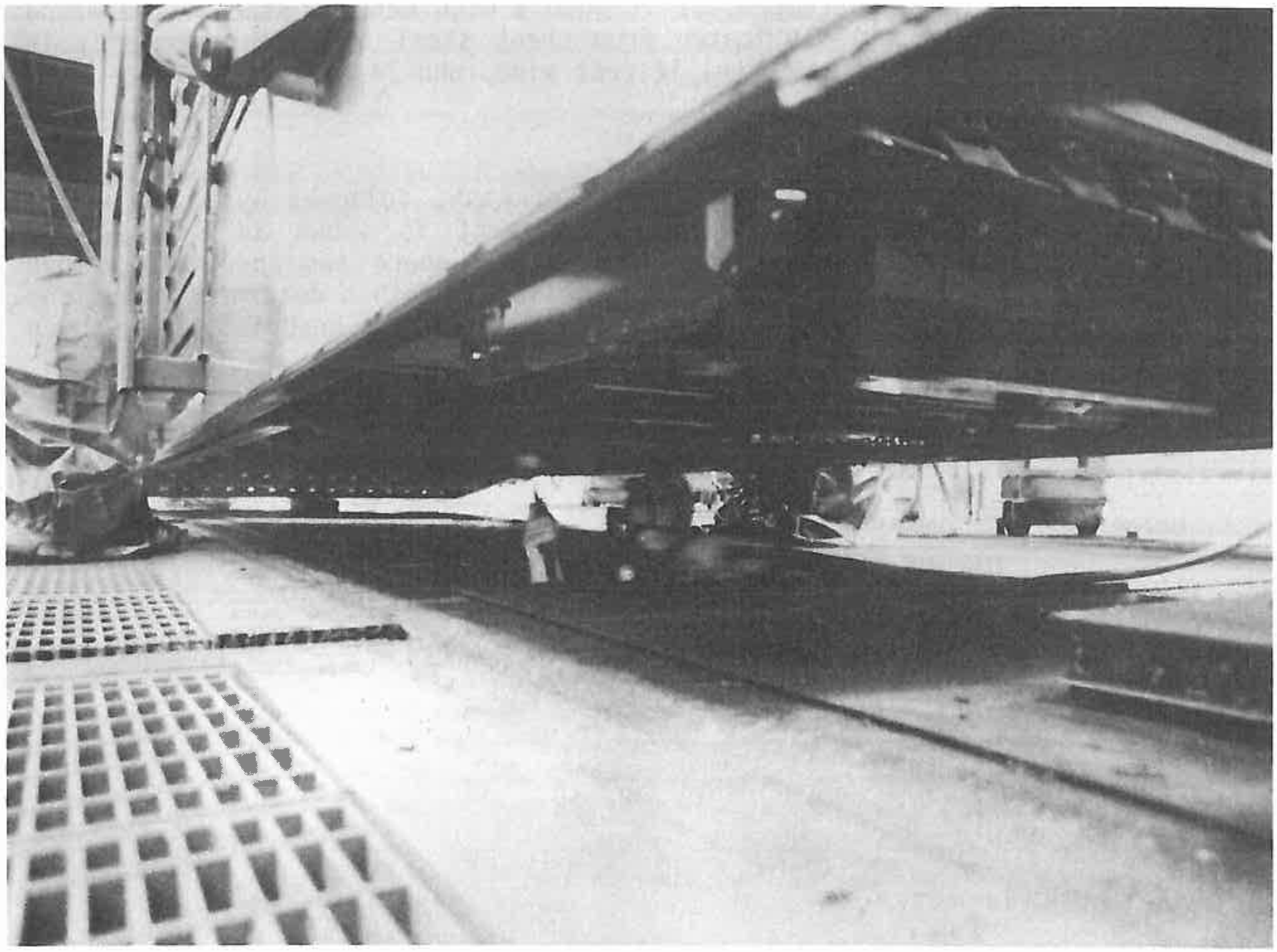


Figure 8-2. Underbody finishing operations.

switching back to an electrostatic gun when the area to be painted is within reach. Painter B enters the wagon and sprays the interior with a pole gun for about 20 minutes (Figure 8-3). He then rides the manlift to the side that is opposite Painter A and paints that side in the same manner. Both painters inspect their work and touch up light areas as necessary. Painter A used the electrostatic gun for approximately 80 percent of his work. Painter B used the electrostatic gun for only 40 percent of his work.

After painting, the wagon is towed to the oven and connected to a floor conveyor. The conveyor draws the wagons through the 175°F oven, allowing a 40 minute cure.

Coating Material

The stack wagons are available in only one color. That color is attained by an alkyd resin enamel containing lead chromate, iron blue, and titanium dioxide pigments. This paint consists of 45 percent solids by weight. Of that solid material, lead represents 11 percent and chromium represents 4 percent.

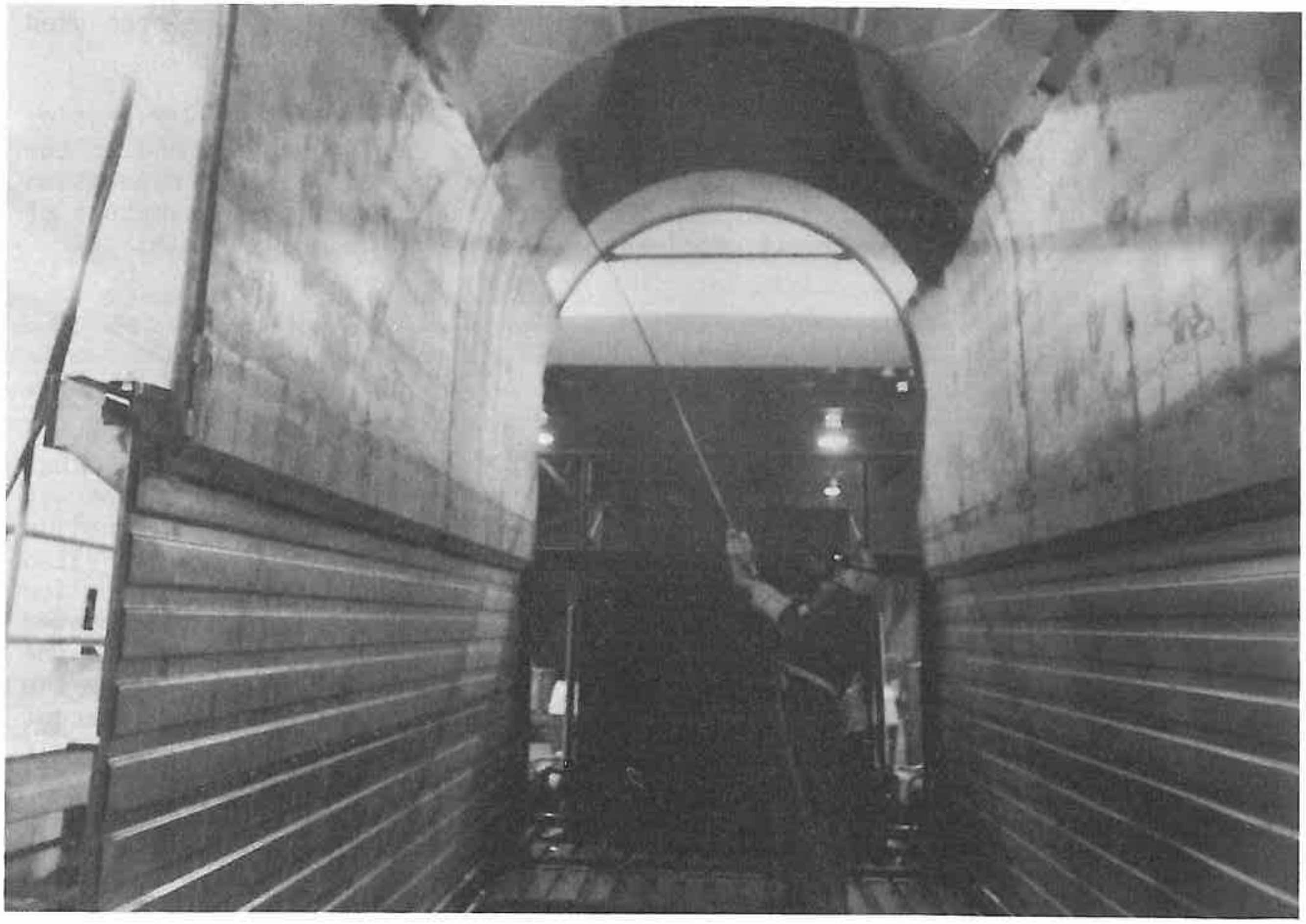


Figure 8-3. Finishing of wagon interior.

Calcium naphthanate, cobalt naphthanate, and zirco catalyst are employed as driers, catalyzing the oxidation and subsequent polymerization of the paint film. Solvents used in formulation include VM&P naptha, mineral spirits, tetramethyl benzene, and xylene in order of decreasing percentage. Up to 2 gallons of tetramethyl benzene per 53 gallons of raw paint are used to adjust the viscosity of the paint.

HAZARD ANALYSIS

The principle hazard associated with the coating in use at this facility is the lead chromate (chrome yellow) pigment employed. Because the inorganic pigments are generally weak tinting colors, a substantial amount of pigment is required. In this particular coating, the chrome yellow pigment amounts to approximately 20 percent of the total paint solids by weight. Lead chromate is one of the least toxic lead compounds with respect to plumbism because of its low solubility; nonetheless, the hazard is still present and must be treated seriously. In addition, lead chromate has been implicated as a lung carcinogen in workers who produce chromate pigments, although a similar situation has not been documented in painters.

The alkyd resin has no unusual toxic properties. Alkyd resins have been used in paints for some time with no reports of any chronic hazards.

The organic solvents employed in these formulations all exhibit similar physiological effects. In general, they are irritants to the conjunctiva and to the mucous membranes of the upper respiratory tract. They all produce depression of the central nervous system and, at high concentrations, produce symptoms of headache, nausea, and drowsiness, followed by unconsciousness and death.

