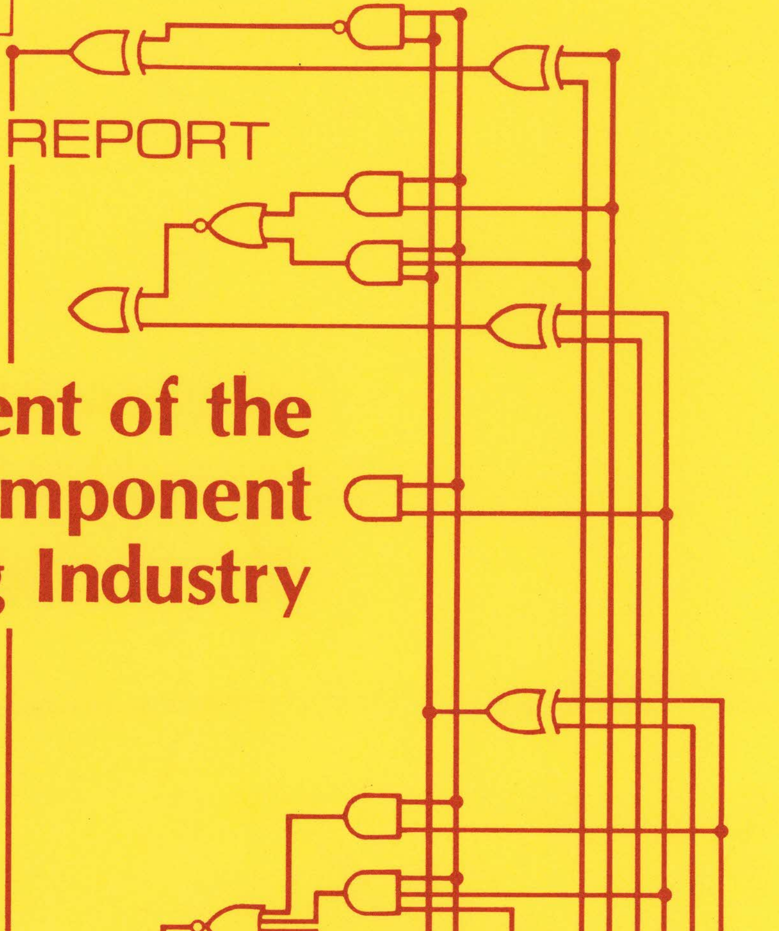
NIOSH

TECHNICAL REPORT

Hazard Assessment of the Electronic Component Manufacturing Industry



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

Hazard Assessment of the Electronic Component Manufacturing Industry

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Research Triangle Park, NC

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Division of Surveillance, Hazard Evaluations, and Field Studies
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ABSTRACT

The scope of the contract was to identify and estimate worker exposure to potentially hazardous chemical and physical agents used to manufacture electronic components. The manufacturing processes studied included those described by the Standard Industrial Classification (SIC) numbers 3671 (receiving electron tubes), 3672 (cathode ray television picture tubes), 3673 (transmitting electron tubes), 3674 (semiconductors and related devices), 3675 (electronic capacitors), and 3676 (electronic resistors).

The hazard assessment encompassed three interrelated tasks: tripartite meetings, literature reviews, and industrial hygiene walk-through surveys. Representatives from the industry, labor, and government were invited to one of two duplicate tripartite meetings held in New York, New York, on November 5, 1980, and San Francisco, California, on November 7, 1980. The purpose of these meetings was to describe the nature, scope and mechanisms of the NIOSH hazard assessment, solicit information and cooperation from the participants, and obtain a preliminary assessment of the participants' views.

A review of the relevant published and unpublished literature from computerized files, reference documents, periodicals, and organizations (industry, trade organizations, unions, government, insurance companies, and academic) provided the basis for an industry profile, process characterization, recommendations of manufacturing facilities for walk-through surveys, and discussion of the chemical agents, physical agents, and ergonomic stresses associated with the process operations. Overall, information is scarce in the published literature specifically related to the occupational health environment in the electronic component manufacturing industry. Efforts should be concentrated on developing a more comprehensive data base on the chemical agents, physical agents, and ergonomic stresses encountered in the manufacture of electronic components.

Industrial hygiene walk-through surveys were conducted at 15 manufacturing facilities. Eight of the surveyed facilities manufactured semiconductors, three manufactured electron tubes, two manufactured capacitors, and the remaining two manufactured resistors. The industrial hygiene surveys provided an overview of the variety of process operations, process intervals, process engineering controls, and health and safety programs instituted industry-wide.

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ACKNOWLEDGMENTS

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Section 1

BACKGROUND

Research Triangle Institute (RTI) conducted a health hazard assessment of the electronic component manufacturing industry, as described by the Office of Management and Budget Standard Industrial Classification Manual, industry numbers 3671 through 3676 under contract to the National Institute for Occupational Safety and Health (NIOSH). Appendix A contains a process/product breakdown for each of these SIC codes.

RTI broadly identified potentially hazardous agents used to manufacture electronic components. Specifically, the contract work was divided into two phases. The first phase involved two Tripartite meetings and a literature search, and the second phase entailed industrial hygiene surveys of 15 representative electronic component manufacturing facilities. Larger electronic component manufacturing facilities were selected for the majority of the walk-through surveys in order to obtain a broad view of the safety and health program instituted in the industry. The walk-through survey sites were not representative of all manufacturing operations even though several low production and small manufacturing facilities were surveyed.

NIOSH is performing preliminary research to identify potential hazards in the electronic components manufacturing industry. Justification for this hazard assessment is based on the large industry workforce; special requests for this research from the California Occupational Safety and Health Administration (OSHA) and special public interest groups; use by the industry of a large number of toxic materials and novel processes; and the lack of pertinent published information that identifies industry health and safety hazards.

The general approach of the hazard assessment was to prepare a brief process overview of the major product lines and identify the types and uses of materials. The industry needed to be described by product outputs; number of employees, potential health hazards, and methods of control needed to be identified; and carefully chosen walk-through surveys of selected facilities needed to be conducted to supplement other information sources. The study was not intended to include sampling, measurements, medical or epidemiological investigations, or any other original research.

This report emphasizes the results of the literature review and the walk-through surveys of 15 electronic component manufacturing facilities. The report contains descriptions of the processes and materials used to manufacture electron tubes, semiconductors, capacitors, and resistors; the methodology used to select the recommended facility operations and locations for the walk-through surveys; industry profile of worker populations data and growth potential; and a general discussion of the literature and survey results with recommendations for further research.

Section 2

SCOPE OF WORK

The hazard assessment is the first step in the NIOSH process of evaluating the occupational environment of industry operations. This type of investigation is based on health and process data collected from the entire industry, including trade organizations, labor groups, and management. Tripartite meetings with industry, government, and trade unions followed by a literature review and facility surveys provided the information required to perform the assessment.

RTI began work on the hazard assessment of the electronic component manufacturing industry in September 1980. The contract award was based on a 2,700-person-hours, 12-month work plan. Among the contract tasks stated in the scope of work were Tripartite reviews on the east coast and west coast, a literature search, and walk-through industrial hygiene surveys.

Representatives from industry, trade associations, government, unions, academia, insurance companies, and occupational safety and health organizations were invited to one of two duplicate Tripartite meetings held in New York, New York, on November 5, 1980, and San Francisco, California, on November 7, 1980. The purpose of these meetings was to describe the nature, scope, and mechanisms of a NIOSH hazard assessment, and to solicit information and cooperation from the participants. A summary of the major points of discussion and a list of participants was prepared for each meeting.

Relevant literature was collected from published sources (computerized files, reference documents, and periodicals) and unpublished sources (industry, union, government, and insurance files) in the following areas.

- Product output and production forecasts
- Types and amounts of raw material used in process operations
- Trade name data sheets
- Facility descriptions (including the number of production workers per process operation and shift and health and safety programs instituted)
- Toxicological, industrial hygiene, environmental, and occupational health studies
- Health assessment data

This report discusses the information collected from the various data sources.

Industrial hygiene walk-through surveys were conducted at 15 facilities that manufacture electronic components. The facilities were geographically distributed over the U.S. to provide a diverse view of the industry in terms of size, products, and health and safety programs instituted. These facilities did not provide a statistically representative distribution of the industry; however, they were selected to obtain the maximum amount of health hazard information possible within the contract limits.

Section 3

INDUSTRY PROFILE

3.1 WORKER POPULATION

Table 3-1 contains the industry worker population for 1979 to 1981. As of July 1981, approximately 179,400 production workers were employed in the United States at facilities that manufacture electronic components and accessories (SIC 3671 to 3678). The largest group, 95,500 workers, was involved in the manufacture of discrete semiconductor components and integrated circuits (SIC code 3674). The second largest group, 57,000 workers, was employed in the production of capacitors, resistors, coils, and connectors (SIC codes 3675 to 3678). The smallest group, an estimated 26,900 workers, was involved in the manufacture of electron tubes (SIC codes 3671 to 3673).[1 5]

3.2 FACILITY AND PRODUCT DATA

In the United States, an estimated 108 companies with 545 plant locations produce semiconductor devices. Twenty or more workers are employed at 219 of the 545 plant locations.[2] The 1977 value of semiconductor products produced in the United States was $6.1 billion, and the value of industry sales has grown about 100 percent since that time (1981 projected data).[3]

Table 3-2 gives the number of companies producing each type of semiconductor. The majority of the establishments manufacturing semiconductors are located in five states: California (181 establishments), New York (59 establishments), Massachusetts (45 establishments), New Jersey (36 establishments), and Texas (35 establishments). Sixty percent of all production workers are employed in these five states. Other major production areas include Pennsylvania (30 plant locations), Florida (20 plant locations), Arizona (16 plant locations), Connecticut (13 plant locations), and Ohio (13 plant locations). The remaining states have a total of 99 plant locations.[4] Table 3-3 shows the company size distribution by total employment for manufacturers of semiconductors and related devices. Table 3-4 is a tabulation of world discrete market share estimates for some of the larger manufacturers.

In the United States, approximately 143 establishments produce electron tubes; 57 of these plant locations employ more than 20 people. California, New Jersey, and New York have 31, 13, and 12 plant locations, respectively. The remaining states have a total of 87 plant locations. Table 3-5 shows the number of companies producing various types of electron tubes in the United States.

A total of 116 establishments produce capacitors for electronic applications; 97 of these plant locations have more than 20 employees. California, which has 26 establishments, has the greatest number of plant locations. Forty plants are located in the states along the eastern seaboard from South Carolina to Connecticut. Approximately 5,000 production employees (the largest number in one state) work in South Carolina. Illinois has nine plant locations, and the remaining states have a total of 43 plant locations.[2] Table 3-6 shows the number of U.S. companies that manufacture several important capacitor types. Table 3-7 gives information on the size of capacitor producers based on total employment.

Resistors are manufactured for electronic applications at a total of 99 establishments; 79 of these plants employ more than 20 people.[2] Table 3-8 lists the number of companies producing some important resistor types. The states with the largest number of plant locations include Pennsylvania (11 plants), New Jersey (9 plants), Indiana (9 plants), Massachusetts (7 plants), New Hampshire (5 plants), and Texas (3 plants). The remaining states have a combined total of 55 plant locations, with more production workers in Indiana (3,000 workers) and Pennsylvania (2,300 workers) than in any other individual state.[4] Table 3-9 presents the employment size distribution of resistor manufacturers.

The semiconductor industry has the largest product output in terms of value—$5.29 billion in product sales. Product sales for the other SIC segments in the assessment are $1.57 billion for electron tubes, $730.1 million for capacitors, and $573.5 million for resistors.

3.3 PROJECTIONS

Semiconductor device consumption will probably continue to grow for many years. The projected growth rate in dollar amount of sales for the semiconductor industry is 20 percent per annum for the next 3 to 5 years.[3] However, this increase does not imply that the number of production workers in the U.S. semiconductor industry will grow at an equal rate. Many U.S. based companies locate their labor intensive operations in foreign countries. Concomitantly advances are being made in automation techniques for semiconductor device manufacturing. Table 3-10 indicates the annual growth rates of various semiconductor devices.

The impetus for these two changes is tremendous. First, approximately 30 percent of the manufacturing cost for semiconductor devices is attributable to direct labor costs.[3] Second, the semiconductor industry is a relatively young industry, and automation has only recently received much emphasis. Advances in the automation of semiconductor processing will depend on sensor capabilities to monitor operations. The potential for increased automation in the other industrial categories is equally large.

Discrete semiconductor device production has increased greatly over the last few years, and projections for the next several years show significant growth in the industry. Figures 3-1 and 3-2 contain data on past and current production levels and industry projections. An important trend in the semiconductor industry is the movement in production from discrete components to integrated circuits. This trend will almost certainly continue to decrease the total market share of discrete semiconductor devices, but discrete production levels are not likely to decrease in the near future. Figure 3-3 contains data on past and current levels and trends in discrete semiconductor and integrated circuit production.

Projections for the electron tube industry (SIC 3671 to 3673) indicate that production will continue its relative decline as semiconductors (SIC 3674) continue to expand their capabilities. The expanding segments of this industry are cathode ray display tubes and high-power/high-frequency tubes, such as magnetrons and klystrons, for which there are no available semiconductor replacements. The demand for these tube types is expected to continue. Table 3-11 shows the 1972 and 1977 product shipments for several important electron tube devices for which data are available. Table 3-12 contains data on cathode ray tube sales and projections through 1983.

A few years ago, growth in the capacitor (SIC 3675) and resistor (SIC 3676) industries was predicted to mirror that of the semiconductor industry; over the last few years, this prediction has been correct. However, fewer capacitors and resistors will be needed in electronic systems built with integrated circuits. Table 3-13 shows capacitor sales over the past 10 years, and Table 3-14 makes growth predictions for various capacitor devices through 1983. Table 3-15 provides data on growth and projected growth in several important electronic resistor categories.

In summary, the major growth in the electronic components industry will be in the semiconductor industry and most of this growth will involve integrated circuits. The number of production workers in the semiconductor industry is likely to increase more slowly than the predicted economic and production growth rate because of foreign assembly and advances in automation. Electron tube production will stabilize as the decreases in low power and receiving tubes are offset by increases in demand for cathode ray, high-power/high-frequency, and camera tubes. The manufacture of discrete components, both passive and active, should also stabilize.

Another factor affecting the U.S. electronics industry is international competition, especially from Japan. Given Japan's penchant for political and financial catalysis of industrial expansion and their commitment to low cost, high quality products, they may gain a large share of the world market.