SPRAY BOOTH

Design

The hay stack wagons are painted in the 40 by 32 foot downdraft booth shown in Figures 8-4 and 8-5. This booth features a pit (for underbody painting) that incorporates a supply of fresh air. In the design stage, careful attention was given to good air distribution within the booth. Fresh, heated air is supplied to the booth by two direct-fired, make-up air units with a combined, rated capacity of 180,000 cfm. Approximately 80 percent of this air is supplied through an overhead plenum. The floor of the plenum chamber is a perforated plate to assist in air distribution to the filter bank. The shape of the filter bank and the gentle slope of the booth's upper wall further diffuse the supply air. Maximum supply air velocity at the filter face is 200 fpm. Except for a small quantity of air supplied to the pit area, the remaining make-up air is supplied to entry and exit vestibules or "air-seals." Because the total quantity of air supplied to the booth exceeds that exhausted by 10 percent, excess make-up air spills out of the air seals, effectively preventing dust-laden plant air from entering the booth. Fresh air enters the pit area through a fresh air plenum located beneath the open grate floor of the pit. This plenum incorporates slots to achieve air distribution. The pit area is covered with movable panels. To paint the bottom of the hay wagon, the painter removes only one or two panels, sliding the cover panels as he progresses.

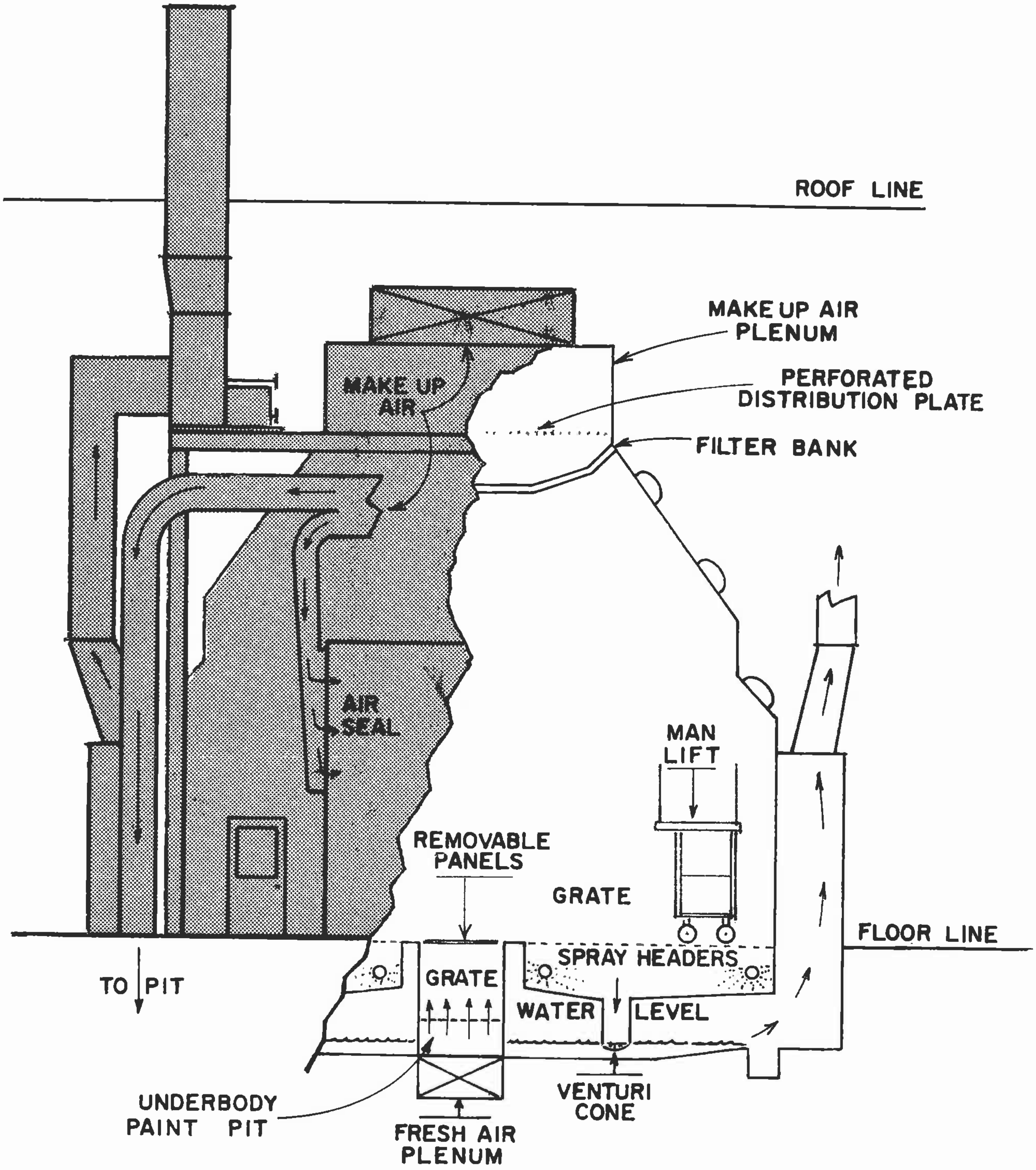


Figure 8-4. Spray booth cross-section.

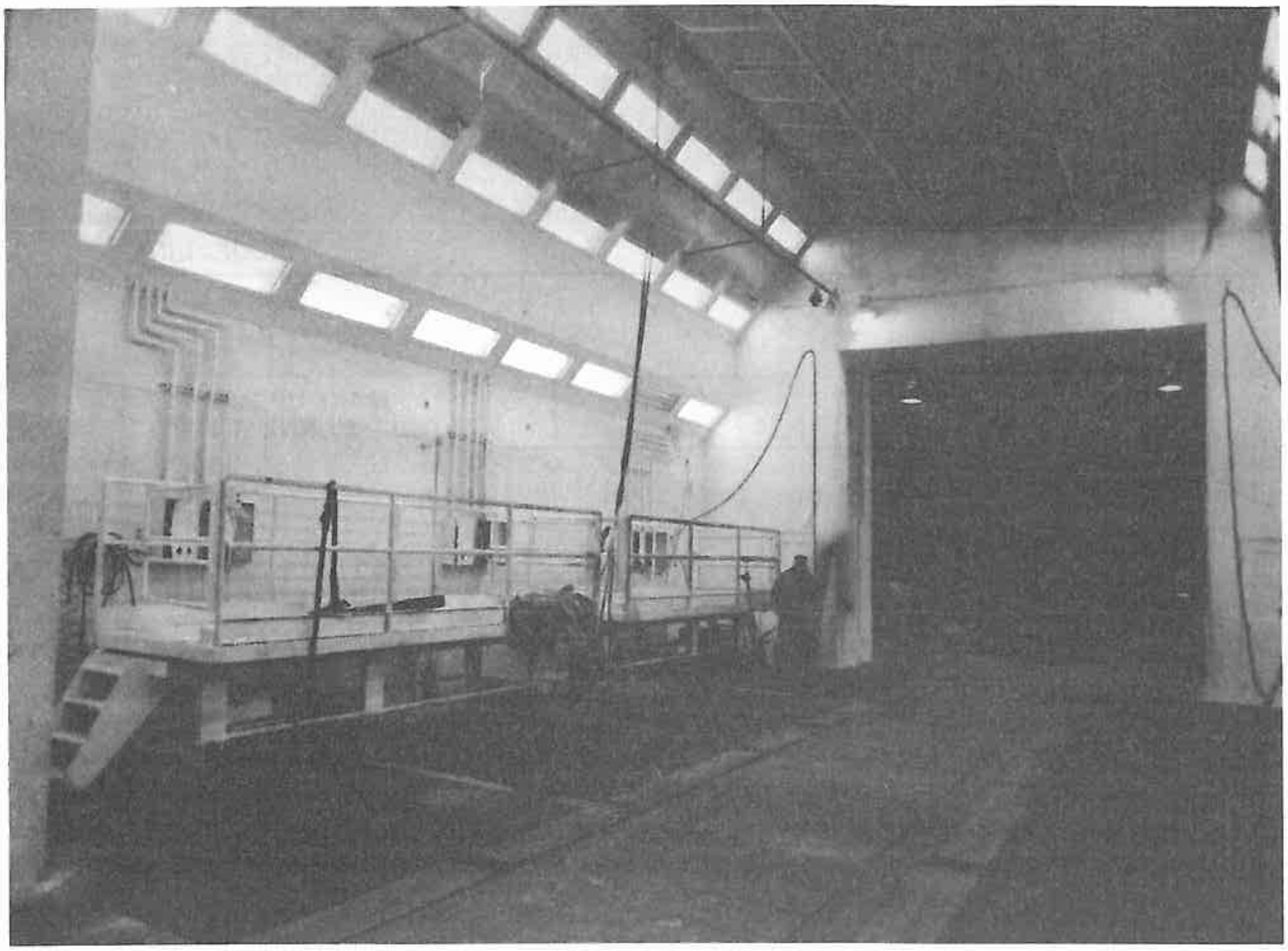


Figure 8-5. Interior of stack wagon spray booth.

Air is exhausted from the booth through floor grates located on each side of the pit area. A flooded pan 2-1/2 feet below the grate collects the overspray. Water from the pans drains down through 16 inch diameter venturi cones into a collecting tank. Booth air is drawn at high velocity (5,000 fpm) through the water swirling down the cone, effectively scrubbing entrained mist from the exhaust stream. These points of high velocity also serve to evenly distribute the exhaust. Six 25,000 cfm centrifugal fans are located on a platform near the top of the booth.