3.4 REFERENCES

1. Employment and Earnings. U.S. Department of Labor, Bureau of Labor Statistics, *28*(7), July 1981.
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3. Eklund, M. H. and W. I. Strass (eds). Status '80—A Report on the Integrated Circuit Industry. Integrated Circuit Engineering Corporation, Scottsdale, Arizona, 1980.
4. 1977 Census of Manufactures. U.S. Department of Commerce, Bureau of the Census, 1977.
5. Employment and Earnings, United States, 1909 to 1978. U.S. Department of Labor, Bureau of Labor Statistics, Bulletin 1312-11, 1979.

TABLE 3-1. WORKER POPULATION DATA[1, 5]

	Standard Industrial Classification (SIC) code		
Production workers by year	3671 to 3673	3674	3675 to 3678
1978			
Number of workers x 1,000	28.0	76.0	49.0
Percent	18.3	49.7	32.0
1979			
Number of workers x 1,000	28.2	90.4	59.9
Percent	15.8	50.6	33.6
1980			
Number of workers x 1,000	26.6	100.6	58.5
Percent	14.3	54.2	31.5
1981[a]			
Number of workers x 1,000	26.9	95.5	57.0
Percent	15.0	53.2	31.8

[a] July 1981, Bureau of Labor Statistics data.

TABLE 3-2. NUMBER OF COMPANIES PRODUCING VARIOUS SEMICONDUCTORS[2] AND THE QUANTITY OF SHIPMENTS OF EACH TYPE

Product	Number of companies
Integrated microcircuits (semiconductor networks)	
As reported in Census of Manufactures—1977 data	108
As reported in Current Industrial Reports MA-36N, selected electronic and associated products, including telephone and telegraph apparatus—1977 data	101
Hybrid integrated circuits	
Thick film (composed of material deposited by silk screen process on a passive substrate combined with discrete active or passive components)	46
Thin film (composed of material deposited by vacuum deposition, sputtering, or similar process on a passive substrate combined with discrete active or passive components)	24
Multichip (circuits not incorporating film techniques; these are usually combinations of chips, active and/or passive; discrete package devices may be used for some, but not all of the circuits)	16
Monolithic digital integrated circuits	
Bipolar	
DTL (diode transistor logic), excluding microprocessors	10
TTL (transistor transistor logic), excluding microprocessors	18
CML/ECL (current mode logic/emitter coupled logic), excluding microprocessors	7
I^2L (integrated injector logic), excluding microprocessors	4
Microprocessors	6
Other bipolar digital integrated circuits, including diode logic, complementary transistor logic, resistor transistor logic, and direct couple transistor logic	10
Metal oxide silicon (MOS)	
Microprocessors	16
MOS memories	21
Other MOS devices	19
Monolithic analog integrated circuits	22
Transistors	
As reported in Census of Manfactures—1977 data	48
As reported in Current Industrial Reports MA-36N, selected electronic and associated products, including telephone and telegraph apparatus—1977 data	37
Signal (less than 1 watt dissipation)	23
Power (1 watt or more dissipation)	23

Diodes and rectifiers	
As reported in Census of Manfactures	61
As reported in Current Industrial Reports MA-36N, selected electronic and associated products, including telephone and telegraph apparatus	41
Signal diodes and assemblies thereof (maximum current 0.5 amps)	13
Semiconductor rectifier/power diodes and assemblies thereof (current rating greater than 0.5 amps)	28
Selenium rectifier	7
Microwave diodes (mixers, detectors, varactors, parametric, and harmonic generators)	17
Zener diodes (voltage regulator and voltage reference diodes)	23
Semiconductor devices (not elsewhere classified) and parts for semiconductors	
As reported in Census of Manufactures	112
As reported in Current Industrial Reports MA-36N, selected electronic and associated products, including telephone and telegraph apparatus	118
Light sensitive and light emitting devices	
Solar cells	7
Light emitting diodes (LED)	8
Other	22
Other semiconductor devices	
Thyristors (SCR's, triacs, PNPN diodes)	14
All other semiconductor devices	15
Semiconductor parts	
Semiconductor devices and circuits—chips (DICE) and wafers (DISCS)	26
All other semiconductor parts (headers, packages, heat sinks, and other accessories)	75

TABLE 3-3. COMPANY SIZE DISTRIBUTION BY TOTAL EMPLOYMENT FOR SEMICONDUCTORS AND RELATED DEVICES[2]

Average employee range	Number of companies
1-4	191
5-9	75
10-19	80
20-49	48
50-99	40
100-249	59
250-499	31
500-999	19
1,000-2,499	10
2,500 or more	12
TOTAL	545

TABLE 3-4. WORLD DISCRETE MARKET SHARE ESTIMATES[2]
($ million)

Company	Year			
	1976	1977	1978	1979
Motorola	290	315	31	419
Philips	220	234	266	290
Texas Instruments	234	227	242	260
Toshiba	146	152	212	242
Siemens	120	135	186	206
Hitachi	147	152	206	284
Nippon	161	182	219	195
Matsushita	137	132	168	134
General Electric	107	109	111	126
RCA	91	98	113	124
Fairchild	103	99	105	116
AEG Telefunken	43	71	88	107
Others	1,107	1,253	1,357	1,567
TOTAL MARKET	2,906	3,159	3,624	3,990

TABLE 3-5. NUMBER OF COMPANIES PRODUCING ELECTRON TUBES IN SHIPMENTS OF AT LEAST $100,000[2]

Product	Number of companies
Black and white television picture tubes	
New	2
Rebuilt	18
Color television picture tubes	
New	
Up to 17-inch	4
18- and 19-inch	5
20-inch or greater	5
Rebuilt	25
Receiving tubes, except cathode ray tubes	6
High vacuum tubes	18
Gas and vapor tubes	15
Klystrons	12
Magnetrons	13
Traveling wave tubes	23

TABLE 3-6. NUMBER OF COMPANIES MANUFACTURING CAPACITORS IN THE UNITED STATES[2]

Type of capacitor	Number of companies
Paper dielectric	
Metal case	20
Nonmetal case	8
Film dielectric, metal and nonmetal case	30
Metalized dielectric	
Metal case	11
Nonmetal case	11
Dual dielectric, metal and nonmetal case	23
Tantalum electrolytic	
Slug and wire solid dry electrolytic	
Metal case, hermetic	6
Metal case, nonhermetic	7
Nonmetal case	11
Foil and wet slug electrolytic	8
Aluminum electrolytic	
Metal case tubular	
Standard (6/8-inch diameter)	9
Standard (under 5/8-inch diameter)	8
All others	9
Mica dielectric, fixed	9
Ceramic dielectric	
Fixed tubular, disc, plate, stand-off tubular and disk, and all two-thermal ceramic devices	9
Monolithic	
Chips	19
Leaded-radial	22
Leaded-axial	14
Other	5
All other fixed	8
Variable air dielectric, mica, ceramic, and glass dielectric	16

TABLE 3-7. SIZE OF CAPACITOR PRODUCERS BASED ON TOTAL EMPLOYMENT[2]

Average employee range	Number of establishments
1-4	7
5-9	3
10-19	11
20-49	20
50-99	11
100-249	32
250-499	15
500-999	16
1,000-2,499	2
2,500 or more	1

TABLE 3-8. NUMBER OF COMPANIES PRODUCING EACH RESISTOR TYPE[2]

Type of resistor	Number of companies
Fixed	
Composition	12
Deposited carbon	17
Evaporated metal film and other metal oxide, metal/glass, or metal/ceramic element	32
Variable, nonwire-wound	
Single turn, carbon and other file, nonprecision	9
Single turn, precision and nonprecision	17
Trimmers (industrial and military grade)	
Square and round	10
Rectangular	7
Fixed, wire-wound	
Nonprecision (fixed and adjustable) over 1 percent	14
Precision, unsealed	6
Precision, encapsulated and miniature, 3 percent or under	18
Variable, wire-wound	
Nonprecision, single turn (wiper or shaft traverses 360° or less)	11
Precision single turn, linear (0.5 percent linearity or less), and nonlinear (1 percent linearity or less)	17
Trimmers (industrial and military grade)	9
Miscellaneous	
Varactors	7
Thermistors, bead type, disc, rod	12
Multiturn, all types, wire-wound and nonwirewound	12
Fixed resistor networks	15

TABLE 3-9. RESISTOR MANUFACTURERS BY EMPLOYMENT RANGE CLASSIFICATION[2]

Average employee range	Number of companies
1-4	9
5-9	6
10-19	6
20-49	17
50-99	16
100-249	18
250-499	15
500-999	11
1,000-2,499	2

TABLE 3-10. SALES OF SEMICONDUCTOR DEVICES[2]
($ million)

Product	Year				Annual growth (%)
	1978	1979	1980	1983 (projected)	
Total semiconductors	3,937.6	5,061.7	6360.5	11,074	18.9
Discrete semiconductors	1,035.6	1,137.1	1,202.2	1,523	7.1
Diodes	370.2	398.2	421.9	548	6.8
Transistors (includes bipolar, MOSFET, and junction FET)	533.9	606.6	640.4	788	7.8
Signal transistors	251.0	269.3	283.3	321	5.2
Thyristors	114.5	115.0	122.4	162	9.0
Integrated circuits	2,694.5	3,684.1	4,876.3	9,121	22.3
Standard logic facilities (includes RTL, DTL, TTL, ECL, and C-MOS)	813.1	1,011.0	1,192.8	1,784	15.3
Microprocessors and microcomputers (includes CPU's, one-chip microcomputers and LSI peripheral chips)	210.9	330.8	532.4	1,506	31.9
Dedicated LSI circuits	95.5	155.0	210.5	595	31.1
Memories (includes random-access read-only, CCD's, magnetic-bubble devices, and shift registers)	850.3	1,289.7	1,922.2	3,560	27.4
Linear integrated circuits	594.7	681.1	746.4	1,158	11.1
Consumer product integrated circuits	130.0	216.5	272.0	518	25.4
Optoelectronic devices (includes photovoltaic cells, photoconductive cells, LED's, laser diodes, photodiodes, phototransistors, and optically coupled isolators)	207.5	240.5	282.0	430	13.3

TABLE 3-11. ELECTRON TUBE MANUFACTURERS AND PRODUCT SHIPMENTS[2]

Product	1972 product shipments Quantity (millions)	1972 product shipments Value ($ million)	1977 product shipments Quantity (millions)	1977 product shipments Value ($ million)
Receiving tubes, except cathode ray				
As reported in the Census of Manufactures—1977 data	N/A	189.6	N/A	104.0
As reported in Current Industrial Reports MA-36N, selected electronic and associated products, including telephone and telegraph apparatus—1977 data	162.2	182.0	60.9	104.6
Power and special tubes—As reported in 1977 Census of Manufactures				
High-vacuum tubes	4.86	75.5	2.11	73.7
Gas and vapor tubes	3.97	32.3	8.47	33.7
Klystrons	0.12	44.3	N/A	48.1
Magnetrons	0.17	35.5	0.19	52.9
Traveling wave tubes	0.02	68.6	0.02	90.3

N/A=not available.

TABLE 3-12. CATHODE RAY TUBE SALES[2]

Type of cathode ray tube	Sales by year ($ million) 1978	1979	1980	1983 (projected)	Annual growth (%)
Television					
Black and white	30.5	30.5	29.0	18.0	-13.3
Color	680.0	762.0	807.7	953.0	5.2
Cathode ray tube (except television)	45.5	47.3	49.2	58.0	4.6

TABLE 3-13. CAPACITOR SALES FROM 1970 THROUGH 1979[2]

Type of capacitor	Year									
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Millions of units										
Paper and film	542	570	496	666	591	396	474	582	662	621
Tantalum	285	272	364	564	610	353	526	637	786	899
Aluminum	204	208	234	312	296	149	195	201	202	205
Mica	173	173	208	278	254	135	164	201		
Ceramic	1,376	1,757	2,113	2,646	2,180	1,659	2,822	3,451	3,614	4,371
Other fixed	49	49	63	79	63	37	62	49	198[a]	7
Variable	50	55	71	103	57	53	62	57	61	53
TOTAL	2,678	3,084	3,609	4,648	4,032	2,781	4,305	5,179	5,523	6,156
Millions of dollars										
Paper and film	185	153	104	138	139	94	129	160	205	214
Tantalum	101	81	91	135	162	108	132	156	188	262
Aluminum	82	77	88	118	137	83	111	128	151	185
Mica	20	22	22	31	34	22	24	24	30	
Ceramic	75	82	106	154	173	139	185	241	289	352
Other fixed	9	7	9	11	13	11	12	13	43	12
Variable	12	12	19	27	19	14	16	16	20	26
TOTAL	483	435	438	612	676	470	608	744	897	1,050

[a] Includes mica.

TABLE 3-14. FORECAST FOR CAPACITOR SALES[2]
($ million)

Type of capacitor	Quantities 1980	 1983 (projected)	Annual growth (x)
Electrolytic	200.0	220	5.7
Tantalum	177.8	215	5.6
Paper	90.4	98	2.4
Film	115.0	123	0.8
Ceramic (except chip)	364.4	509	13.1
Ceramic chip	50.3	78	15.1
Mica	NA	36	1.4
Variable dielectric	29.0	34	5.3
Glass and porcelain	5.2	4	-7.2

NA=Data not available.