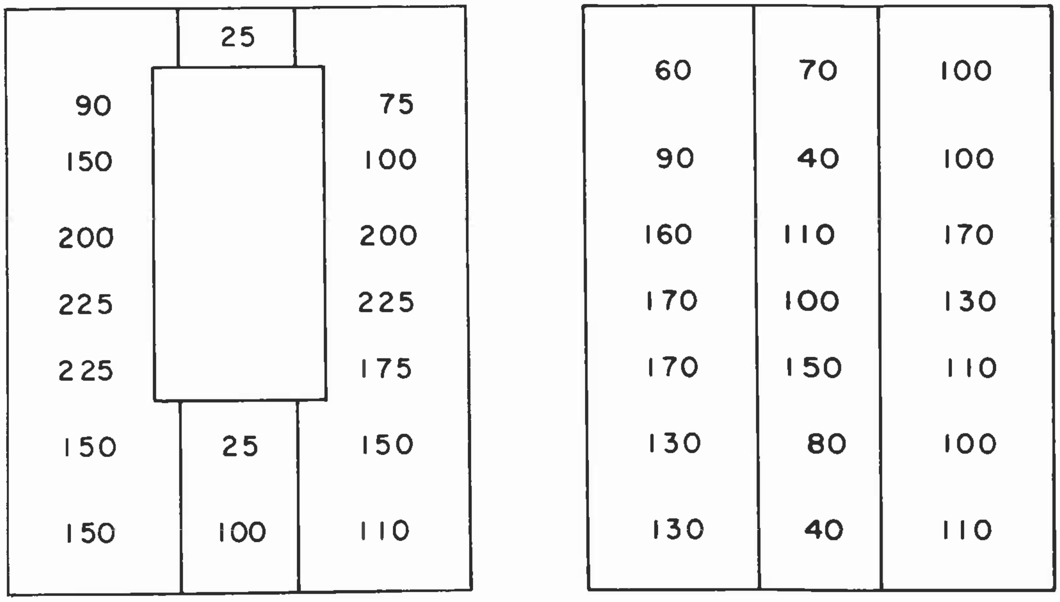
For any spray booth to be effective, it is essential that the painter be upwind of the object being painted. When painting a product that is 15 feet high, it becomes necessary to provide access to elevated areas. This booth is equipped with powered manlift platforms, which not only make all exterior surfaces readily accessible but also allows the painter to maintain the proper orientation with respect to the airflow. This arrangement is far superior to a fixed access platform where, more often than not, the painter will be spraying above his head.

Airflow Measurements

Total exhaust air was measured by a pitot tube traverse of the stacks of each of the 6 exhaust fans. Total supply air, and pit and vestibule supply air were also determined, and the ceiling air was determined from the difference. Airflow measurements are summarized in Table 8-1. Control velocity was determined with a hot wire anemometer held approximately 5 feet above the grate area, with the wagon in the booth, and repeated with the wagon absent. These measurements are shown in Figure 8-6. Air velocity was relatively uniform over the grate area, dropping slightly near the booth exits. A drop in air velocity was also noted above the pit area, and was exacerbated by the presence of the tall wagon.

Table 8-1. Booth airflow summary.

Exhaust:		
northeast fan	21,000 cfm	(All fans 25,000 cfm design volume)
north fan	25,000 cfm	
northwest fan	23,000 cfm	
southeast fan	29,000 cfm	
south fan	27,000 cfm	
southwest fan	24,000 cfm	
Total exhaust	149,000 cfm	
Make-up Air:		
west unit	91,000 cfm	(Both units 90,000 cfm design volume)
east unit	80,000 cfm	
make-up air distribution:		
overhead plenum	133,000 cfm	
west air seal	18,000 cfm	
east air seal	16,000 cfm	
booth pit	4,000 cfm	
Air velocity:		
wagon absent from booth mean 110 fpm (39 SD)		(Measured 5 feet above floor)
wagon in booth mean 140 fpm (65 SD)		



WAGON IN BOOTH

WAGON ABSENT FROM BOOTH

Figure 8-6. Air distribution through horizontal section of booth (air velocity in fpm).

PROTECTIVE EQUIPMENT

At the start of each workshift painters don clean coveralls and safety glasses. Before painting they don head socks, painters' hats, gloves, and respirators, then they coat exposed areas of their faces with petroleum jelly. Gloves have the palms cut out so that the painters are grounded to the handle of the electrostatic guns. Respirators are of the half-facepiece variety, with twin organic vapor-removing cartridges and mist filters.

EVALUATION

Two painters are engaged in painting the hay stack wagons. Total spraying time for a stack wagon is approximately 60 minutes, and the painters will spray up to 5 stack wagons on a typical workday. In addition to painting, these workers are responsible for paint mixing, skimming paint sludge from the booth water tank, maintaining spray guns, and general housekeeping in the spray booth. These tasks are all of short duration and were judged not to contribute significantly to the painters' exposure.

To determine control effectiveness, the breathing zone concentrations of spray mist, lead, chromium, and organic solvents were determined by personal air samples taken during the time required to paint each stack wagon. Total mist, lead, and chromium were collected using closed face cassettes with a pair of matched weight, 37 mm cellulose ester membrane filters of 0.8u pore size at a sampling rate of 2.0 lpm. After weighing, the filters were ashed and analyzed by atomic absorption spectroscopy for lead and chromium. Organic solvent samples were collected on 150 mg charcoal tubes with personal pumps operated at

100 cc/min. Tubes were subsequently desorbed and analyzed by gas chromatography.

Initial observations indicated that Painter B was exposed to considerably more overspray, primarily from painting the interior of the wagon. To determine the impact of this operation on his overall exposure, a second sample for total mist was collected for the duration of the interior painting, which was approximately 17 minutes. A preweighed polyvinyl chloride filter was used for this determination.

To determine the ability of the booth air seals to contain the spray mist and solvent vapors within the booth, area air samples were taken at the booth exits. Sampling and analyses were identical to the personal samples noted above, except for duration and a charcoal tube sampling rate of 50 cc/min.

RESULTS

Airborne levels of paint mist, lead, and chromium in the breathing zone of the spray painters (outside of the respirator) and in the area of the booth exits are reported in Table 8-2. The breathing zone samples were collected for the

Table 8-2. Airborne levels of total paint mist, lead, and chromium in heavy equipment finishing.

		Concentration (mg/m^3)#					
	Number of samples	Total mist GM	Total mist GSD	Lead GM	Lead GSD	Chromium GM	Chromium GSD
Painter A	5	2.0	1.4	0.23	1.3	0.031	1.5
Painter B	6	11.9	1.3	1.300	1.2	0.230	1.2
Painter B (interior only)	4	36.5	1.2	--	--	--	--
Booth Exits (area sample)	4	0.3	1.9	0.006	1.8	0.003	1.0
OSHA PEL*		15		0.05		1.0**	
ACGIH TLV (1979)*		10		0.15		0.050	
NIOSH Recommendation*		--		0.10		0..001	

GM: Geometric mean
GSD: Geometric standard deviation
Results are reported for short term samples. 8-hour time-weighted averages would be approximately 50 percent lower; see text.
* For full shift exposure
**Chromium metal and insoluble salts

duration of the wagon painting, a period of approximately 60 minutes. An additional gravimetric sample was taken on Painter B for the duration of painting the interior of the wagon. The area samples were collected over the time required to paint several wagons.

The mean concentration of total paint mist, lead, and chromium in the breathing zone of Painter B was six times that of Painter A. This can be explained by the high mist levels measured during the painting of the wagon interior. The concentration of paint mist in the breathing zone of Painter B during exterior painting operations was determined by calculation to be 2.2 mg/m^3, a level virtually identical to that of Painter A.

Eight-hour time-weighted average (TWA) concentrations would be approximately one-half the values reported in Table 8-2. Levels of paint mist are well below the maximum allowed by OSHA for total dust. Lead concentrations exceed the 50 ug/m^3 standard; however, both painters wear half-facepiece respirators, with organic vapor-removing cartridges and mist filters. As half-mask respirators offer a protection factor of ten, Painter A would be well protected, but Painter B would not be as well protected.

Airborne levels of organic solvents in the breathing zone of the spray painters and in the area of the booth entrance and exit are reported in Table 8-3. These samples were taken in parallel with the particulate samples. Maximum

Table 8-3. Airborne levels of organic solvents in heavy equipment finishing.

		Concentration (mg/m^3)						
		Xylene		Tetramethyl benzene		Refined solvents		
	Number of samples	GM	GSD	GM	GSD	GM	GSD	C_E*
Painter A	6	3	1.3	<2	1.0	21	1.5	0.01
Painter B	6	5	1.3	<2	1.0	96	1.8	0.05
Booth Exits (area sample)	4	<0.5	1.0	<0.5	1.0	<6	--	<0.01
OSHA PEL		435		--		2,950		1
ACGIH TLV (1979)		435		--		1,350**		--
NIOSH Recommendation		435		--		350		--

GM: Geometric mean
GSD: Geometric standard deviation
**VM&P Naptha

*Combined Exposure: $$C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots \frac{C_n}{L_n}$$

where C is the concentration of the individual contaminant, and
L is the exposure limit.

combined solvent levels did not exceed more than 5 percent of currently allowable levels. For the same reasons cited earlier, solvent levels in the breathing zone of Painter B were approximately 5 times higher than Painter A.

The low concentration of paint mist and solvent vapors measured at the air seals is indicative of the degree of containment. That any contaminants were measured at all is due to the observed painting of some small parts within the air seal area itself.

DISCUSSION

Paint mist levels were well controlled despite the size and complex shape of the stack wagon and the high rate of paint delivery. The excellent control of total paint mist was due to the use of sophisticated application techniques, and a well designed spray booth suitably adapted to the painting of the stack wagon.

The use of heated paint allows the airless atomization to take place at relatively low paint pressures. This results in low droplet velocity with little rebound. The addition of the electrostatic charge to the hand guns further increases the efficiency of application.

Careful attention in design of the spray booth resulted in uniform air velocities throughout the booth. The use of man lifts avoided the exposure to paint mist seen in other case studies when tall objects were painted in downdraft booths. The fresh air-supplied painting pit provided excellent protection in underbody painting, a problem also noted in other case histories.

There is little room for improvement in the control of paint mist. Spray gun maintenance could be facilitated by use of a solvent purge or soak, and more frequent replacement of spray gun tips and charging wires. Although no commercial electrostatic pole guns are currently available, perhaps a handgun could be modified with an extension handle for painting wagon interiors.

Company blood lead data indicates that the present respiratory program is adequate. Nonetheless, a full facepiece style respirator is suggested for two reasons. First, it would provide protection of the eyes, absent in the present respirator. (The viewing window can be kept clear with plastic food wrap.) Second, it offers increased wearing comfort because the load is distributed over a larger facial area.

The substitution of a heavy metal free pigment for the lead chromate requires discussion. The lead chromate is used primarily for its color stability and low cost. An organic pigment may provide a good color match, but is liable to cost more. Company blood lead data would indicate that the painters are not at a significant risk due to lead, and that an immediate change to a lead-free material is not warranted. In light of proposed rule making on chromium, continued investigation of possible substitutes would be prudent.

CASE STUDY 9

METAL FURNITURE: CONVENTIONAL AND HIGH SOLIDS COATINGS

File cabinets and office partitions are finished with high-solids polyester or acrylic baking enamels in two separate plants. Both plants apply identical coatings in similar processes. Differences in product shape require different degrees of manual reinforcement and slight variations in application equipment. The appropriate selection of application equipment and spray booths result in low levels of paint spray mist and organic solvents with both product lines. Airless equipment was selected for painting the interiors of filing cabinets in a succesful attempt to reduce the bounce-back of paint overspray in that operation.

FILE CABINETS (Process "A")

PROCESS

Operations

Cases for file cabinets and associated sheet metal parts are finished on a high speed (22 fpm) conveyor line. Cases represent approximately two-thirds of the line finishing time.

Prior to finishing, the prefabricated sheet metal components are hung on an overhead conveyor system and routed through a 4-stage washer, a single stage rinse unit, and a 360°F dry-off oven. The four washer stages consist of two detergent/phosphatizing baths, followed by water and chromic acid rinses.

A 1.5 mil polyester or acrylic finish is applied in two coats (wet-on-wet) in a 4-step application process. These steps consist of manually spraying the case interiors and edges, applying two coats electrostatically (using reciprocators) to flat surfaces, and again manually spraying the edges and light areas. A layout of this finishing line is shown in Figure 9-1.

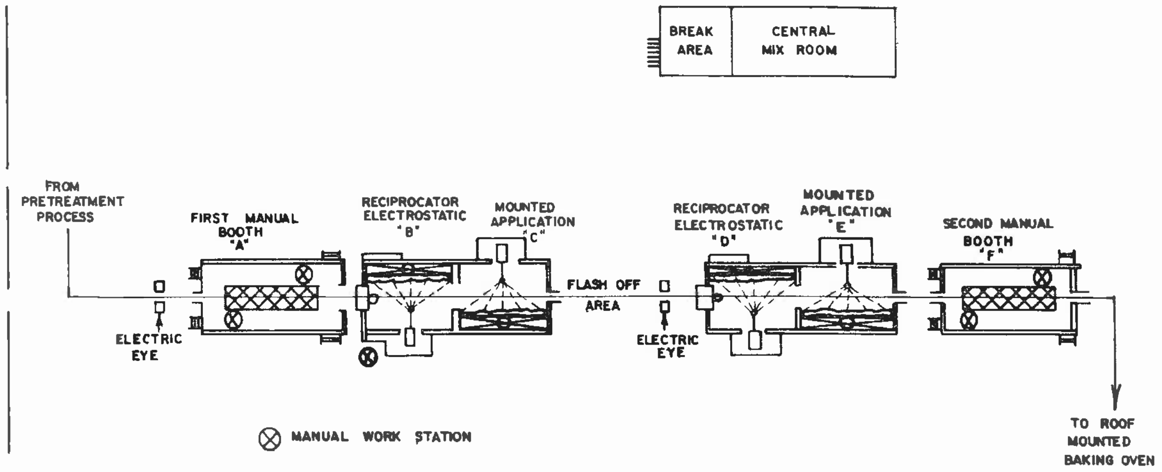


Figure 9-1. Process A layout.

The application process begins in a downdraft booth where one manual sprayer applies a gray reclaimed paint to the interiors of the file cabinet cases with an airless spray gun operating at 1,800 psi. The airless equipment was selected for use in this operation specifically for reduction of overspray.

A second painter stationed in this booth (on the opposite side of the conveyor) applies the exterior color to the edges and recesses with a conventional, air-atomized spray gun. When drawer dividers and other small flat pieces are to be painted, both operators use conventional air-atomized equipment. Compressed air guns for the booth are operated at an air-atomizing pressure of 60 psi, and a paint delivery pressure of 15 psi. Because of bleed-through of the gray interior paint on black exterior surfaces, the interiors for black cases are coated with black exterior paint. In this instance both finishes are applied with conventional air-atomizing equipment, however, air-atomizing pressure is reduced to 40 psi to lessen overspray.

Application of the first coat is completed in two successive sidedraft booths positioned on opposite sides of the conveyor. Each booth houses four electrostatic spray guns, mounted on reciprocators, applying the paint in a vertical plane. The first of these booths contains an additional reciprocator to coat (in a horizontal plane) the backs of the cabinets, while the second contains similar equipment to coat the top of each workpiece. The spray guns are operated with an air-atomizing pressure of 25 psi, a paint delivery pressure of 15 psi, and a voltage of 100,000 volts. An array of electronic eyes and associated logic circuitry identifies parts and schedules the painting sequence to minimize paint waste. A solvent purge system allows a 15 second color change.

Following a two minute flash-off period, the second finish coat is applied with automated equipment similar to that applying the first coat. One operator/mechanic is responsible for both sets of automated systems.

Two manual spray operators are stationed in a downdraft booth (similar to the first booth) to reinforce workpiece edges and touch up light areas. This is accomplished with conventional air-atomized equipment, operated at air pressures that are generally higher than the first stage of the process. Air pressures in this booth range from 65 psi for solid colors up to 80 psi for metallics.

The workpieces are then transported to roof-mounted curing ovens (for 8 to 9 minutes) operating at 375^{o}F.

Coatings

In order to meet environmental regulations, coating formulations are currently being switched from conventional thermosetting acrylic enamels to medium high-solids polyester baking finishes. Presently, the polyester finishes are being used in the three most common colors, and represent approximately 55 percent of the total paint applied on this line. These materials are 53 percent by weight paint solids, and are formulated from hydroxyl functional, saturated polyester resins, which are cross-linked with a melamine resin. The amount of cross-linking agent is not increased over that which is used in a conventional acrylic baking enamel, though relatively low molecular weight polyester resins are used to achieve fluidity at the high-solids content.

The conventional thermosetting acrylic enamels are formulated from hydroxyl functional acrylic resins, which are modified by the addition of alkyd resins, and cross-linked by urea and melamine resins.

Both finishes are pigmented with the same types of pigment materials; titanium dioxide, yellow and red iron oxides, and lamp and furnace blacks, are the most common. Both types employ the same solvents--n-butanol, xylene, an aromatic petroleum distillate, and butyl acetate--although the high-solids material contains less total solvent and a comparatively greater percentage of butyl acetate.

The high-solids material is formulated for application performance similar to conventional coatings. These performance parameters include no increase in air-atomization pressure, cure in 8 to 10 minutes at a peak oven temperature of 340°F, and dry to touch in 30 minutes at ambient conditions.

All colors of waste paint collected in the spray booths are combined with additional solvent to produce a gray-colored paint. This recycled paint is used to coat the interior of file cabinets and other unseen areas where protection, but not appearance, is required.

All colors of paint (except for the gray interior paint described above) are supplied directly to the spray guns from a central paint mix and storage room through circulating paint lines. The gray interior paint is supplied to a single airless spray gun by a 30:1 paint pump, and 55 gallon drum located directly outside of the spray booth where the coating system is applied.

HAZARD ANALYSIS

The principle hazard associated with the coatings used is a result of the volatile organic materials that they contain. These substances, chiefly xylene, butyl alcohol, and butyl acetate, are employed in the coating formulation as solvents. They can produce irritation of the skin, the conjunctiva, and the mucous membranes of the upper respiratory tract. Repeated or prolonged dermal contact with these finishes should be avoided because they can cause drying and defatting of the skin, which may lead to dermatitis. Acute exposure to xylene vapor may cause central nervous system depression and minor reversible effects upon the liver and kidneys. At high concentrations, xylene vapor can cause dizziness, staggering, drowsiness, and loss of consciousness. At very high concentrations, this substance can cause pulmonary edema, loss of appetite, nausea, vomiting, and abdominal pain.

The majority of the colors are natural or earthtone shades. However, a limited amount of reds and yellows are used and these colors contain lead chromate pigments. The other pigments that are used are essentially inert from a physiological standpoint. To date, no evidence of harm has been demonstrated by the thermosetting acrylic resin or baking enamel systems that are used. However, as a minimum, these materials should be controlled to below the maximum levels recommended for nuisance materials.

SPRAY BOOTHS

Manual Spray Booth Design

All manual spray operations are performed in one of two identical downdraft booths similar to the one shown in Figure 9-2. The exterior of each booth measures 21 feet wide by 17 feet long with an interior height of 10 feet. Filtered fresh air is supplied through the open top of the booths, and removed at the bottom through a water curtain by two exhaust fans mounted on the roof of the booth. Spray headers located in each exhaust air plenum clean paint