TABLE 3-15. INDUSTRY-WIDE CONSUMPTION OF RESISTORS SHIPPED BY U.S. AND FOREIGN MANUFACTURERS FOR THE U.S. MARKET[2] ($ million)

Type of resistor	1978	1979	1980	1983 (projected)	Annual growth (%)
Fixed (total)	218.5	229.4	229.1	258	3.0
Carbon composition	60.0	62.3	62.6	63	0.3
Deposited carbon	21.5	23.1	22.0	26	3.0
Metal-film	75.0	79.0	81.0	99	5.8
Wire-wound	62.0	65.0	63.5	70	1.9
Variable (total)	239.5	267.2	272.0	318	4.4
Potentiometers, wire-wound	38.5	43.0	43.0	50	3.8
Potentiometers, nonwire-wound	98.5	109.7	109	130	4.3
Trimmers, wire-wound	22.5	24.5	25.5	28	3.4
Trimmers, nonwire-wound	80.0	90.0	94.5	110	5.1
Resistive networks (total)	149.0	177.6	198.2	269	10.9
Thin-film	69.0	79.0	88.0	114	9.6
Thick-film	80.0	98.6	110.2	155	12.0

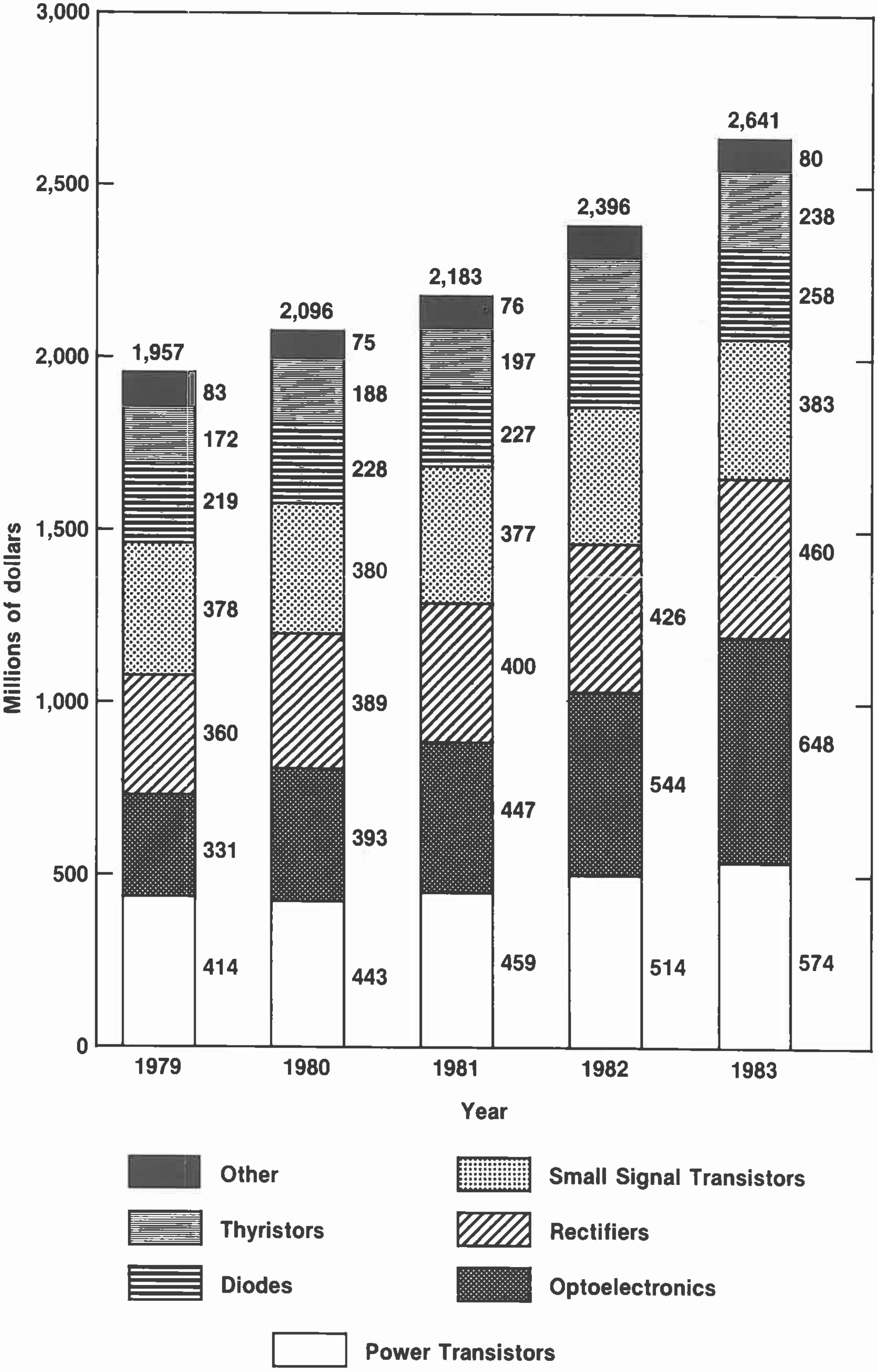

Figure 3-1. Worldwide discrete semiconductor shipments by U.S. companies ($ million).[2]

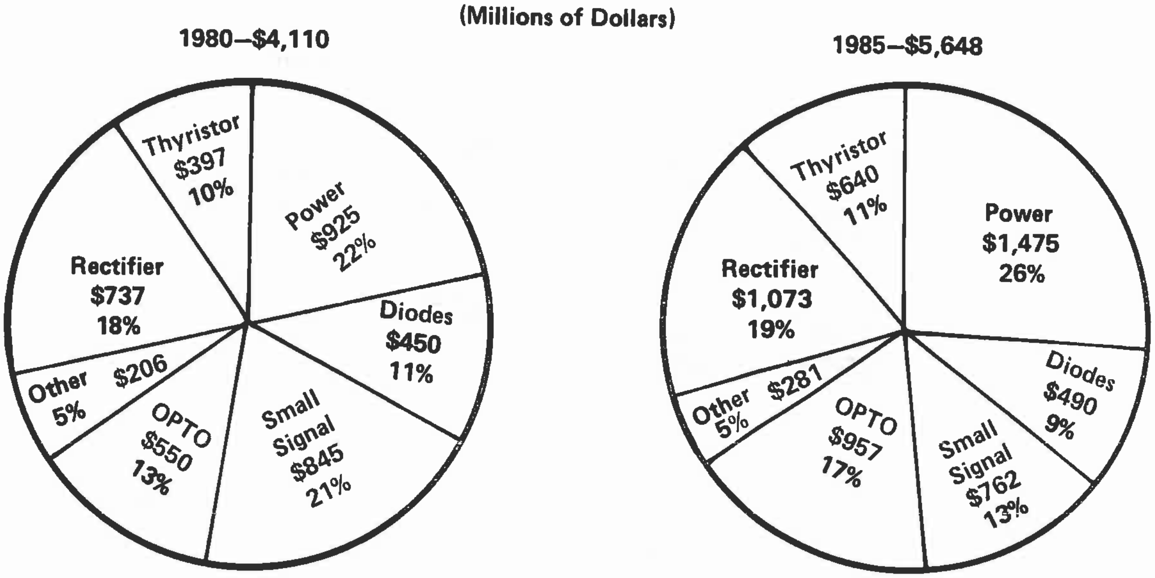

Figure 3-2. World discrete semiconductor market for worldwide suppliers ($ million).[2]

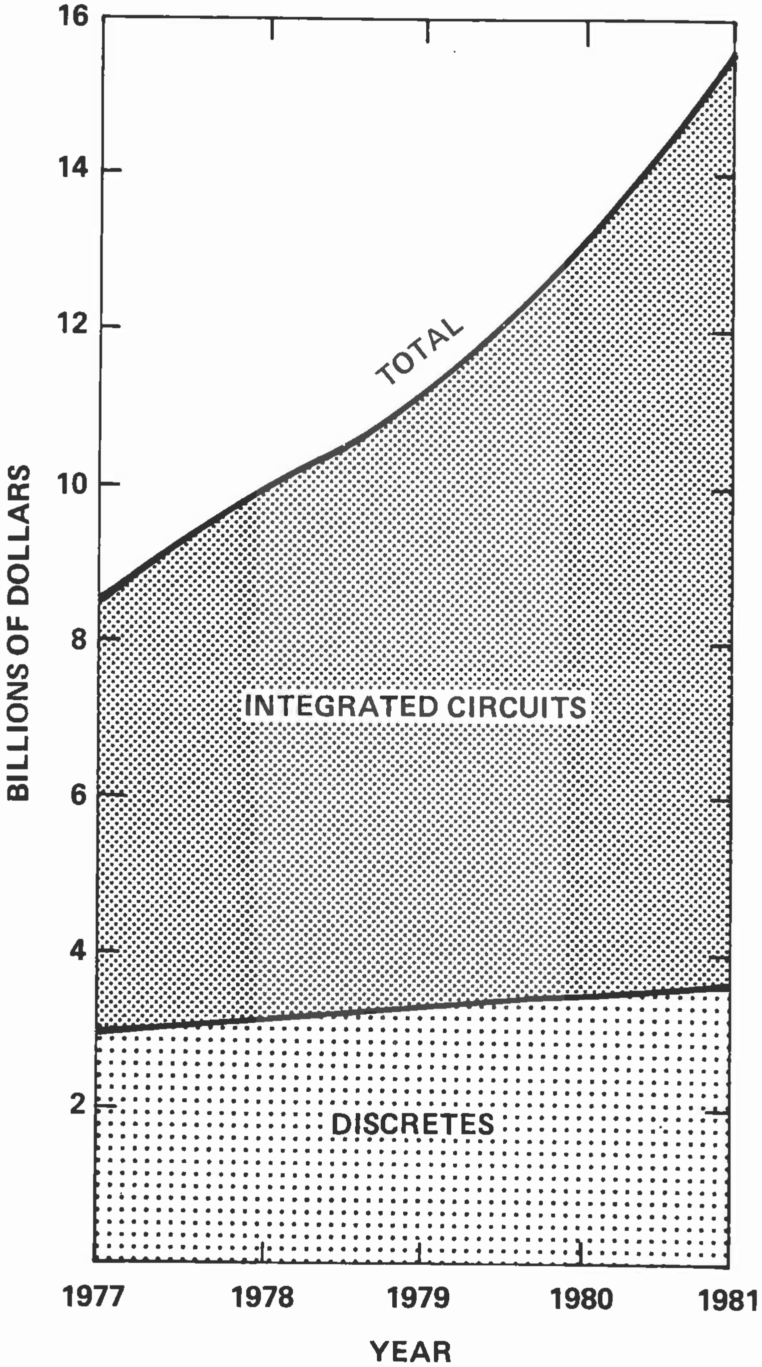

Figure 3-3. World total semiconductor production.[2]

SECTION 4

PROCESS DESCRIPTIONS AND MATERIALS

The following section provides a general description of the process technologies used to manufacture electron tubes, semiconductors, capacitors, and resistors, with specific reference to materials used in the process operations. General process flow diagrams are presented for electron tube, semiconductor, capacitor, and resistor manufacturing operations. The major chemicals used to manufacture electron tubes, semiconductors, capacitors, and resistors are listed in this section along with their process operation and/or application.

Process and material information is presented on only those manufacturing operations observed in the walk-through surveys or uncovered in the literature review. The process descriptions and materials are not meant to be inclusive of all manufacturing operations but rather are meant to represent basic operations and common materials used or generated as a byproduct throughout the industry. More detailed information on the process materials and operations may be obtained from the referenced literature and from the process description in the walk-through survey reports contained in Appendix F.

4.1 ELECTRON TUBE MANUFACTURING

An electron tube consists of an airtight envelope in which electrons flow between electrodes. In the operation of electron tubes, the emission of electrons from an electrode is caused by raising the surface energy of certain elements and compounds by heat, light photons, or the kinetic energy of bombarding particles. The movements of the emitted electrons are directed and controlled by electric and magnetic fields. Figure 4-1 provides a list of common materials used in electron tube manufacturing operations and their process applications.

4.1.1 Fabrication—Cathodes, Electrodes, and Other Parts

The fabrication processes for receiving, power, and microwave electron tubes are quite similar from a technique and materials standpoint (see Figures 4-2 and 4-3). Intricately punched, formed, and shaped copper, nickel, iron, and steel parts are cleaned and conditioned in a strong acid solution. Hydrochloric, hydrofluoric, sulfuric, and nitric acids are commonly used. Some of the metal parts are electroplated with highly conductive elements such as copper, chromium, nickel, gold, and silver. For some tube types, the usual iron or nickel cathode is coated with a getter material which absorbs gas molecules when it is heated or vaporized. Common getter materials include magnesium and barium oxides, tantalum, magnesium, barium, and calcium.

4.1.2 Face Plates of Display Tubes

A display tube consists of four major parts—the glass panel, the steel aperture mask, the glass funnel, and the electron gun assembly. The glass panel or facepiece is the front of the display tube, i.e., the viewing screen. Directly behind the panel is the steel aperture mask which is a steel screen with equally spaced holes through which materials such as photoresists and phosphors are applied. The photoresist solutions are also exposed to light through these holes in the aperture mask to give a desired pattern. The glass funnel extends backward from the panel to an apex at the electron gun mount. The electron guns generate the signal that excites the phosphors on the glass panel and produces the image.

Fabrication of a cathode ray display tube is outlined in Figure 4-4. A steel aperture mask is formed to size and degreased with a solvent such as trichloroethylene. The steel mask is inserted behind the glass panel; this process is called a panel-mask mate. The mate is annealed and the two pieces are separated. The glass panels are washed several times in hydrofluoric/sulfuric acid glass washes. After the washings, the panels are sent to photoresist application.

Photoresists are applied to the glass panel to prepare the surface for phosphor application in selected areas. The photoresist solution is composed of dichromate, an alcohol, and proprietary substances. The aperture masks and panels are mated, and the panels are exposed to light through the masks. The mask is removed, and the panel is developed in a solution usually composed of hydrogen peroxide and deionized water. The panel is coated with a graphite solution and cleaned in a hydrofluoric/sulfuric acid solution. The photoresist process results in a graphite-coated panel with small clear dots that conform to the pattern of the holes in the aperture mask.

The process of applying the phosphors to the panel is called screening, and a variety of techniques are used to apply these phosphors. Common phosphor materials include cadmium sulfide, zinc sulfide, yttrium oxide, and europium oxide. Before the phosphors are applied, the panel is coated again with a photoresist solution. After phosphor application, the panel is exposed to light and developed. The panel is now coated with toluene-based lacquer and silicate coatings. These coatings seal the phosphors in place and protect them from damage. Next, the panel is coated with an aluminum film through a vacuum deposition process. The mask and panel are mated again and the unit is cleaned with solvents such as trichloroethylene, methylene chloride, methanol, isopropanol, or acetone.

4.1.3 Assembly and Sealing

Assembly of display tubes and other high volume tubes is a highly automated process; other types of tubes usually are assembled by hand. The electron tube components undergo operations such as soldering, brazing, welding, heat treating, and polishing. The constituents of the hard solders used in electron tube manufacture include aluminum, antimony, cadmium, copper, indium, silver, and tin.

A flux is needed to clean the metal oxide from the base metal and to lower the surface tension of the solder to create a durable solder bond. Fluxes can be classified into three general categories: corrosive fluxes containing inorganic acids and salts, intermediate fluxes containing organic acids and bases, and noncorrosive fluxes containing resins. Corrosive fluxes may contain the following inorganic acids such as hydrochloric, hydrofluoric, and phosphoric. Among the salts used in corrosive fluxes are zinc, ammonium, and tin chlorides.

The active components of a flux are suspended in a vehicle. For corrosive fluxes, these vehicles are water, petrolatum paste, and polyethyleneglycol. Typical intermediate fluxes are composed of lactic, oleic, stearic, glutamic, and phthalic acids, and aniline. The vehicles employed with intermediate fluxes are usually organic solvents.

Amines and amides such as urea and ethylene diamine are used as fluxes in some applications. Rosin fluxes are prepared from colophony—the resinous consitituent of crude turpentine. Water white (W/W) is an especially pure grade of colophony. Vehicles for colophony include isopropyl alcohol, organic solvents, and polyethylene glycol.

For brazing operations, nickel-based alloys with chromium, silicon, boron, and iron are used as filler materials. Fillers of pure and alloyed silver, manganese, copper, platinum, and palladium also are used in brazing. Oxide formation can be prevented by using fluxes such as fluoride or brazing under a hydrogen atmosphere or vacuum.

The finished panels of display tubes are soldered onto the glass funnel that extends to the rear of the electron gun; the solder used in this operation contains lead oxide. At least one electron gun is mounted at the apex of the glass funnel, and the electrical connections are attached in this area. After soldering, the tubes are exhausted and sealed.

Power tubes such as magnetrons undergo operations where glass or ceramic feedthroughs are brazed to several metal components. The tubes are cleaned with an alkaline solution, rinsed with alcohol, and finally cleaned with acid.

Power, receiving, and microwave tubes may be encased in glass, metal, or ceramic, depending on the intended application. Metal tube assemblies are welded to the glass feedthrough or header. The tubes are evacuated or filled with inert gas to a specific pressure and sealed.

Material	Process operation and/or application
Acetic acid	Etch
Acetone	Cleaner
Acrylic lacquer	Insulator
Aluminum	Metallization
Aluminum cobalt	Blue phosphor
Aluminum oxide	Tube coating, panel polish, abrasive material
Amyl acetate	Tube coating, funnel seal
Anhydrous ammonia	Disassociated furnace fuel
Arsenic	Alloy component
Arsine	Dopant (N-type)
Barium	Getter material
Barium carbonate	Tube coating
Barium oxide	Getter material
Boron	Brazing material
2-Butoxyethanol	Glass cleaner, solvent
n-Butyl acetate	Solvent
Cadmium sulfate	Green phosphor
Calcium	Getter material
Calcium carbonate	Tube cathode coating
Ceramic	Tube component
Chloroform	Cleaner, degreaser, solvent
Chromium	Brazing material
Copper	Conducting metal, brazing material
Deionized water	Wash, rinse
Electroplating solutions[a]	Copper, gold, nickel, and silver plating
Epoxy resins	Bonding material
Ethanol	Cleaner, washing and rinsing parts
Ethylene glycol	Insulator
Europium oxide	Red phosphor
Ferric oxide	Conductive coating
Freon®	Solvent
Glass	Tube component
Glycol ethers	Solvent
Gold	Tube component material
Graphide silicate	Funnel coating
Ground glass frit	Funnel seal
Helium	Vacuum leak detector
Hydrochloric acid	Etch
Hydrofluoric acid	Etch, panel wash
Hydrogen peroxide	Photoresist developer
Iron	Brazing material
Isopropanol	Cleaner, solvent
Latex graphite paint	Coating material
Lead	Solder component
Lead oxide	Solder component
Manganese	Getter material

Electroplating solutions include acetic acid, aluminum etch solution, anodizing dye, bright nickel, caustic soda, gold plate, hydrochloric acid, hydrofluoric acid, nickel chloride, nickel fluoborate, nickel strike, nitric acid, potassium cyanide, potassium hydroxide, silver cyanide, sodium hydroxide, and sulfuric acid.

Figure 4-1. A list of common materials used in the manufacture of electron tubes.

Material	Process operation and/or application
Manganese oxide	Brazing material
Methanol	Cleaner, washing parts
Methylene chloride	Cleaner, solvent
Methyl ethyl ketone	Resin and adhesive solvent
Mica	Insulator
Molybdenum	Tube component
Nickel	Tube component, brazing material
Nitric acid	Etch
Nitrocellulose lacquer	Funnel seal
Nitrogen	Purge gas
Oxygen	Glass working gas
Palladium	Brazing material
Petroleum distillates	Degreaser, solvent
Phosphoric acid	Electrolyte
Photoresist (positive and negative)	Photolithography
Platinum	Brazing material
Polyacrylate	Sealing material
Potassium silicate	Funnel coating
Selenium	Tube coating
Silicon	Brazing material
Silver	Brazing material
Solder and solder flux	Soldering
Strontium carbonate	Tube coating
Sulfamic acid	Etch
Sulfuric acid	Etch, wash parts
Tetrachloroethylene	Solvent
Titanium	Getter material
Tin	Solder component
Toluene	Lacquer thinner
Trichloroethylene	Degreaser, solvent
Xylene	Solvent
Yttrium oxide	Red phosphor, tube coating
Yttrium oxide sulfide	Red phosphor
Zinc	Solder component
Zinc cadmium	Green phosphor
Zinc sulfide	Blue phosphor

Figure 4-1. A list of common materials used in the manufacture of electron tubes. (continued)

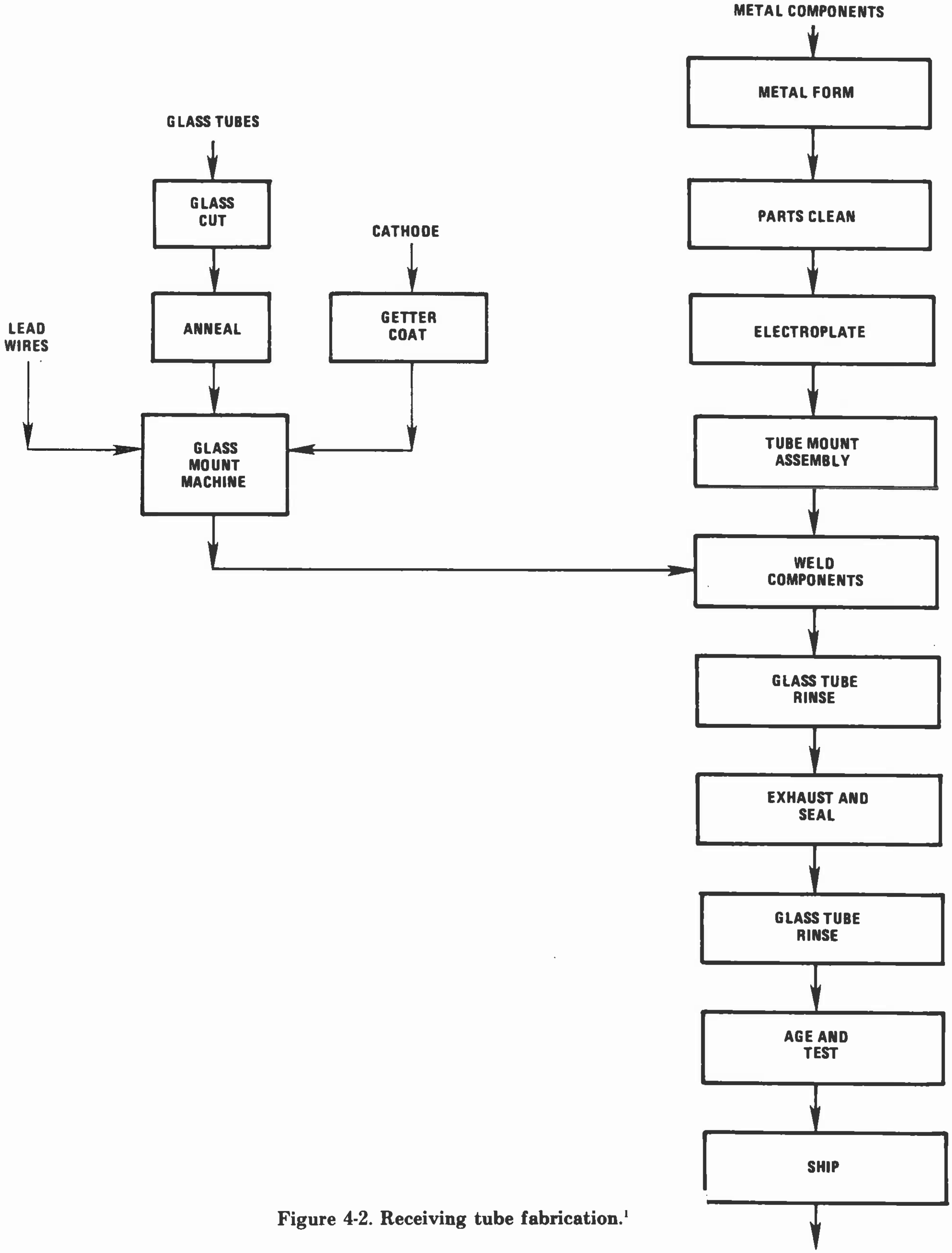

Figure 4-2. Receiving tube fabrication.[1]

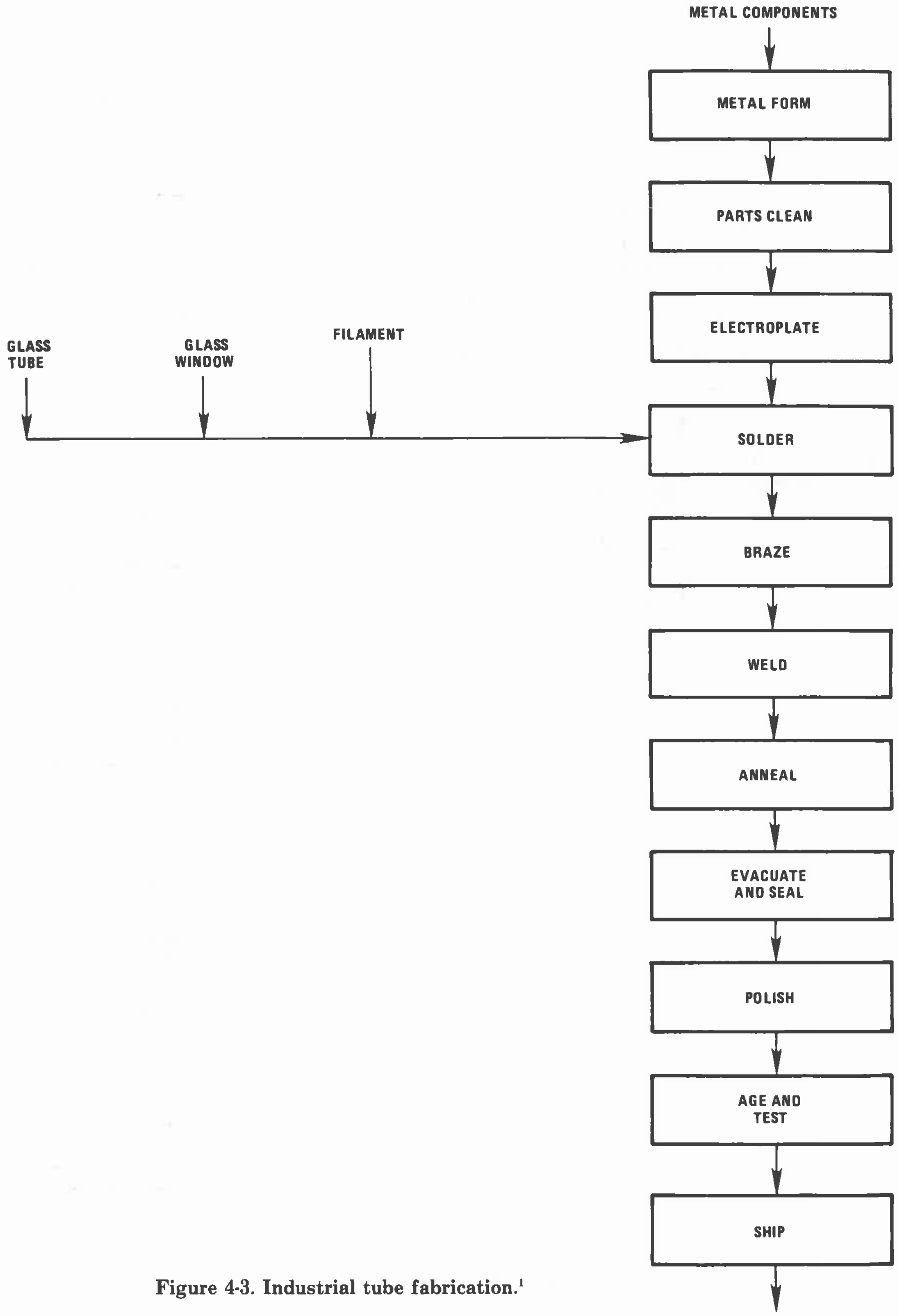

Figure 4-3. Industrial tube fabrication.[1]

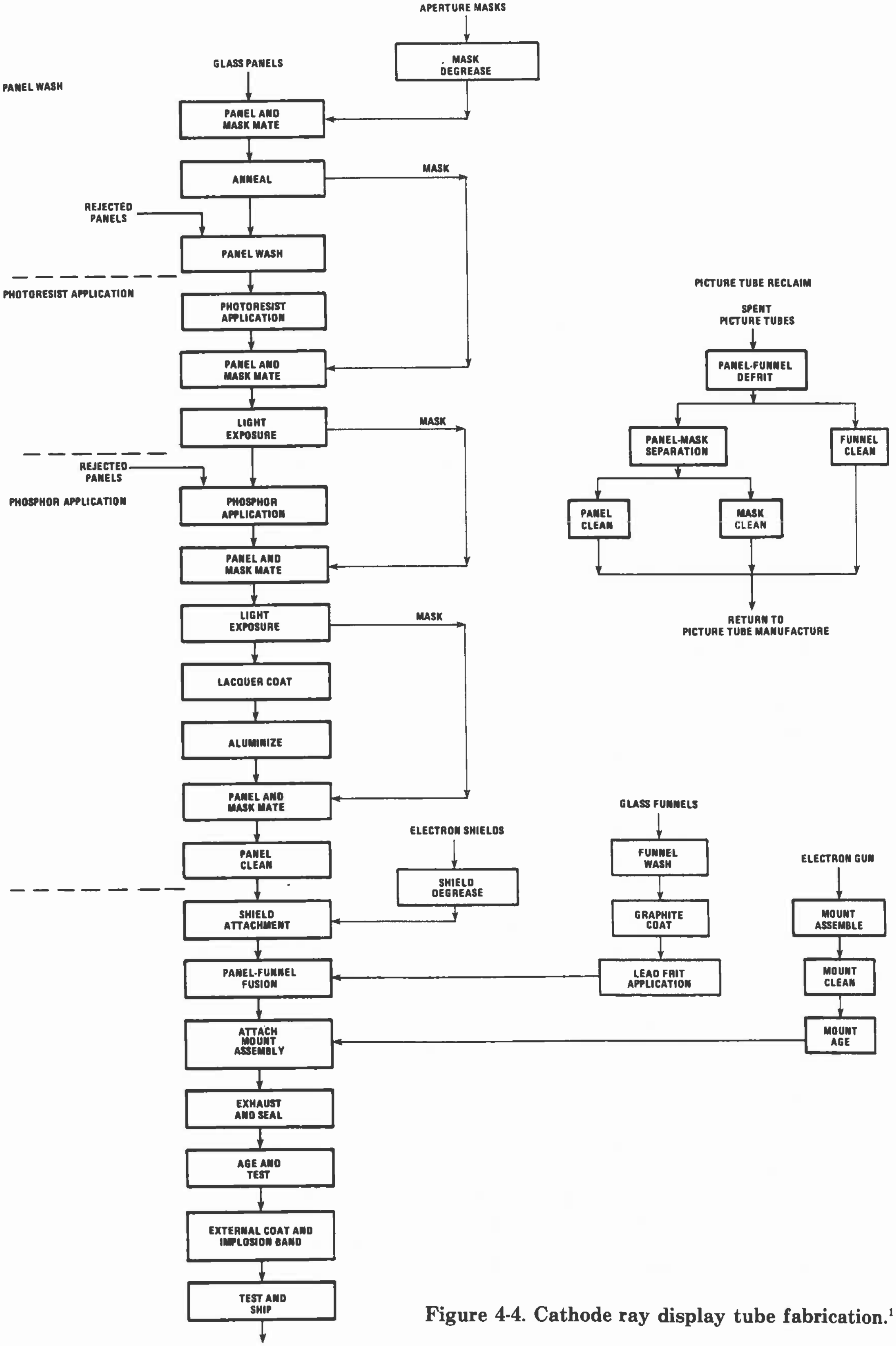

Figure 4-4. Cathode ray display tube fabrication.[1]

4.2 SEMICONDUCTOR MANUFACTURING

Operations in semiconductor device manufacture are basically similar even though different components are produced using different process materials and conditions. Figure 4-5 is a general flow diagram illustrating semiconductor wafer fabrication, which uses the basic processes of wafer lapping, lapping and polishing, wafer cleaning and etching, photolithography, epitaxial growth, impurity deposition, diffusion, ion implantation, annealing, conductor deposition, alloying, oxidization, wafer coating, wafer testing and dicing, die and lead attachment, encapsulation, labeling, and testing. The following subsections describe these major operations and other common processing steps.