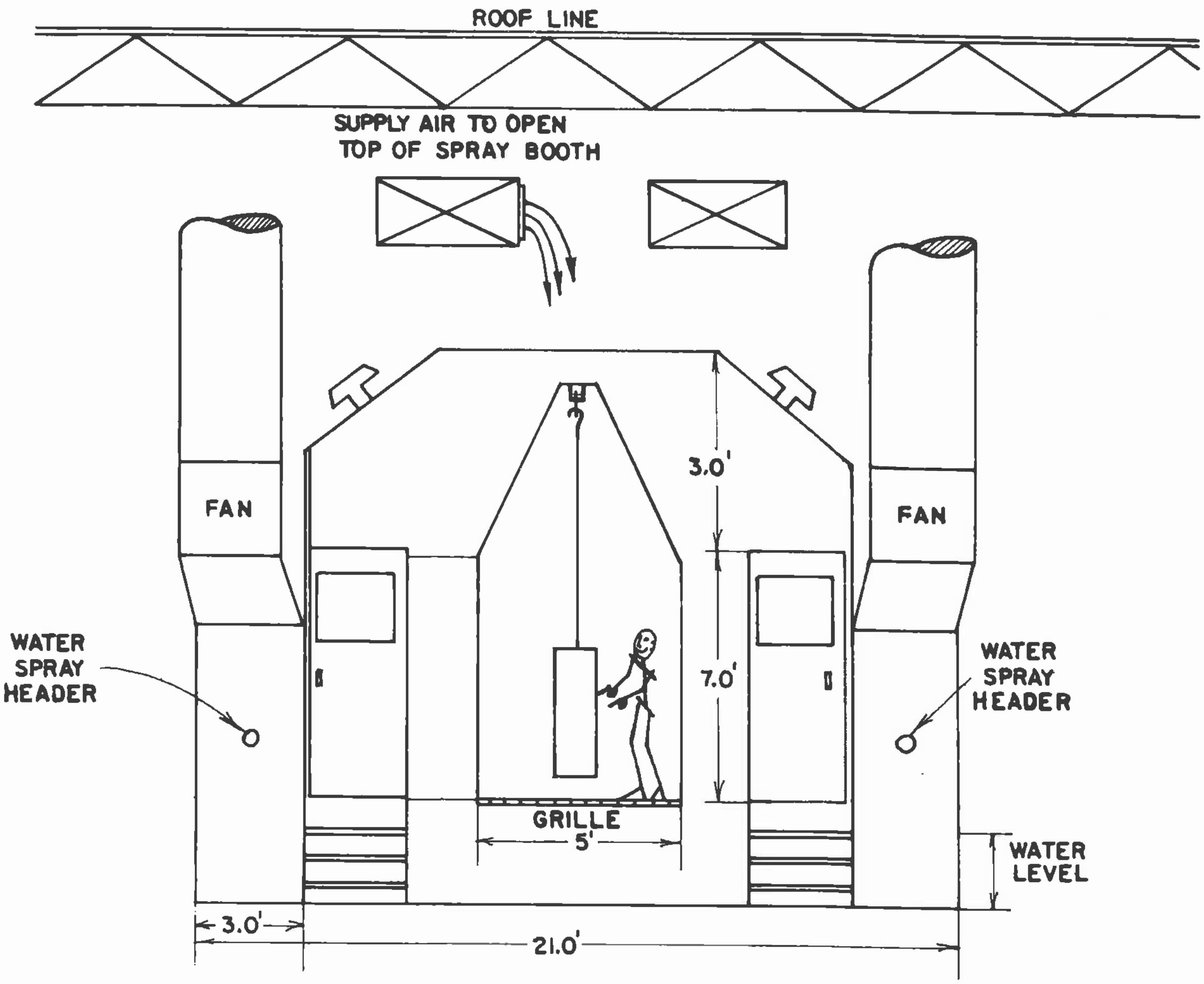


Figure 9-2. Manual spray booth.

mist from the exhaust air stream. The floor of each booth contains a 5 foot wide exhaust grate running its entire length. Parts to be coated enter and exit the booths through conveyor vestibules.

The first manual booth on this paint line was fitted with a prefilter to the water wash that was similar to the prefilter on the automatic spray booths. The prefilter assembly did not significantly affect the total airflow, but did reduce the average control velocity between 10 and 20 percent. This reduction was because of the filter assembly's adverse effect on the air distribution in the booth. The results of these measurements are presented in Table 9-1.

Table 9-1. Manual spray booth data (Process A).

Booth	Total airflow (cfm)	Average control velocity (fpm) 4' above grate	SD
Booth A			
(no filter)	27,000	100	55
(clean prefilter)	--	90	55
(dirty filter)	--	80	55
Booth F	30,500	100	37

Automatic Spray Booth Design

One of the four automatic spray booths for electrostatic application is shown in Figure 9-3. These identical sidedraft water wash booths measure 20 feet wide by 12 feet high. They are equipped with thick mesh filters, fitted over the water curtain to prefilter exhaust air. These filters are changed at the end of each workshift. The booths house four electrostatic spray guns mounted on reciprocators. An additional electrostatic spray gun is mounted just inside the conveyor entrance vestibule in order to coat the tops (in one instance) and bottoms (in the other instance) of the file cabinets.

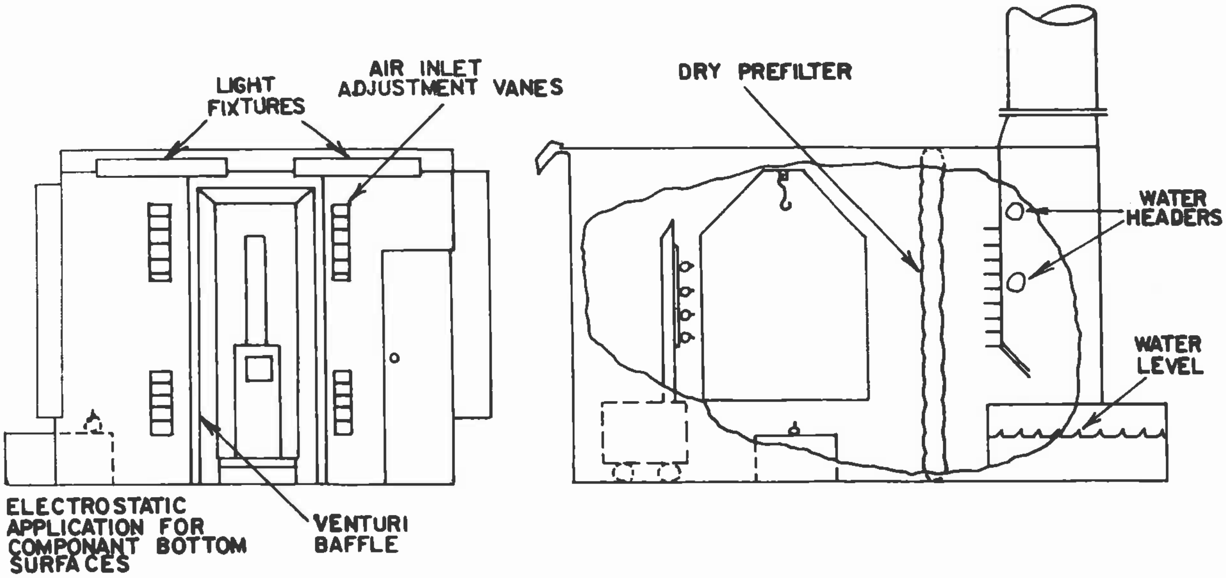


Figure 9-3. Automatic electrostatic spray booth.

The reciprocator opening, on the side of each booth, is fitted with a venturi baffle that surrounds the operating equipment. This was installed to increase the inlet velocity in the vicinity of the reciprocators. Two air inlet adjustment vanes are located on each side of the venturi baffle. These vanes permit adjustment of air velocity through the venturi, to reduce any adverse effects on the spray pattern of the application system. The differences in adjustments of these vanes may be a major contributing factor that affects the average control velocity data presented for Booths C and D in Table 9-2.

Table 9-2. Automatic electrostatic spray booth data (Process A).

		Average control velocity (fpm)			
Booth	Total airflow (cfm)	Conveyor vestibule	SD	Reciprocator ventilation	SD
C	5,400	31	21	90	32
D	11,200	71	39	61	23

Airflow Measurements

Total airflow was measured in both of the manual spray booths, and in two of the automatic booths. Control velocity in the manual booths was measured with a hot wire anemometer at 25 points in a horizontal plane at an elevation of 4 feet and the measurements were averaged.

EVALUATION

Four employees are potentially exposed to paint spray mist and organic solvents in this process: two spray painters in the first manual booth, and two spray painters in the finish, or second, manual booth. Potential sources for exposure include spray mist and solvent vapors from spraying, and solvent vapors evaporating from finished cabinets.

As an index of control, the 8-hour time-weighted average (TWA) concentrations of total spray mist, lead, chromium, and selected organic solvents were determined for the paint sprayers. The spray painters spend their entire workshift in the finishing department, excluding scheduled breaks and lunches. Area samples were collected to determine the degree of containment in the automatic spray booths. These samples were collected at the exit vestibule of the second automatic electrostatic booth, and at the entrance vestibule of the third automatic electrostatic booth. Area samples were also collected at the booth face (at the reciprocator venturi baffle) of these booths.

The 8-hour TWA concentrations were calculated from separate morning and afternoon samples over a three-day period. Samples of total spray mist were collected using closed-face cassettes with preweighed 37 mm polyvinyl chloride membrane filters and personal sampling pumps operated at 2.0 lpm. Organic solvent samples were collected on 150 mg charcoal tubes with personal pumps operated at 50 cc/min.

Organic solvents selected for analysis were based on the composition stated by the manufacturer and on qualitative analyses of selected charcoal tube samples by gas chromatography/mass spectroscopy. Major components identified were xylene and higher molecular weight aromatics, such as trimethyl benzenes, diethyl benzenes, dimethyl ethyl benzenes, tetramethyl benzenes, pentamethyl benzenes, ethyl trimethyl benzenes, and naphthalene. Minor components identified were toluene, n-butyl acetate, n-propyl benzene, methyl amyl ketone, butyl-Cellosolve, and Cellosolve acetate. No benzene was detected.

RESULTS

Results of air sampling for total paint mist, lead, and chromium are reported in Table 9-3. Mean concentrations of all contaminants are within the maximum levels allowed by OSHA and recommended by the ACGIH for an 8-hour exposure to total dust, lead, and chromium. A primary factor in the low levels of lead and chromium that were measured is the limited popularity of red and yellow colors in office-type furniture.

Organic solvent concentrations are reported in Table 9-4. Solvent levels are well below all recommended maximums. The highest concentrations were recorded at electrostatic Booth D. The elevated solvent levels measured at this booth were probably a result of an extensive manual cleanup with a xylene spray of the spray equipment in this booth.

Table 9-3. Airborne levels of total paint mist, lead, and chromium in metal furniture finishing (Process A).

Operation	Number of samples	8-hour time-weighted average concentration: Paint mist (mg/m^3) GM	Paint mist (mg/m^3) GSD	Lead (ug/m^3) GM	Lead (ug/m^3) GSD	Chromium (ug/m^3) GM	Chromium (ug/m^3) GSD
Manual prime booth							
Painter 1*	3	2.9	1.3	22	1.1	6.0	1.2
Painter 2	3	6.2	1.3	22	3.4	9.0	2.0
Manual finish booth							
Painter 3	3	4.0	1.4	19	1.6	6.0	1.2
Painter 4	3	4.2	1.1	26	1.6	6.0	1.6
Electrostatic booth B							
Face	3	0.1	1.7	5.0	1.0	5.0	1.0
Exit	3	0.1	1.6	9.0	2.0	4.0	1.3
Electrostatic booth C							
Face	3	0.3	2.0	5.0	1.0	5.0	1.0
Entrance	3	0.1	1.2	7.0	2.0	6.0	1.3
OSHA PEL		15		50		1,000	
ACGIH TLV (1979)		10		150		100	
NIOSH		--		100		1	

*Painter 1 uses airless for cabinet interiors, compressed air for other items; other manual painters use only compressed air guns.