The hazard assessment concentrated on the semiconductor manufacturing operations and reviewed crystal growing operations only as a supplement to device fabrication. A list of common materials used or generated in semiconductor fabrication and their process application is given in Figure 4-6.

4.2.1 Material Preparation

Silicon, germanium, gallium arsenide, gallium phosphide, and gallium arsenic phosphide crystals are used for device fabrication. The major crystal growth technique is the Czochralski process. In this process, polycrystalline material (silicon or germanium) and a dopant are melted in a quartz crucible. A seed crystal is used to pull the cylindrical single-cell crystal from the crucible at a controlled rate. In the flat zone method, a single crystal is produced from a polycrystalline rod using a crystal seed at one end and a liquid plant zone. The liquid zone also purifies the crystal.

Approximately 99 percent of the semiconductor material used in the industry is silicon. Crystals may be circular, semicircular, or trapezoidal and they are usually 5 inches or less in diameter.

Regardless of the material used, the crystals must be sliced into wafers. Wafer cutting may be accomplished with abrasive impregnated saws, wire saws, or ultrasonic cutters. Common abrasive materials used include diamond, boron carbide, silicon carbide, and garnet.

The wafers, approximately 0.03-inch thick, are lapped or ground to remove saw damage and give the wafer flat, parallel surfaces. Residual damage is removed from the wafer by polishing with abrasives or chemical etches. Diamond, aluminum, zirconium, and chromic oxide are common abrasives, and nitric acid, hydrofluoric acid, sulfuric acid, and sodium hydroxide are the commonly used etches.

The finished wafers are rinsed in deionized water and cleaned with an organic solvent such as acetone, methanol, isopropanol, or 1,1,1-trichloroethane. The wafers are visually checked for scratches under a mercury lamp and packaged for shipment.

4.2.2 Diffusion and Oxidation

The wide variations in diffusion operations include use of different materials, procedures, and degrees of control. The basic process involves the introduction of a dopant or impurity source (usually a boron, arsenic or phosphorous compound) into a semiconductor to modify its electrical properties. The vaporized dopant is transported by a carrier gas (usually nitrogen) over the wafers and is discharged. The system usually is contained in glass or quartz tubing, and the process temperatures range from 900° to 1,200° C. Radio frequency heating is commonly used.

Phosphorus dopant sources used in the industry include phosphorus oxychloride, phosphorus tribromide, phosphorus pentoxide, and phosphine. Boron dopant sources used in the industry include boron tribromide, boron trichloride, boron trifluoride, boron trioxide, diborane, and boron nitride. Arsenic dopant sources in use include arsine, arsenic trichloride, and arsenic trioxide.

Several methods are used to prepare an oxide layer on the silicon wafer surface. Normally, oxides are grown at high temperatures in oxidizing atmospheres--either steam, wet oxygen, or dry oxygen. The resulting oxides have different physical properties such as porosity, density, conductivity, and purity. Alternately, oxides can be formed by evaporation or chemical vapor deposition.

Grown oxides are formed in a tube furnace through which steam, oxygen, and/or inert gases flow. The silicon wafers are inserted into these tubes for a specific time and at a specific temperature which is determined by the oxide thickness required. Oxidation temperatures range from 800° to 1,000° C. Newer techniques involve forming oxides in a high- or low-pressure environment by decomposition of silane or other silicon-containing vapors, or by exposing the silicon wafer to an oxygen-containing plasma.

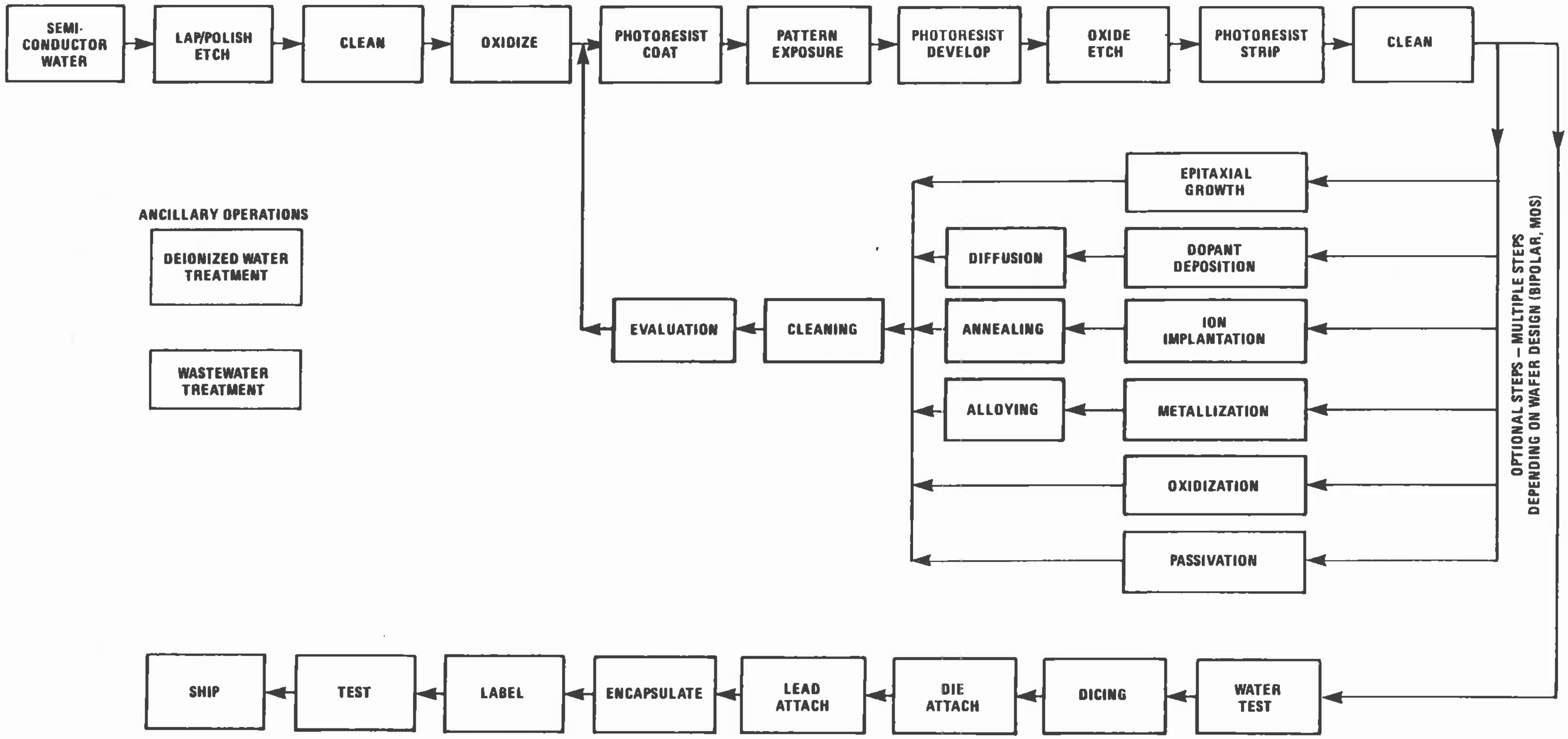

Figure 4-5. Wafer-processing flow diagram.[1]

Material	**Process operation and/or application**
Abietic acid	Solder flux component
Acetic acid	Metal and semiconductor etch component
Acetone	Wafer cleaner, solvent
Acetylene	Welding gas
Aluminum	Metallization
Aluminum acetate	Etch component
Aluminum oxide	Packaging material; abrasive—wafer polish
Ammonia	Carrier gas—epitaxial deposition; plasma etch component
Ammonium bifluoride	Oxide etch component
Ammonium chloride	Etch component
Ammonium fluoride	Oxide etch component
Ammonium hydroxide	Wafer cleaner, etch component
Ammonium persulfate	Wafer cleaner, etch component
Aniline	Solvent
Antimony	Dopant (P-type)—diffusion, ion implantation, crystal growth
Antimony trioxide	Dopant (P-type) source—diffusion, crystal growth
Argon	Carrier gas—ion implantation
Arsenic	Dopant (N-type)—diffusion, ion implantation, crystal growth
Arsenic trichloride	Dopant (N-type) source—epitaxial deposition
Arsenic trioxide	Dopant (N-type) source—diffusion
Arsine	Dopant (N-type) source—diffusion, epitaxial deposition, ion implantation
Asbestos	Insulator, packaging material
Beryllium	Metallization
Beryllium oxide	Insulator, packaging material
Boric acid	Dopant (P-type) source—diffusion, epitaxial deposition, ion implantation, crystal growth
Boron	Dopant (P-type)—diffusion, epitaxial deposition, ion implantation, crystal growth
Boron carbide	Abrasive—wafer dicing, lapping, and polishing
Boron nitride	Dopant (P-type) source—diffusion, epitaxial deposition, ion implantation
Boron tribromide	Dopant (P-type) source—diffusion, epitaxial deposition, ion implantation
Boron trichloride	Dopant (P-type) source—diffusion, epitaxial deposition, ion implantation
Boron trifluoride	Dopant (P-type) source—diffusion, epitaxial deposition, ion implantation
n-Butyl acetate	Photoresist developer
Cadmium	Dopant (P-type)—epitaxial deposition, ion implantation; solder component
Calcium hydroxide	Wastewater treatment
Calcium hypochloride	Etch component, oxidizer

Figure 4-6. A list of common materials used or generated in the manufacture of semiconductors.

Material	Process operation and/or application
Carbon dioxide	Testing gas, coolant
Carbon monoxide	Reducing gas—metallization, epitaxial deposition
Carbon tetrafluoride	Nitride etch component
Ceric ammonium nitrate	Etch component, oxidizer
Chlorobenzene	Solvent, degreaser
Chloroform	Solvent, degreaser
Chloromethane	Solvent, degreaser
Chlorosilane	Epitaxial deposition, passivation, ion implantation, crystal growth
Chromic acid	Etch component, cleaning solution, photoresist stripper solution component
Chromic oxide	Abrasive—wafer polishing
Chromium	Metallization, plating operation
Chromium trioxide	Crystal growth
Citric acid	Etch component
Cobalt	Conductor metal, packaging material
Colophony (generic)	Solder flux
Copper	Conductor metal, metallization, packaging material
Copper nitrate	Etch component, oxidizer
712D (trade name)	Negative photoresist stripper
Deionized water	Wafer cleaner, rinse, oxidization
Detergent (generic)	Wafer cleaner
Diamond	Abrasive—wafer dicing, lapping, and polishing
Diborane	Dopant (P-type) source—diffusion, epitaxial deposition, ion implantation
Dichlorosilane	Epitaxial deposition, passivation, ion implantation, crystal growth
Diethyl telluride	Dopant (N-type) source—epitaxial deposition
Dimethyl formamide	Solvent
Electroplating solutions (generic)	Copper, gold, nickel, and silver plating
Epichlorohydrin	Epoxy resin component
Epoxy resins and strippers	Packaging material, crystal slicing
Ethanol	Wafer cleaner
Ethanol amine	Photoresist stripper component
2-Ethoxy ethanol	Wafer cleaner, degreaser, solvent, photoresist component
Ethyl acetate	Solvent, degreaser
Ethylene glycol	Photoresist remover
FC-85 (trade name)	Wetting solution, photolithography
Ferric chloride	Etch component, oxidizer
Fluoride	Solder flux component
Fluoroboric acid	Dopant (P-type) source—epitaxial deposition, crystal growth
Fluorocarbons (chlorofluorocarbons)	Wafer cleaner, degreaser, solvent, cleaner, dewaxing
Formaldehyde	Solder by-product gas
Gallium	Dopant (P-type)—epitaxial deposition, ion implantation, crystal growth; solder component

Figure 4-6. A list of common materials used or generated in the manufacture of semiconductors. (continued)

Material	**Process operation and/or application**
Gallium arsenic phosphide	Semiconductor material
Gallium arsenide	Semiconductor material
Gallium chloride	Dopant (P-type) source—epitaxial deposition
Gallium oxide	Dopant (P-type) source—diffusion, crystal growth
Gallium phosphide	Semiconductor material
Garnet	Abrasive—wafer dicing, lapping, and polishing
Germane	Epitaxial deposition, crystal growth
Germanium	Semiconductor material, metallization, solder component
Glycerine	Etch component
Gold	Conductor metal, lead attachment, metallization, solder component
Graphite	High-temperature material—epitaxial deposition, metallization, crystal growth
Helium	Process and carrier gas, leak detector
Hexamethyl disilizane (HMDS)	Patterning, wafer surfactant
Hexane	Solvent
Hydrobromic acid	Etch component
Hydrochloric acid	Etch component
Hydrofluoric acid	Oxide and semiconductor etch component
Hydrogen	Carrier gas—epitaxial deposition, annealing, ion implantation
Hydrogen chloride	Gas phase etch, epitaxial deposition
Hydrogen peroxide	Etch component, wafer cleaner, oxidizer
Indium	Dopant (P-type)—metallization; solder component
Indium antimonide	Semiconductor material
Iodine	Etch component, oxidizer
Isodecane	Photoresist component
J-100 (trade name)	Negative photoresist stripper
Krypton 85	Leak testing
Lacquer (paint and thinner)	Coating
Lead	Solder component
Liquid nitrogen	Coolant
Magnesium	Packaging material, lead material
Manganese	Packaging material, lead material
Mercury	Epitaxial deposition
Methanol	Wafer cleaner, solvent
2-Methoxyethyl acetate	Solvent, degreaser
Methylene chloride	Solvent
Methyl ethyl ketone	Solvent
Methyl isobutyl ketone	Solvent
Mixed acid etch*	Etch component
Molybdenum	Packaging material, metallization
Nickel	Packaging material, metallization, lead material

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*Combination of various acids, e.g., hydrofluoric and nitric; hydrofluoric, nitric, and acetic; nitric and hydrochloric; and nitric and sulfuric.