GM: Geometric mean

GSD: Geometric standard deviation

Table 9-4. Airborne levels of organic solvents in metal furniture finishing (Process A).

		8-hour time-weighted average concentration (mg/m^3)										
	Number of	Xylene		Butyl acetate		Naphthalene		n-Butanol		Aromatic distillates		
Operation	samples	GM	GSD	GM	GSD	GM	GSD	GM	GSD	GM	GSD	C_E*
Manual prime booth	3											
Painter #1		22	1.3	3	1.3	0.7	1.1	2	1.5	30	1.0	.14
Painter #2		55	1.4	6	1.4	1.0	1.1	4	1.3	60	1.4	.31
Manual finish booth	3											
Painter #3		10	4.1	2	2.5	0.7	1.3	2	2.3	10	1.2	.07
Painter #4		24	1.1	4	1.0	0.7	1.1	2	2.0	5	1.1	.09
Electrostatic booth C												
Face	3	10	3.4	0.9	1.1	0.7	1.5	0.7	1.5	7	6.8	.06
Entrance	3	65	1.2	7	1.4	1.	1.8	4	1.3	80	1.2	.38
Electrostatic booth D												
Face	3	121	2.4	4	1.7	1.5	1.7	2	1.0	84	1.3	.51
Entrance	3	26	1.6	3	1.3	1.0	1.5	2	1.6	20	.32	
OSHA PEL		435		710		50		300		435**		1.0
ACGIH TLV (1979)		435		710		50		150		--		1.0
NIOSH		435		--		--		--		--		--

*Combined Exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \dots \frac{C_n}{L_n}$

where: C is the concentration of the individual contaminant, and
L is the environmental limit.

**By analogy with xylene

DISCUSSION

In various other processes during this study, it has been shown that application of a coating material to interior cavities contributes significantly to the mist and solvent exposure of spray painters. Visual observation of the airless techniques used at this plant indicated a marked reduction in bounce back of the overspray while painting the interiors of the file cabinets. These observations were confirmed by the sampling data (Note: the lower 8-hour time-weighted averages of paint mist for Painter 1 in Table 9-3).

The dry mesh prefilters that are fitted over the water curtain in the automatic electrostatic spray booths tended to load quickly; however, these filters are changed at the end of each workshift to reduce the possibility of overloading the exhaust systems. In addition, booth cleanup time and subsequent exposures are drastically reduced.

A similar prefilter system was installed in the first manual spray booth. This additional filter had an adverse effect of the airflow patterns in the booth, as shown in Table 9-1. The major effect was a 10 to 20 percent reduction of the control velocity at the painters breathing zone.

Part hangers which are free from accumulated paint deposits are essential for any form of electrostatic painting, in order to maintain grounding for the part being painted. These hangers are typically cleaned by immersion in a high temperature bath containing caustic soda, often requiring extended periods of soaking. This time consuming and hazardous process was eliminated in this plant by the installation of a burn-off oven followed by a high pressure washer.

OFFICE PARTITIONS (Process B)

PROCESS

Operations

Office partition panels and associated sheet metal parts are finish-coated on a high speed (26 fpm) conveyor line. The processes and operations in this plant have been in use for four years. Small sheet metal parts represent approximately 70 percent of the conveyor footage. Large, flat sheet metal panels that are either 3 by 6 feet or 4 by 6 feet represent the remaining 30 percent.

All components that are to be finish-coated are hung on the overhead conveyor and are transported through a totally enclosed 4-stage metal pretreatment process: a detergent phosphatizing bath, water rinse, chromic acid rinse, and a final water rinse. They are then routed through a roof-mounted flash-off oven, operating at 400°F.

A 1.0 mil, high-solids, polyester baking enamel or acrylic finish is applied to the component parts. This is accomplished by a 2-coat (wet-on-wet), 4-step application process (Figure 9-4). The first coat is applied by air-atomized electrostatic spray guns mounted on reciprocators, followed by a manual touch-up operation also using air-atomized electrostatic guns. Application of the second coat is by a process similar to that of the first coat.

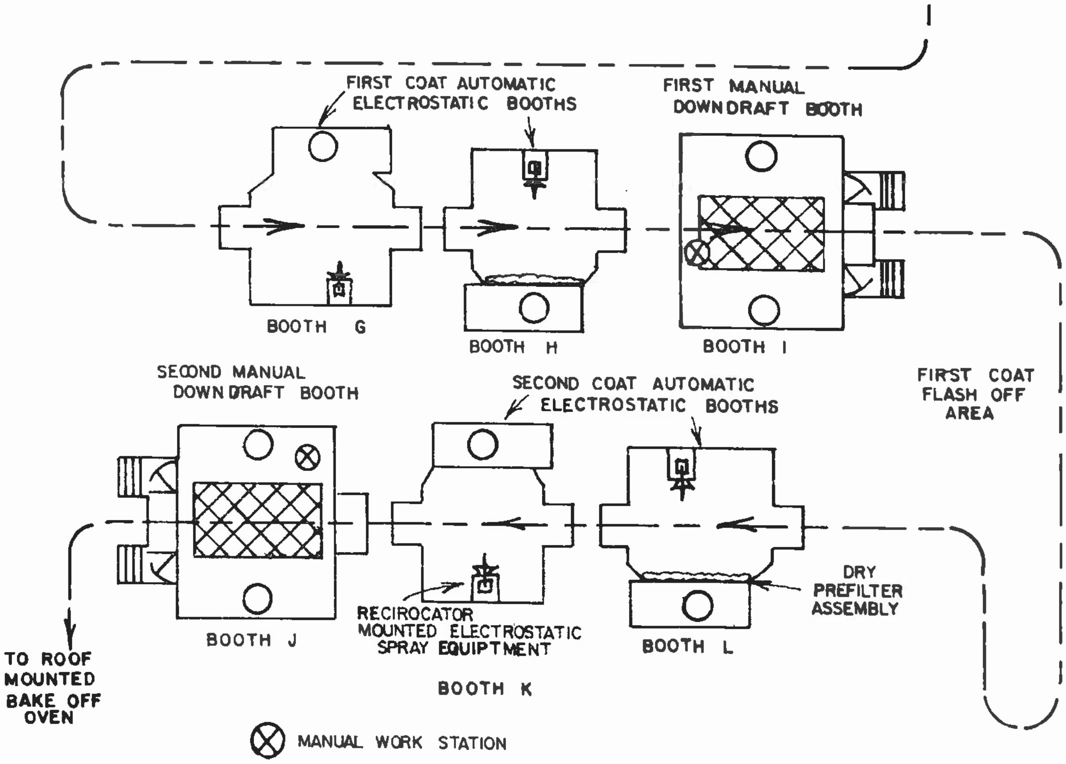


Figure 9-4. Process B layout.

The automatic stages of the process are accomplished by air-atomized, electrostatic spray guns mounted on reciprocators. Each reciprocator is equipped with six guns and is housed in an individual sidedraft water-wash spray booth. The reciprocators are installed as pairs and located on opposite sides of the conveyor system in each stage, thus eliminating the need to rotate component parts during paint application. The electrostatic spray guns operate at 90,000 volts, with an air-atomizing pressure of 25 to 30 psi. Individual coating systems are supplied to the guns from a central mix room under a pressure of 15 to 20 psi. At the entrance to each pair of spray booths is an array of electric eyes and a logic device that controls operation of the reciprocators.

The manual steps of the process consist of individual downdraft water-wash spray booths. One person is stationed inside these booths to touch up and assure adequate coating on non-uniform component surfaces. Much less manual spraying is required in this operation than in Process A because of the simpler product shape. Manual spraying is accomplished by electrostatic spray equipment operating with an air-atomizing pressure of 95 psi, and a paint pressure of 60 psi.

One operator/mechanic tends each of the operating reciprocator systems. The responsibilities include continuous visual inspection for paint and solvent line leaks, and appropriate scheduled or unscheduled maintenance.

The component parts are then routed through a roof-mounted curing oven that is operated at 350°F. Both (flash-off after pretreatment and curing) oven temperatures are automatically monitored at a station located in the paint shop supervisor's office.

Coatings

The coating materials used in this plant are the same as those previously described in Process A of this case study. Specifically, thermosetting acrylic resins and medium high-solids polyester baking enamels are used in colors that are common to the file cabinet plant so that finishes on the various components of metal office furniture will match.

SPRAY BOOTHS

Manual Spray Booth Design

All manual spray operations are performed in one of two identical spray booths identified as Booths I and J in Figure 9-4. These booths are similar in design to the booths of Process A, with the following exceptions: centrifugal, rather than duct fans, are used and the fans are mounted on the building roof, rather than on the booth. This change creates a noticeable difference in noise inside the booth. These fans are driven by a 15 hp motor and are rated at 12,000 cfm. Two pumps are required in each of the booths to power the water wash. These pumps are rated at 5 hp and 350 gpm.

Automatic Spray Booth Design

The automatic electrostatic spray booths in this plant resemble those of Process A. These booths are identified as Booths G, H, K, and L in Figure 9-4.

Each booth is equipped with a single centrifugal fan. The fans are rated at 10 hp and 10,670 cfm . The water curtain of the booths is provided by a 5 hp pump, which is rated at 350 gpm. Each of the automatic electrostatic spray booths is fitted with a thick mesh prefilter assembly that is similar to those booths in Process A of this case study.

Airflow Measurements

Total airflow was measured in both of the manual booths and in two of the four automatic electrostatic booths used in this process. Air velocity was measured in the manual booths with a hot wire anemometer at 25 points in a horizontal plane at an elevation of 4 feet and the measurements were averaged. Inlet air velocities were also measured at the reciprocator venturi and at the conveyor inlet vestibule of the automatic electrostatic booths. The results of these measurements are reported in Tables 9-5 and 9-6.

Table 9-5. Manual spray booth data (Process B).

Booth	Total airflow (cfm)	Average velocity (fpm) 4' above grate	SD
I	20,800	80	60
Vestibule indraft		20 to 80	
J	20,700	80	65
Vestibule indraft		10 to 75	

Table 9-6. Automatic electrostatic spray booth data (Process B).

Booth	Total airflow (cfm)	Velocity at reciprocator venturi (fpm)	SD
H	8,300	60	16
L	10,200	25	18

EVALUATION

Two employees are potentially exposed to organic solvents or paint mists in this process: one spray painter in each of the manual spray booths. Potential sources for exposure include paint mist and solvent vapors from spraying and solvent vapors evaporating from finished panels.

Eight-hour time-weighted average (TWA) concentrations of total spray mist and selected organic solvents were determined for the paint sprayers. This was accomplished to provide an index of control. The spray painters spend their entire workshift in the finishing area, excluding scheduled breaks and lunches. Area samples were collected at the entrance vestibule of automatic electrostatic Booth H and at the exit vestibule of automatic electrostatic Booth K. Area samples were also collected at the face of these booths (reciprocator inlet venturi baffle). These area samples were collected to document the performance of the booths.

The 8-hour TWA concentrations were calculated from separate morning and afternoon samples that were collected over a two-day period. Sampling procedures were identical to those used in Process A except that no qualitative analyses were performed.

RESULTS

As reported in Table 9-7, the 8-hour TWA concentrations of total particulates for the manual spray painters was less than both legal and current recommended maximums. These low levels were to be expected because each manual booth has only one painter per shift. The responsibilities of these painters is primarily a touch-up function to cover light areas, and the majority of surfaces to be coated are large flat pieces. Therefore, there is no overspray from opposed spraying and little bounce-back of paint mist from irregular surfaces. These facts, combined with the excellence of booth design, work practices, and maintenance, are primary reasons for the low mist levels.

One of the automatic electrostatic booths did exhibit a high level of particulate at the exit vestibule (Table 9-7). This is probably attributed to a misaligned spray head on one of the reciprocators in that booth. Visual observations of the process did not indicate this as a problem area. The physical size of the workroom and distance of manual work stations also do not indicate that this situation is a potential exposure area.

Airborne levels of organic solvents in the breathing zone of the spray painters and in the face and entrance or exit vestibules of the automatic electrostatic booths are reported in Table 9-8. These samples were taken in parallel to the particulate samples. Maximum combined solvent levels were well below current allowable airborne concentrations.

Table 9-7. Airborne levels of spray mist, lead, and chromium in metal furniture finishing (Process B).

		8-hour time-weighted average concentration					
		Paint mist (mg/m^3)		Lead (ug/m^3)		Chromium (ug/m^3)	
Operation	Number of samples	GM	GSD	GM	GSD	GM	GSD
Manual prime booth							
Painter 1	2	0.5	1.2	5.0	1.0	5.0	1.0
Manual finish booth							
Painter 2	2	0.9	2.2	5.0	1.0	5.0	1.0
Electrostatic booth H							
Face	2	0.2	2.7	5.0	1.0	5.0	1.0
Entrance	2	4.0	2.0	2.3	3.0	7.0	2.0
Electrostatic booth K							
Face	2	0.2	2.2	5.0	1.0	5.0	1.0
Exit	2	17.8	1.2	6.0	1.3	5.0	1.0
OSHA PEL		15		50		1,000	
ACGIH TLV (1979)		10		150		100	
NIOSH		--		100		1	

GM: Geometric mean
GSD: Geometric standard deviation

Table 9-8. Airborne levels of organic solvents in metal furniture finishing (Process B).

Operation	Number of samples	8-hour time-weighted average concentration (mg/m^3)										C_E*
		Xylene		Butyl acetate		Naphthalene		n-Butanol		Aromatic distillate		
		GM	GSD	GM	GSD	GM	GSD	GM	GSD	GM	GSD	
Manual prime booth												
Painter 1	2	6	1.3	0.8	1.3	<1	1.1	<1	1.6	30	1.6	.10
Manual finish booth												
Painter 2	2	10	1.3	1	2.7	<1	1.0	1	1.6	30	1.6	.11
Electrostatic booth H												
Entrance	2	2	2.8	3	4.0	1	4.0	2	2.1	40	2.7	.18
Electrostatic booth K												
Face	2	7	1.1	1	1.1	<1	1.1	1	1.2	45	8.3	.13
Exit	2	68	1.1	24	1.6	7	1.2	11	1.2	200	1.1	.83
OSHA PEL		435		710		50		300		435**		1.0
ACGIH TLV (1979)		435		710		50		150		--		1.0
NIOSH		435		--		--		--		--		-

*Combined Exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots \frac{C_n}{L_n}$

where: C is the concentration of the individual contaminant, and
L is the environmental limit.

**By analogy with xylene

DISCUSSION

Although this process is far removed from the physical location of Process A of this case study, it is operated under the same corporate management, with similar safety and health direction. This process is much newer than Process A; it has been in production only four years.

The air exhaust fans for each spray booth are located on the roof of the facility. This differs from Process A where the fans were mounted inside the plant building. The roof-mounted fans provided a noticeable reduction in the noise level inside the booths, with the system exhaust equipment operating.

Medium high-solids polyester paints require exceptional housekeeping techniques because they do not readily air dry. At this facility high traffic areas are covered with tar paper in order to prevent the spreading of semi-dried material throughout the rest of the plant. In order to be most effective, the paper must be changed at frequent invervals. All of the tar paper was neatly trimmed and secured in place with tape, to prevent safety hazards associated with tripping and falling.

CASE STUDY 10

PAINT STORAGE AND MIXING

Work practices and equipment that minimize solvent evaporation are employed together with dilution ventilation in order to limit the exposure of paint room attendants to organic solvent vapors.

PROCESS

Operations

Approximately 750 gallons of paint are mixed and delivered each shift to the paint booths in this plant, which produces components for metal office furniture. The paint mixing and storage room is manned by two attendants. The senior attendant is responsible for inventory control, and for mixing and thinning raw paint to application viscosity. The other attendant assists him in these duties and, in addition, is responsible for clean-up details.

The 5,000 square foot room is organized into storage areas for paint and empty drums, solvents, and paint mixing tanks as shown in Figure 10-1. Because not

Figure 10-1. Paint mixing and storage room.

all colors are equally popular, some paints are stored in 350-gallon bulk containers, others in 5-gallon buckets, and the majority in 55-gallon drums. Nine 80-gallon paint containers and seventeen 55-gallon drums are continuously agitated, and the paint is pumped to the spray guns and returned back to the container. All but one of the drums is equipped with a heavy barrel cover, with an integral agitator, sealed pipe openings, and a closable access door. This cover is pictured in Figure 10-2. The larger paint containers have a similar arrangement. The single paint drum without this feature uses the clamp-on agitator and partially closed drum lid shown in Figure 10-3.

Coatings

Typical paint formulations in this plant required thinning with 10 to 15 gallons of additional solvent per drum of raw paint. Xylene and an aromatic petroleum distillate are the most commonly used solvents in this operation. These materials are stored in remote tanks and pumped to the mix room. Those solvents used less frequently are stored in drums equipped with spigots. All solvents are transported within the mix room in 5-gallon containers.

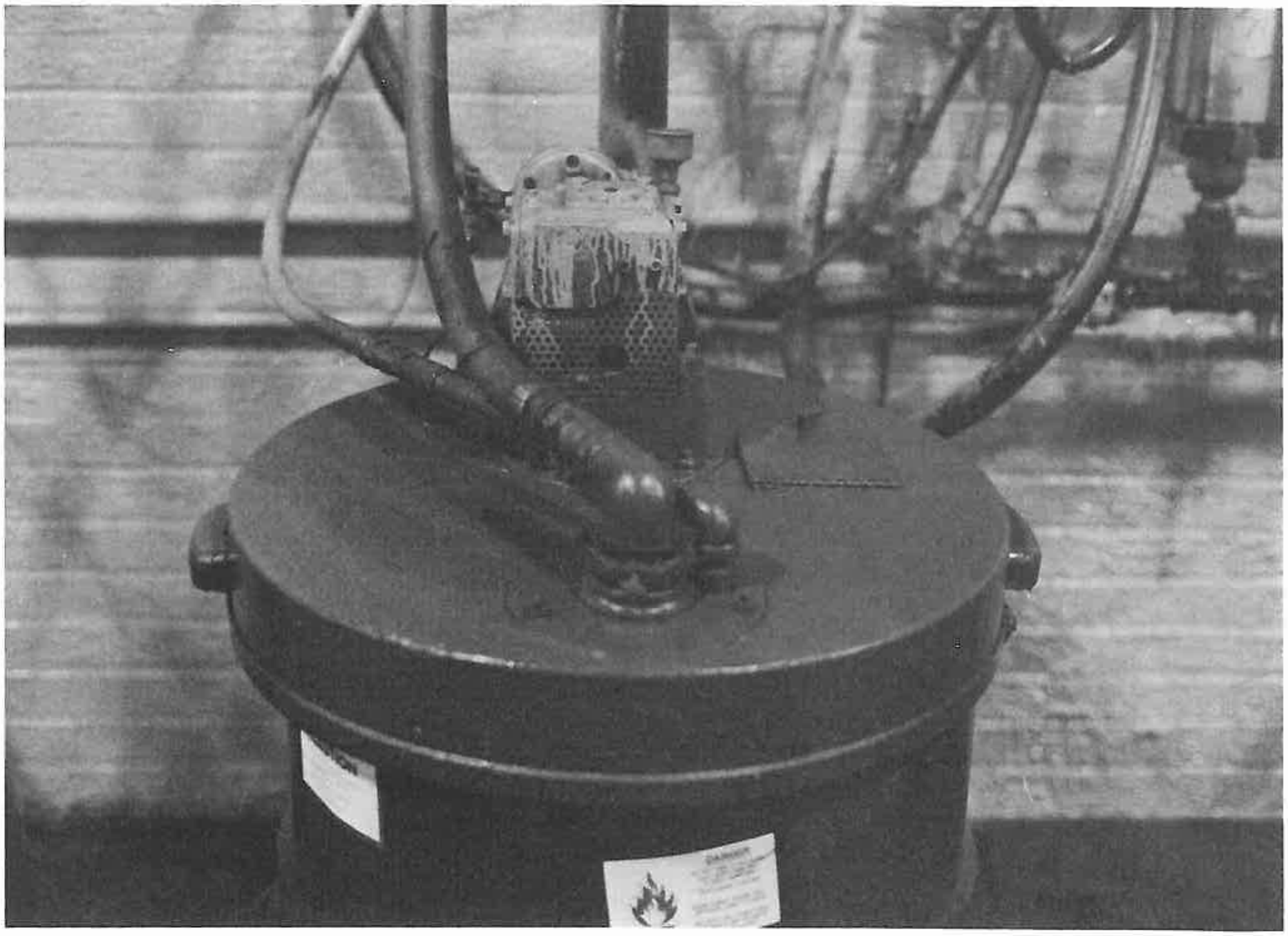


Figure 10-2. Paint mixing drum with integral cover and agitator.