Figure 4-6. A list of common materials used or generated in the manufacture of semiconductors. (continued)

Material	Process operation and/or application
Nitric acid	Metal and semiconductor etch component, photoresist stripper component
Nitric oxide	By-product gas from etch tanks
Nitrogen	Carrier gas—diffusion, epitaxial deposition; bonding gas
Nitrogen dioxide	By-product gas from etch tanks
Nitrous oxide	By-product gas from etch tanks, epitaxial deposition, passivation
Oxygen	Oxidization, passivation, bonding gas
Ozone	Oxidation, by-product gas from ultraviolet photoresist exposure step
Palladium	Metallization
Paraffinic mineral oil	Pump lubrication
Perchloric acid	Etch component
Phenol	J-100 component
Phosphine	Dopant (P-type) source—diffusion, epitaxial deposition, ion implantation, passivation
Phosphoric acid	Aluminum and semiconductor etch
Phosphorus	Dopant (N-type) source—diffusion, epitaxial deposition, ion implantation
Phosphorus oxychloride	Dopant (N-type) source—diffusion, epitaxial deposition, ion implantation
Phosphorus pentoxide	Dopant (N-type) source—diffusion, epitaxial deposition, ion implantation
Phosphoric tribromide	Dopant (N-type) source—diffusion, epitaxial deposition, ion implantation
Photoresists (positive and negative)	Photolithography
Photoresist developers (positive and negative)	Photolithography
Photoresist rinses	Photolithography
Photoresist strippers	Photolithography
Platinum	Metallization
Polyisoprene	Encapsulation material
Potassium dichromate	Etch, oxidizer
Potassium hydroxide	Etch component
Potassium iodide	Photolithography
Propane	Fuel gas
Propanol (1,1; 1,2; iso-; n-)	Wafer cleaner, etch additive
Rhodium	Conduction metal, plating, packaging material
Selenium	Dopant (N-type)—epitaxial deposition
Silane	Epitaxial deposition, passivation, ion implantation, crystal growth
Silica (amorphous, crystalline)	Glass, ceramic packages
Silicon	Semiconductor material
Silicon carbide	Abrasive—wafer dicing, lapping, and polishing
Silicon dioxide	Passivation coat and packaging material
Silicon nitride	Passivation coat and packaging material
Silicone	Packaging material, pump lubrication
Silicone rubber	Packaging material
Silver	Conductor metal, metallization, solder component

Figure 4-6. A list of common materials used or generated in the manufacture of semiconductors. (continued)

Material	Process operation and/or application
Sodium hydroxide	Etch component, wastewater treatment
Solder and solder flux	Soldering
Stoddard solvent	Wafer cleaner, degreaser
Sulfur hexafluoride	Gas phase etch component
Sulfuric acid	Etch component, wafer cleaner, photoresist stripper component
Tellurium	Metallization
Tetrachloroethylene	Solvent
Tetrachlorosilane	Epitaxial deposition, passivation, ion implantation, crystal growth
Tetramethyl ammonium hydroxide	Etch component
Tin	Solder component
Titanium	Metallization
Toluene	Photoresist component, wafer cleaner, solvent, varnish component
Toluene diisocyanate (TDI)	Flux component
Tributyl phosphate	Encapsulation material
1,2,4-Trichlorobenzene	Solvent
Trichloroethane (1,1,1)	Solvent, degreaser
Trichloroethylene	Wafer cleaner, degreaser, dewaxing, J-100, component
Trichlorosilane	Epitaxial deposition, passivation, ion implantation, crystal growth
Trifluoroethylene	Degreaser, wafer cleaner
Trimethyl gallium	Dopant (P-type) source—epitaxial deposition
Tungsten	Metallization
Vanadium	Metallization
Varnish	Packaging material
Wax	Wafer mounting
Xylene	Photoresist component, wafer cleaner, solvent
Zinc	Dopant (P-type)—diffusion, epitaxial deposition; solder component
Zirconium	Metallization
Zirconium oxide	Abrasive—wafer polishing

Figure 4-6. A list of common materials used or generated in the manufacture of semiconductors. (continued)

4.2.3 Photolithography

Photolithography is a process by which patterns are formed on silicon wafers to define areas for diffusion, contact, or interconnection patterns. Wafer spinners, wafer aligners, precision masks, and wafer developers are employed in photolithography. The photo operations are performed in an area with yellow-red (nonblue) light so the resist is not exposed.

Conventionally, the photoresist is placed on the wafer by a dispensing apparatus, while the wafer is spinning at high speed in an exhausted enclosure. After the photoresist dries, the wafer is baked at a low temperature. After baking, the wafer is microscopically aligned to a mask pattern. The pattern is printed by exposing the unmasked photoresist with ultraviolet light from a mercury lamp. The unexposed photoresist is developed, dried, and baked in a vacuum oven. The pattern is etched and the wafer is cleaned and/or inspected before transfer to the next process step.

Photoresists are organic compounds with solubilities that are affected by ultraviolet light exposure. Either a negative or positive photoresist may be used in the photolithography step. Negative photoresists cause the exposed wafer surface to have a lower solubility in a solvent developer, whereas the exposed areas are more soluble in the developer when a positive photoresist is used. Negative photoresists are composed of a polymer (polyisoprene), a sensitizer, and a solvent (xylene). Positive photoresists are composed of a resin, sensitizer (derivative of diazo-oxides or orthoquinone diazides), and a solvent (xylene, cellosolve, cellosolve acetate).[3]

4.2.4 Epitaxial Growth

A thin layer of single crystal material can be deposited on a wafer in an epitaxial reactor. The epitaxial films may have a different resistivity than the wafer substrate. Common gases used in the process include hydrogen, hydrogen chloride, silane, phosphine, dichlorosilane, diethyl telluride, tetrachlorosilane, arsine, ammonia, and diborane.

A typical epitaxial system consists of a radio frequency (RF) induction heater, quartz bell jar, wafer holder, and gas dispensing apparatus. The wafers are heated to approximately 800° C and exposed to hydrogen. The hydrogen gas cleans and etches the surface of the wafers. A reactant vapor such as tetrachlorosilane or dichlorosilane is pumped into the system. On the hot wafer surface, pyrolysis occurs and the reactant vapor decomposes to form the epitaxial layer.

4.2.5 Ion Implantation

Wafers may be doped with selected impurities by using a high energy ion beam. The deposition pattern may be determined by masking, and the impurity depth may be determined by the ion energy. Common process materials include boron trifluoride, diborane, phosphine, arsine, arsenic, and hydrogen.

A process diagram is illustrated in Figure 4-7. A vapor source generates a beam of neutral atoms (depositant) that are bombarded with a beam of accelerated electrons. The vapor is ionized and contained in the ion plasma region by a magnetic field. Ions are extracted from the plasma and focused on the substrate. A mass analyzer allows only ions of a specific mass to be passed; beam diameters of 1 micrometer or less are feasible (assuming a high purity source) for localized implantation.

4.2.6 Metallization

Metal evaporation is conducted in a vacuum at a pressure of 10^{-7} to 10^{-6} torr. The system may use filament evaporation, flash evaporation, an electron beam heated source, sputtering, or a magnetron sputtering source. Large evaporant charges are held in a crucible and heated by an electron beam, RF induction, or a resistance heater. The material to be evaporated is sometimes in the form of a rod that is continuously fed into the crucible. In this operation, the material is evaporated for several minutes to allow the initial gas burst to be pumped away and to remove surface contamination. A clean substrate is heated rapidly to over 1,200° C, to remove oxygen, and positioned over the source for deposition. Then the shutter is opened and the material is evaporated to obtain the desired film thickness. Aluminum is the most common evaporant used for conductor patterns on integrated circuits. Other metals evaporated on wafers include gold, silver, nickel, chromium, and titanium.

4.2.7 Nitride Deposition and Passivation

Chemical vapor deposition (CVD) is used to obtain insulating, conducting, or semiconducting layers on a wafer. One application is a low-pressure CVD nitride reactor. In this unit, silane, ammonia, nitrogen, and hydrogen

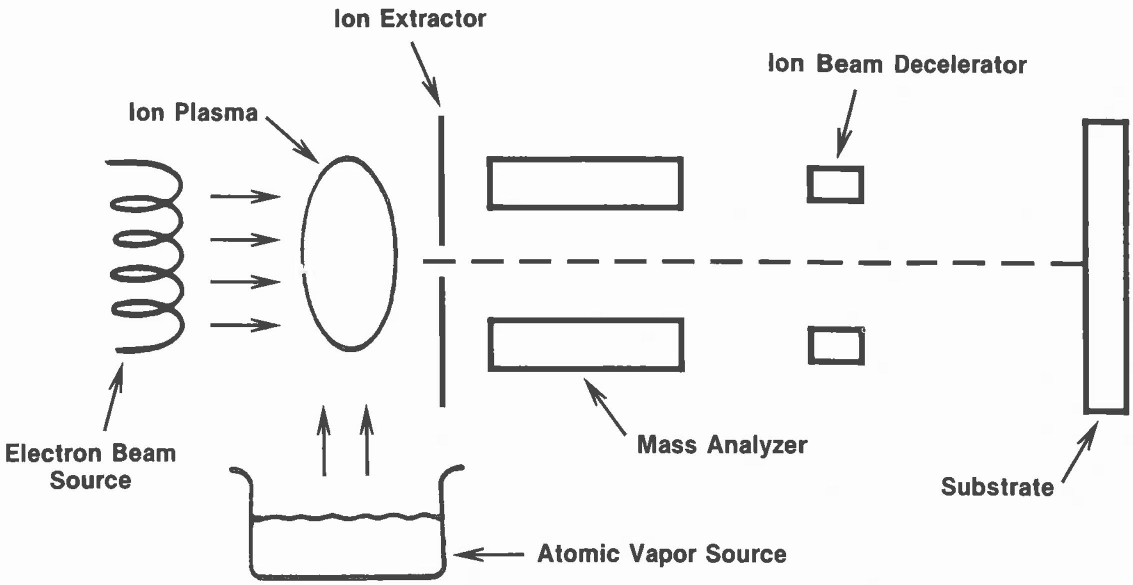

Figure 4-7. Ion implantation flow diagram.

gases are used to produce a thin silicon nitride layer on a wafer. A passivation system deposits doped and undoped silicon film on a wafer surface at temperatures up to 450° C. Input gases include oxygen, nitrogen, silane, and phosphine. State-of-the-art CVD reactors are completely enclosed in a cabinet with automated controls.

4.2.8 Wafer Etch and Cleaning

Wafer etching and cleaning are among the most common process operations used in the fabrication of integrated circuits. Hydrofluoric acid and ammonium fluoride are used as oxide etches; phosphoric acid, nitric acid, and acetic acid are used as metal etches; and carbon tetrafluoride is used as a nitride etch. Sulfuric acid, hydrogen peroxide, 1,1,1-trichloroethane, and isopropanol are used to clean wafer surfaces. Wafer etching and cleaning may be performed in an open bath or a completely enclosed automated unit.

4.2.9 Plasma Etching

Plasma etching can be used to remove materials from a wafer, as an improved alternative to chemical etching. Radio frequency sputter etching is accomplished by exposing the wafer surface to a gas discharge. Ion milling refines this process by extracting high energy ions from the plasma to impinge on the wafer surface, thereby producing cleaner patterns. In either case, inert and chemically active (tetrafluoromethane) gases may be used.

4.3 CAPACITOR MANUFACTURING

Capacitors, resistors, conductors, and inductors are passive electronic components. There are two types of capacitors—variable and fixed—and each type is designed and fabricated in numerous shapes and sizes from different materials using several processes. All capacitors consist of opposing electrodes separated by a dielectric. Figure 4-8 contains a list of the common materials used in capacitor manufacture and their process application. Figure 4-9 contains a general manufacturing flow diagram for capacitors.

4.3.1 Electrolytic Capacitors

4.3.1.1 Tantalum Foil Capacitors—

Tantalum foil capacitors are wound; therefore, the maximum surface area is available for capacitance. Figure 4-10 outlines the fabrication of a tantalum foil capacitor. The dielectric surface of the capacitor is provided by electrochemically reacting strips of tantalum foil with a mildly acidic glycol solution. This process forms a dielectric coating of tantalum oxide over the surfaces of the foil strip.

After drying, the oxide-coated foil is layered with kraft paper or plastic sheeting. These layers are wound to form the capacitor core, which is inserted into a metal container that is, in effect, the cathode. These containers are placed in a chamber under vacuum. The vacuum is released by flooding the chamber with electrolyte to fill the capacitors with the solution. The capacitors are sealed with an epoxy or phenolic resin, and the leads are soldered into place. The units are electrically aged by impression of a direct current (DC) potential to improve the oxide coating, evaluated, and packaged.

4.3.1.2 Aluminum Foil Capacitors—

Aluminum foil capacitors provide the greatest capacitance per unit volume at the lowest cost per microfarad. These capacitors are used frequently in communications networks, and their construction (outlined in Figure 4-11) is similar to that of a tantalum foil electrolytic capacitor.

To increase the effective surface area, the high purity aluminum foil is etched by passing a current through the foil while it is submerged in a strong acid bath. The dielectric is a thin layer of aluminum oxide coating on the foil surface. This coating is formed by application of a DC potential between the foil and the wall of a steel tank. The foil is unrolled and passed through a dilute ammonium pentaborate solution. Acids, such as sulfuric and nitric acid, and bases, such as potassium and sodium hydroxide, are used in these etching and forming reactions. Organic solvents such as trichloroethylene and isopropyl alcohol are used in the cleanup operations.

After etching and forming, the oxide-coated foil is cut and leads are attached. The foil is interwoven with kraft paper, and the paper and foil are wound into a cylinder and placed in a metal container. The electrolyte, usually water with traces of ethylene glycol, phosphoric acid, and/or ammonium borate, is added under a vacuum. The external leads are attached with solder, and the capacitors are sealed by soldering or with epoxy or phenolic resins.

4.3.2 Mica Capacitors

Mica capacitors are used frequently because they exhibit exceptional tolerance to temperature, pressure, and voltage extremes.

4.3.2.1 Dielectric Fabrication—

Mica is a silicate which usually contains less than 5-percent free silica. To produce the mica sheets required for capacitor fabrication, pure mica is ground or shredded into thin, small flakes by high velocity water jets. The flakes or particles are deposited on a moving vacuum belt, which dries and compresses them into a sheet. Silicon resins are added to strengthen the fragile mica paper.

4.3.2.2 Conducting Surface Application—

Metals such as gold, silver, and platinum are dissolved into strong solutions of sulfuric or nitric acid. This solution is processed through several precipitation reactions. The precipitated inks are spread onto the surfaces of the mica dielectric in an automated process by a machine that controls the amount of ink deposited. When the ink solvents dry, the precious metal-conducting surfaces are left on both sides of the mica sheet.

A multiple-layered capacitor is manufactured by alternating a sheet of mica with a sheet of precious metal until the desired capacitance specifications are obtained. Leads are attached, usually by soldering or the use of a conductive adhesive, and the units are encapsulated with epoxy or phenolic resins or glass.

4.3.3 Film Capacitors

4.3.3.1 Aluminum and Dielectric Roll Films—

Aluminum and dielectric roll film capacitors frequently are manufactured because of the relatively simple process operations involved in their fabrication. Sheets of aluminum foil and a dielectric such as mylar, polyethylene, or polypropylene are alternately stacked. These stacks are cut into strips of appropriate dimensions for the required capacitance value. Leads are soldered into place, and the flat stacks are rolled into a tubular configuration. The stacks may be encased in metal containers or in preformed plastic containers or molded with plastic material.

Material	Process operation and/or application
Acetic acid	Etch, oxide coat
Acetone	Drying agent, rinse
Acetylene	Welding gas, sealing
Acrowax	Capacitor impregnation, sealing
Alumina	Capacitor component
Aluminum (foil, wire, cans)	Capacitor component
Ammonium pentaborate	Oxide coat
Argon	Carrier gas
Aromatic amine	Epoxy resin catalyst
Babbit spray	Spray lubricant
Benzene	Solvent rinse
Brass (cans)	Capacitor component
2-Butoxyethanol	Cleaner, degreaser
n-Butyl acetate	Solvent, cleaner
Butyl carbitol acetate	Solvent, cleaner
Carbon (colloidal)	Capacitor component
Carbon dioxide	Carrier gas
Ceramic	Capacitor component
Chromium	Conductor metal
Colophony	Soldering flux
Copper (powder, strips, cans)	Capacitor component
Dichlorobenzene	Solvent
Dimethylformamide	Solvent
Di-2-ethyl hexyl phthalate	Impregnation oil
Epoxy resins	Coating, impregnation, containers
2-Ethoxyethyl acetate	Solvent, cleaner
Ethanol	Thinner for coating
Ethyl acetate	Solvent, cleaner
Ethylene glycol	Electrolyte, oxide coat
Freon®	Hermetic seal, degreaser
Gold	Conductor metal
Helium	Carrier gas
Hydrochloric acid	Etch
Hydrogen	Fuel and carrier gas
Hydrogen peroxide	Oxidizer, cleaner
Ink	Labelling
Isopropanol	Binder solvent, cleaner
Isopropyl biphenyl	Impregnation fluid
Lead	Solder component, metal foil
Manganese dioxide	Capacitor component
Manganese nitrate	Capacitor component
Mapp gas	Fuel gas
Methanol	Cleaner
Methylene chloride	Cleaner, degreaser
Methyl ethyl ketone	Epoxy solvent
Methyl isobutyl ketone	Epoxy and adhesive solvent
Mica (strip, powder)	Capacitor component
Mylar	Capacitor component
Nickel (wire, cans, powder)	Capacitor component
Nitric acid	Etch, oxide coat

Figure 4-8. A list of common materials used in the manufacture of capacitors. (continued)

Material	Process operation and/or application
Nitrogen	Carrier gas
Oxygen	Oxidizer gas
Parylene dimer	Insulator
Petroleum naphtha	Binding solvent
Phenolic powder	Coating material
Phosphoric acid	Electrolyte
Platinum	Conductor material
Polybutene	Impregnation fluid
Polycarbonate film	Capacitor component
Polyethylene film	Capacitor component
Polyimide	Adhesive, encapsulation, dielectric film
Polyolefin	Insulator
Polypropylene (film, resins, discs, sleeves, tape)	Capacitor component
Potassium hydroxide	Etch
Rhenium	Conductor metal
Silicon varnish	Insulator
Silicone	Impregnation fluid
Silver (paste)	Conductor metal
Sodium hydroxide	Etch
Solder	Soldering
Solder flux	Soldering
Sulfuric acid	Etch
Surfactants	Wetting agent
Tantalum (powder)	Capacitor component
Tert-butyl-anthraquinone	Impregnation fluid
Tetrachloroethylene	Cleaner, degreaser
Tin	Solder component
Toluene	Solvent
1,1,1-Trichloroethane	Degreaser
Trichloroethylene	Cleaner, degreaser, solvent
Varnish	Insulating coating, sealer
Vegetable oil	Impregnation fluid
Vinyl paint and thinner	Coating
XX Heavy cable oil	Insulator
Xylene	Varnish thinner, solvent
Zinc	Metallization, solder component

Figure 4-8. A list of common materials used in the manufacture of capacitors. (continued)

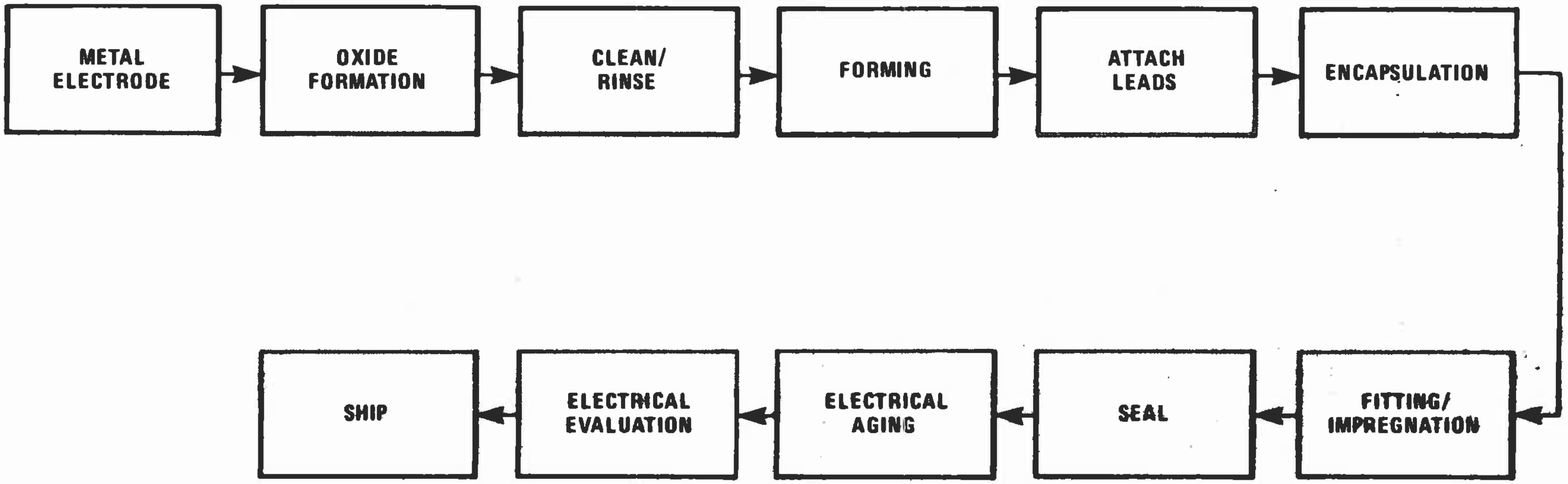

Figure 4-9. General capacitor manufacturing process flow diagram.

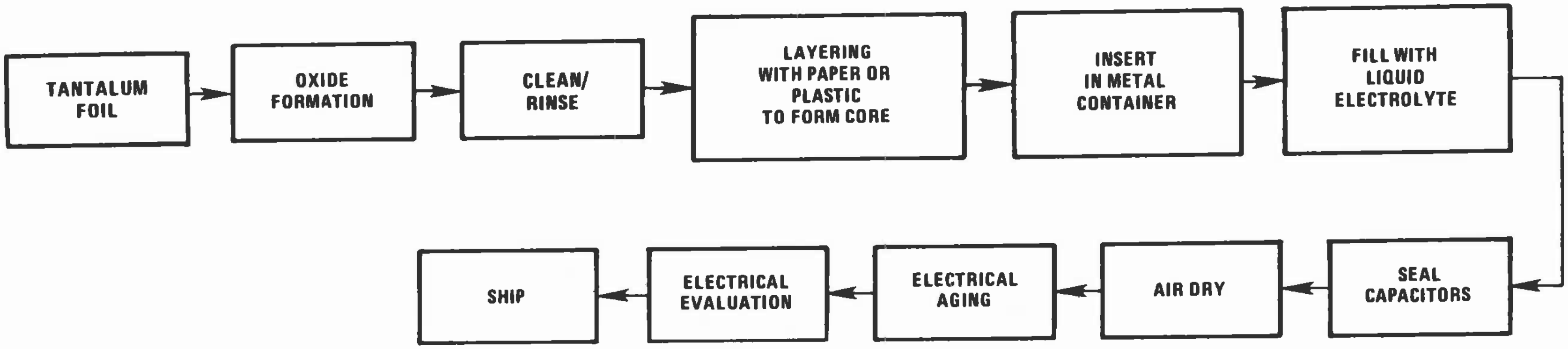

Figure 4-10. Tantalum foil capacitor fabrication.[1]

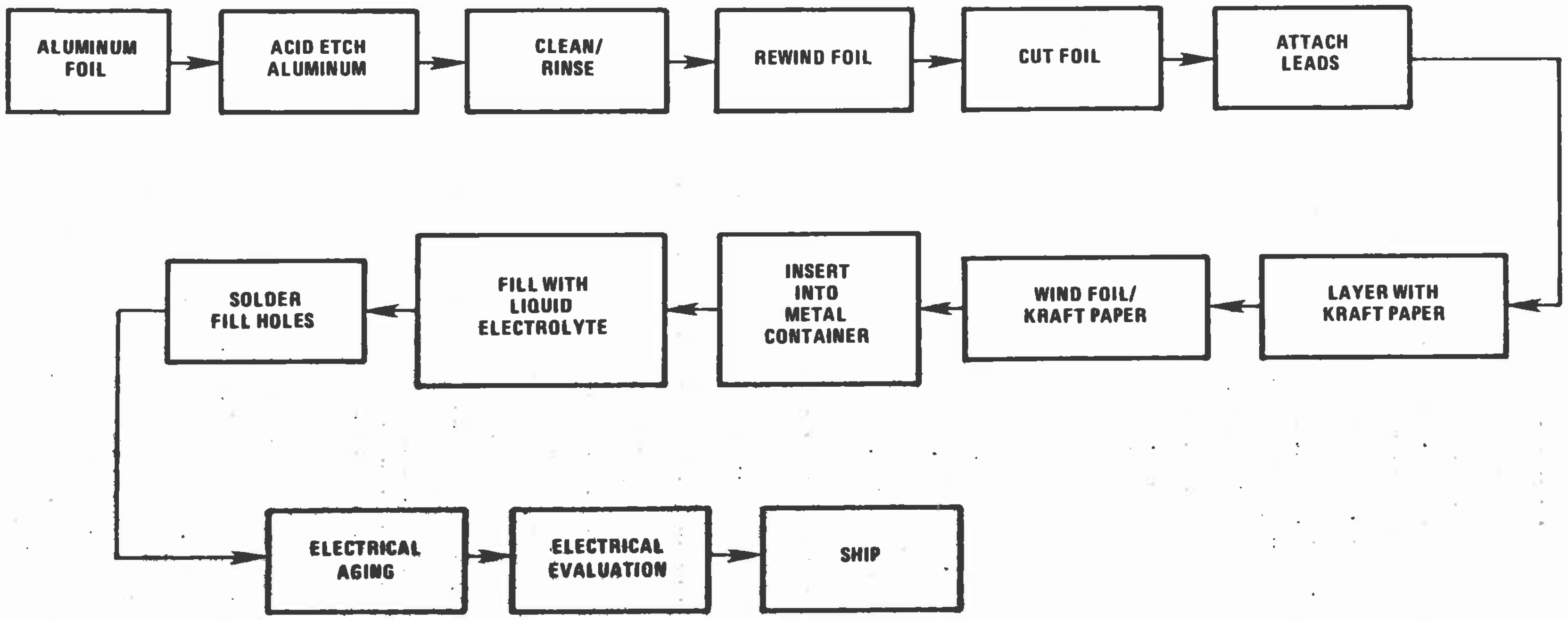

Figure 4-11. Aluminum foil capacitor fabrication.[1]

4.3.3.2 Deposited Thick-Film Capacitors—

A thick film is defined as a conductive, resistive, or insulative film that is greater than 10^{-4} inch thick and is produced by deposition and subsequent firing of a paste on a substrate. Pastes usually have three constituents—inorganic solids such as metals or metal oxides, powdered glass binders, and an organic vehicle in which the former two ingredients are suspended.

The thick-film processes and materials used in the manufacture of capacitors and resistors are very similar. Capacitors are composed of three layers, and resistors consist of only one deposited layer. The pastes used for resistors have a higher percentage of glass and organics than the conductive layers of capacitors.

A common method of thick-film component fabrication is screening and firing. A stencil-like screen, usually composed of fine wire, is used to deposit the pastes or inks on the substrate, which is generally alumina or other ceramics. The deposition pattern on the screen is produced by photolithography, and the holes in the screen mesh are occluded by emulsion. A plastic squeegee is used to force the depositant through the screen. The films are fired to volatilize the organic vehicle and form a bond between the glass powders and the substrate material. After firing, the components are ready for lead attachment, usually by soldering, and encapsulation.