Figure 10-3. Paint mixing drum with loose fitting lid and clamp-on agitator.

HAZARD ANALYSIS

The principal hazard to which the paint room attendants are exposed is from the inhalation of organic solvents. The solvents come from two sources: rapid evaporation during filling and pouring, and slow evaporation from paint containers, spills, and leaks. Xylene and an aromatic petroleum distillate are the main constituents of the short exposures during pouring operations. These materials, together with other solvents in the raw paint formulations, n-butanol and butyl acetate, contribute to the background concentration. All of these solvents exhibit similar physiological effects. They are irritants to the conjunctiva and to the mucous membranes of the upper respiratory tract. They all produce depression of the central nervous system and, at high concentrations, produce symptoms of headache, nausea, and drowsiness, followed by unconsciousness.

VENTILATION

A dilution ventilation system introduces fresh air through registers located in a plenum that runs directly below the ceiling. Six exhaust grilles are located along the opposite wall at floor level, providing an effective sweep of fresh air across the room.

PROTECTIVE EQUIPMENT

The protective equipment used includes uniforms, safety glasses, and rubber gloves. Half-facepiece respirators, with organic vapor cartridges, were available. Respirator use was limited to the mop-up operation, using methyl chloroform.

WORK PRACTICES

Because many sources of potential solvent evaporation are present, the mix room attendents have considerable responsibility for the maintenance of low background concentrations of organic solvents. Safety cans are used below solvent spigots as shown in Figure 10-4 to catch any paint drippage and lessen the subsequent evaporation. Paint spills are quickly cleaned up and the smooth con-

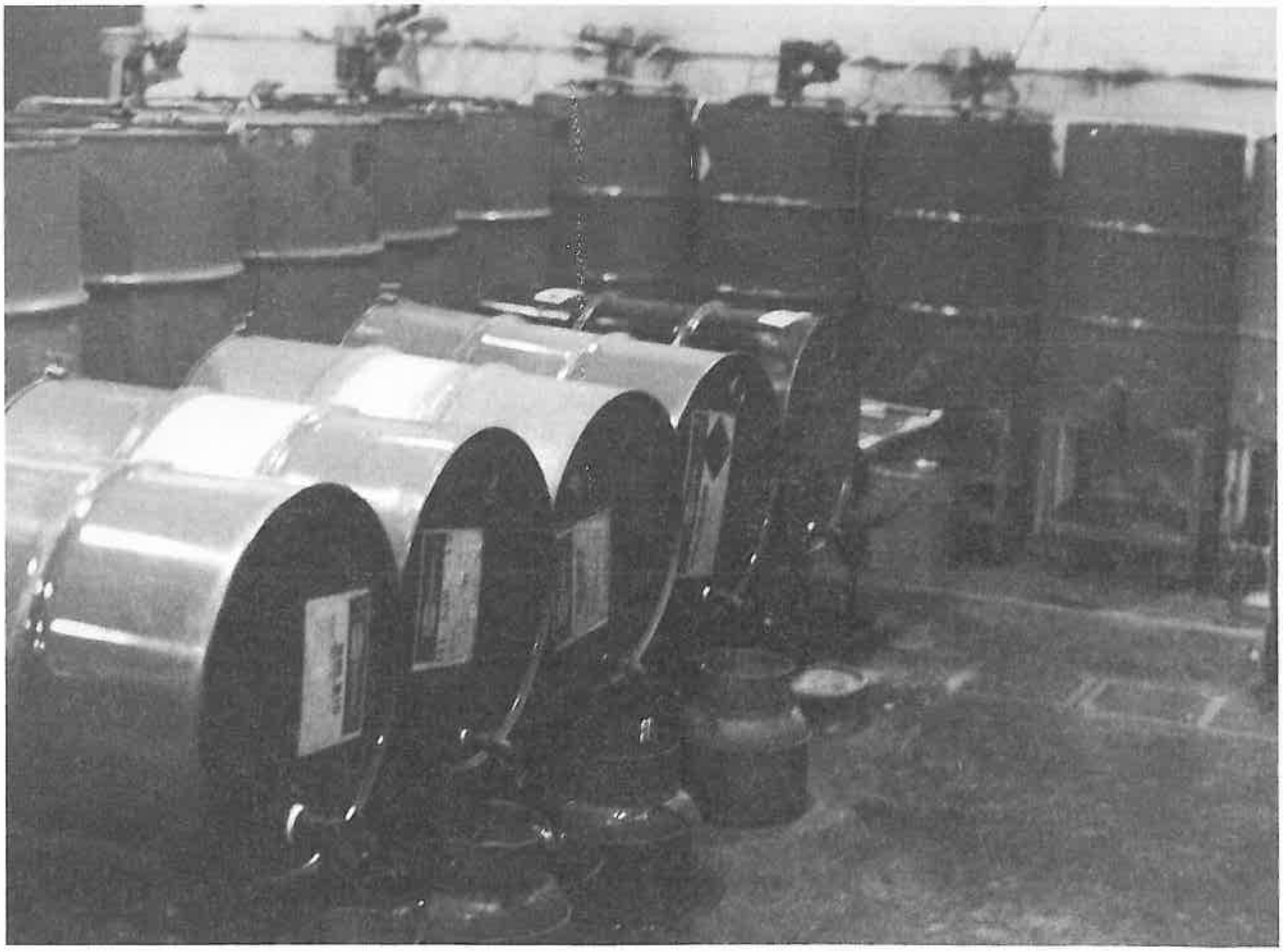


Figure 10-4. Solvent dispensing area.

crete floor is washed down periodically with methyl chloroform in order to remove any paint residue. Spill cleanup is facilitated by a sewer grate running the length of the paint mix tank area. Methyl chloroform was selected because of its low flammability and high solvency. Considerable attention is paid to keep access ports on mix containers closed, and to replace all lids and bungs on empty drums. Housekeeping is assisted by roller conveyors for both paint and empty drum storage.

EVALUATION

Because a majority of the operations involve sporadic rather than continuous exposure, a combustible gas meter was used in order to determine approximate solvent levels during short duration operations, such as pail filling and solvent addition, and in order to evaluate the significance of various solvent sources.

Eight-hour time-weighted average (TWA) breathing zone and background concentrations were determined using 150 mg charcoal tubes and portable personal sampling pumps operated at 50 cc/min. Following desorption with carbon disulfide, the resultant solution was analyzed by gas chromatography for n-butanol, butyl acetate, xylene, and petroleum distillates.

RESULTS

The exposure of mix room attendants can be characterized as a continuous low exposure to solvents evaporating from multiple small sources, punctuated by brief, higher exposures from various manual operations. Combustible gas indicator measurements of solvent levels are reported in Table 10-1. Results of full shift sampling are reported in Table 10-2.

Combustible gas indicator measurements of methyl chloroform concentrations are reported in Table 10-3. The values reported were obtained by multiplying meter readings by a factory-specified correction factor.

Table 10-1. Solvent levels for selected paint mix room operations as measured by a combustible gas indicator.

Concentration (ppm)	Location
10 to 20	Center of mix room
25	One ft above 55-gal paint drum, with integral agitator and top cover
75	One ft above 55-gal paint drum, with clamp on agitator and loose fitting lid
100	Directly above floor drain
40	Breathing zone above four 5-gal solvent pails
10	Directly above solvent spigots with safety cans
30 to 40	Breathing zone during filling of 5-gal pails with xylene
30 to 50	Breathing zone while adding solvent to paint mix tanks

Table 10-2. Mix room solvent concentrations - (8-hr time-weighted average values).

	Concentration (mg/m^3)					
Sample	Xylene	n-Butyl acetate	Naphthalene	n-butanol	Aromatic distillate	C_E*
Senior attendant	12	1	<0.5	13	30	0.15
Attendant	22	2	<0.5	12	20	0.15
Center of room	38	4	<0.7	15	80	0.34
OSHA PEL	435	710	50	300	435	1.0
ACGIH TLV (1979)	435	710	50	150	--	1.0
NIOSH	435	--	--	--	--	--

*Combined exposure: $C_E = \frac{C_1}{L_1} + \frac{C_2}{L_2} + \ldots \frac{C_n}{L_n}$

where C is the concentration of the individual contaminant, and
L is the environmental limit

**By analogy with xylene

Table 10-3. Methyl chloroform concentrations using a combustible gas meter.

Methyl Chloroform (ppm)	Location
90 to 180	Breathing zone of sweeper
450	Directly over bucket
675 to 900	"Cleaned" area, 30 ft from sweeper
3,000 to 4,500	Directly over drain grate
350	OSHA PEL (8-hr TWA)
350	ACGIH TLV (1979 8-hr TWA)
350	NIOSH (15 min ceiling)

DISCUSSION

The data in Table 10-1 indicate that the integral agitator with top cover is far more effective in preventing solvent evaporation than a clamp-on agitator and loose fitting lid. The safety cans appeared to be an effective means of preventing solvent evaporation from dripping spigots. As might be expected, areas where solvent was exposed to the air (floor drains and open pails) showed the highest airborne solvent levels. Open floor drains require construction with a steep slope, and frequent cleaning in order to prevent pooling and subsequent evaporation of solvent.

Cleanup of paint spills requires the use of a solvent for easy removal. Mop-up operations, using hydrocarbon solvent, could produce a fire hazard, thereby, methyl chloroform was selected because it is nonflammable and is only moderately toxic. Prospective users are cautioned, however, that high concentrations are rapidly disabling. The NIOSH Pocket Guide lists the concentration of 1,1,1 trichloroethane (methyl chloroform) immediately hazardous to life as 1,000 ppm.

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