4.3.3.3 Deposited Thin-Film Capacitors—

Thin-film components are composed of multiple layers of various materials with a depth of 50 to 5,000 angstroms. Thin films may be applied by vacuum evaporation (the most common technique), sputtering, anodization, and vapor plating.

The two types of conductive materials used in thin-film components are films of pure metals or metal alloys and films that are a mixture of a metal and an insulator. Commonly used metals are chromium, tantalum, aluminum, and rhenium; nichrome is a commonly used alloy. Cermet, an acronym for ceramic plus metal, denotes the metal-insulator component. A popular cermet is a mixture of chromium and silicon monoxide.

Ceramic and glass are commonly used substrate materials. Ceramics are generally composed of beryllium oxide, aluminum oxide, cordierite, or sapphire. Because of the high toxicity of beryllium compounds, their use is limited to situations where a substrate with an extremely high thermal conductivity is required. A coating of silicon monoxide may be deposited over the substrate surface to enhance the smoothness of some substrates.

The fabrication principle is based on vacuum evaporation and deposition of a conductive material onto an insulative substrate. Although several evaporation heat sources can be used, the most common source is a resistance-heated tungsten wire filament similar to to that used in incandescent lamps. If the evaporant can be electroplated onto the source, it will sublime off the heated filament or melt into small droplets that will evaporate.

Other evaporation heat sources include open boats and refractory metal tubes with an effusive opening. These sources are used when higher rates of vapor evolution are desired, and they may be heated by thermal radiation, electron beams, or electrical resistance. Depositants employed in this process include nichrome, which is the most common depositant; chromium, a cermet composed of chromium and silicon monoxide; rhenium; aluminum; and copper.

After evaporation and deposition, the component is encapsulated and tested. Epoxies and silicons are the two main types of encapsulation resins that are used for capacitors. If solvents are involved in the resin system, the components must be air-cured to solidify the resin capsule.

4.4 RESISTOR MANUFACTURING

The manufacturing processes for film, carbon-composition, and wire-wound resistors were reviewed in the hazard assessment. A list of common materials used to manufacture resistors is presented in Figure 4-12. Figure 4-13 contains a general manufacturing flow diagram for resistors.

4.4.1 Film Resistors

The thick- and thin-film resistor fabrication processes are very similar to those used to fabricate capacitors. The materials and methods are essentially the same as those described in Sections 4.3.3.2 and 4.3.3.3; therefore, they will not be repeated in this section.

Material	Process operation and/or application
Aluminum oxide	Coating material
Aluminum silicate	Coating material
Amyl acetate	Banding vehicle
Antimony salts	Coating material
Asbestos	Coating material
Butyl carbitol acetate	Ink thinner
Capryl alcohol	Wetting agent for fill material
Carbon	Coating material
Chloromethane	Cleaner, degreaser
Chromium	Metallization
Cobalt	Coating material
Copper (wire)	Resistor component
Epoxy resins	Coating and banding material
Ethanol	Wetting agent for fill material
Fiberglass	Resistor component, coating material
Fluoride	Solder and brazing flux
Freon®	Test material
Glass frit	Banding material
Glass rod	Resistor component
Hydrochloric acid	Etch, test material
Ink and ink thinner	Labeling
Iron	Resistor component
Isopropanol	Coating material, cleaner
Lead	Solder component
Manganese	Resistor component
Methylene chloride	Degreaser, cleaner
Methyl ethyl ketone	Solvent, test material
Methyl isobutyl ketone	Resin and adhesive solvent
Mica	Coating material
n-Methyl-2-pyrrolidone	Coating material
Nickel	Metallization
Oxygen	Oxidizer gas
Phenol	Solvent
Polyester powder	Coating material
Portland cement	Resistor component
Silica (powder)	Resistor component, coating material
Silicon epoxy powder	Coating material
Silicone resins	Coating material, encapsulant
Silver paste	Banding material
Styrene	Coating material
Tetrachloroethylene	Cleaner, degreaser
Tin	Solder
Tin oxide	Metallization, coating material
Titanium dioxide	Coating material
Toluene	Resin solvent, coating material
1,1,1-Trichloroethane	Resin solvent
Trichloroethylene	Cleaner,degreaser
Varnish	Coating material
Xylene	Resin solvent, varnish solvent
Zinc	Solder component
Zinc powder	Test material

Figure 4-12. A list of common materials used in the manufacture of resistors.

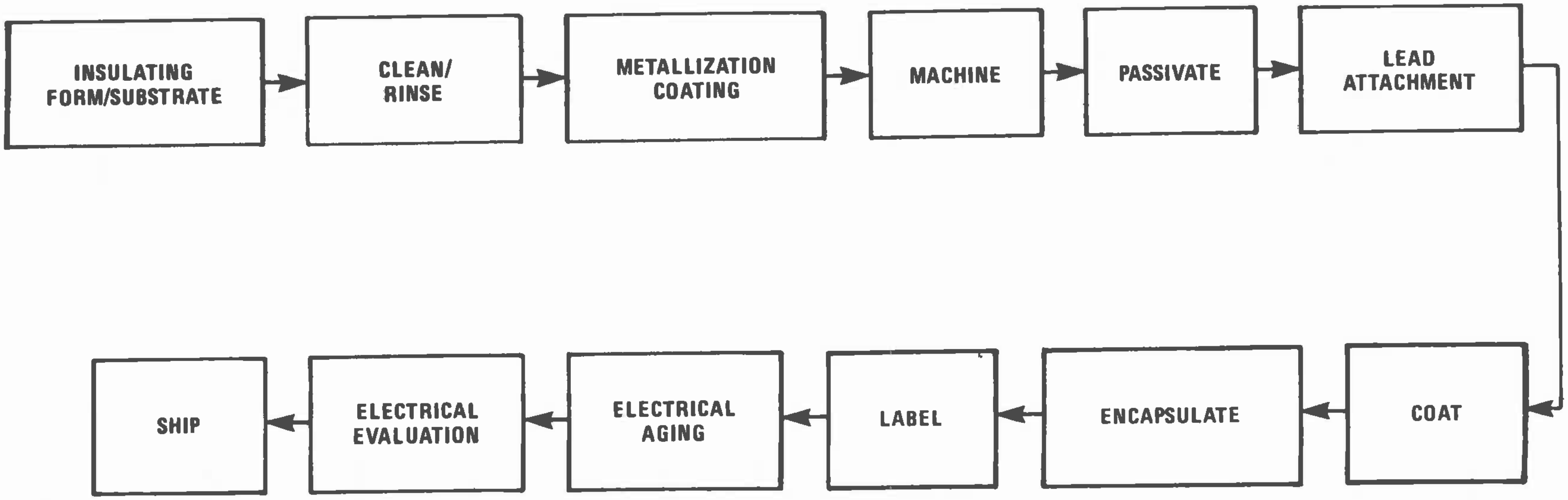

Figure 4-13. General resistor manufacturing process flow diagram.

4.4.2 Carbon-Composition Resistors

Slug carbon-composition resistors are manufactured from a mixture of carbon and organic binders or resins. The mixture is molded, pressed, or extruded into a rod. The type of carbon and its concentration in the rod determine the resistive properties. The axial terminals are typically pressed with the slug in the molding process, or they may be fitted in a separate operation. Usually the resistor is encapsulated with a phenolic resin in a separate molding step and the leads are soldered into place. Then the resistors are evaluated, and color coding paint bands are applied.

Film carbon-composition resistors are prepared by hot drawing a large tube of glass into a thin capillary or filament. This tube or filament is coated with a liquid mixture of carbons and resins and then thermally cured. A helical path may be abraded around the resistor to increase the resistance to a desired range. An electrically conductive adhesive is used to cement lead wires in place, and the resistors are molded in resin jackets. Testing and color coding completes the fabrication process.

4.4.3 Wire-Wound Resistors

Wire-wound resistors are made from an alloy wire, which is wound on insulators such as ceramic or fiberglass. Nickel and copper are the most frequently used elements in these alloys, and metals alloyed with these elements include chromium, iron, and manganese. The resistors are wound on a special machine that controls uniformity in the spacing of the windings and the tension of the wound wire. The windings may be spaced to avoid contact between the windings or the wire may be coated with an insulator which allows the windings to contact and be layered on top of each other. Organosilicon varnishes, enamel, and resin-impregnated fiberglass may be coated on the resistor wire before winding to provide the insulative film. Terminals are usually soldered or welded onto the resistor casing, or they may be embedded in the terminal caps or leads during their fabrication.

4.5 REFERENCES

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2. Suran, J. J., A Perspective on Integrated Electronics, IEEE Spectrum, The Institute of Electrical and Electronic Engineers, Inc., New York, New York, pages 67 to 79, January 1970.
3. Glaser, A. B., and Subak-Sharpe, G. E., *Integrated Circuit Engineering,* Addison-Wesley Publishing Company, Reading, Massachusetts, 1979.

SECTION 5

INDUSTRIAL HYGIENE SURVEYS

5.1 FACILITY SELECTION

Electronic component manufacturing facilities operating in the United States were identified and classified by process operation. These facilities were categorized by their geographical location, process technology, product output, extent of operations, health and safety programs, extent of union organization, and number of production workers. These data were evaluated and used as a basis for selecting the fifteen recommended facilities for the walk-through surveys. The individual walk-through survey reports are available upon request from NIOSH.

5.1.1 Facility Investigation

Published and unpublished information was used to identify the facilities manufacturing electron tubes, semiconductors, capacitors, and resistors in the United States. The data contained in the references listed in Table 5-1 comprised the majority of the information collected on manufacturing operations. Communication with industry representatives and unions were used to illuminate present operations when the available information was limited or possibly erroneous. After the manufacturing facilities were identified, they were paired with the appropriate SIC code.

5.1.2 Facility Pairing by Industry Code

Division of the electronic component manufacturing industry into six four-digit SIC codes highlights six broad product categories. Many process operations are employed within each of these codes. Each process operation in each SIC code could not be surveyed because of the fixed number of walk-through surveys proposed for the study. Therefore, allocation of the 15 walk-through surveys was based on the number of production workers in a given SIC code.

A specific number of surveys was designated for each SIC code, based on a percentage breakdown of the 1980 projected worker population data. Three surveys were assigned to facilities manufacturing electron tubes (SIC 3671 to 3673), eight surveys were assigned to facilities manufacturing semiconductors and related devices (SIC 3674), two surveys were assigned to facilities manufacturing capacitors (SIC 3675), and two surveys were assigned to facilities manufacturing resistors (SIC 3676). The Department of Labor does not report individual population data for SIC codes 3675 and 3676; therefore, composite data which encompass SIC codes 3675 to 3678 were used. SIC 3677 incorporates the manufacture of electronic coils, transformers, and other inductors, and SIC 3678 incorporates the manufacture of electronic connectors.

5.1.3 Facility Pairing by Process Operation

Because of the limited amount of surveys per four-digit SIC code, the surveys were matched with the major process operations in each code. The selection of these process operations was based on product type and production volume. The specific factors used to distinguish those operations are discussed for each code.

5.1.3.1 Electron Tubes—

The electron tube industry has a mature technology base. The first electron tubes (diodes) were manufactured in 1904 and triode electron tubes were made in 1906. This industry experienced a long growth period which peaked in 1958. Currently, the four significant classes of electron tubes are receiving, image or display, microwave, and power tubes. Each class is characterized by unique fabrication processes.

Receiving tubes are low-cost assemblies in vacuum tight metal or glass envelopes which usually are produced manually. Because receiving tubes are usually low-power devices, they are being rapidly replaced by semiconductors. Receiving tubes differ from the other tube classes in their size, manufacturing equipment employed, and materials.

Cathode ray picture tubes represent a type of imaging and display tubes that have an optical output or input. These tubes include the television picture tube, computer terminal display tube, radar displays, and image detectors such as the iconoscope. Most of these tubes have an electron gun which has a material composition and structure that is similar to receiving tubes. For display tubes, a very large glass envelope with a phosphor-coated face plate is employed. Imaging tubes incorporate a matrix of light sensitive

TABLE 5-1. ELECTRONIC COMPONENT MANUFACTURING FACILITIES—REFERENCES

Electronics Buyer's Guide 1980, McGraw-Hill Inc., May 1980.

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1979 Yearbook and Directory, Semiconductor Industry Association, Cupertino, California.

The Annual SEMI Directory, Semiconductor Equipment and Materials Institute, Inc., Mountain View, California, 1981.

American Electronics Association Directory, Palo Alto, California, 1980.

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Electronics Safety Group Membership List (AEA affiliation)

Semiconductor Safety Association Directory (SIA affiliation)

Semiconductor Safety Division Steering Committee—List of Members (SIA affiliation)

Dun and Bradstreet Facility listing for SIC codes 3671 to 3676

OSHA MIS listing for SIC codes 3671 to 3676 materials. The size of the product and the emloyment of special light sensitive or phosphorescent materials are unique to display tube fabrication. The production of display tubes has expanded continuously since their introduction in the 1940's.

Microwave tubes include traveling wave tubes, klystrons, and magnetrons. Each type of tube has a unique configuration. For example, magnetrons, which have found wide use in microwave ovens, are heavy metal structures. High power klystrons may incorporate metal and ceramic parts in their envelope assembly. Special materials such as beryllium oxide, alumina, and heavy metals are included in microwave tubes, and fabrication of these tubes is a complex and precise series of material forming, assembly, and heat treatment operations.

Power tubes, such as ignitions and thyratrons, are devices that may handle hundreds of kilowatts of power and drive large loads. The massive design of these tubes provides for dissipation of large thermal losses and for the ruggedness and reliability requirements of utility and industrial operations. Power tube production requires metal machining, ceramic shaping, and glass forming. These steps are followed by chemical and physical cleanup and plating operations before the tubes are evacuated and sealed. In some types of power tubes, special low-pressure gas mixtures are provided in the tube instead of a high vacuum.

5.1.3.2 Semiconductor Devices—

The importance and rapid expansion of the U.S. production of silicon circuitry diverts attention from other important classes of semiconductor devices. Integrated circuits (CMOS, NMOS, and bipolar types) constitute the largest and most interesting segment of the industry. Other classes such as power devices, light emitting diodes, microwave devices, and discrete transistors and diodes also are significant. To provide a complete hazard assessment of this industry, all of these major classes of semiconductor devices should be surveyed.

Some of the manufacturing processes and intervals used for each of these component classes are similar. However, even among integrated circuits, a large variety of manufacturing processes are used. Therefore, in the selection of the recommended plant surveys, facilities that included production lines for a spectrum of devices were emphasized. As a result, variations in process operations and materials could be viewed in a variety of facilities manufacturing the same component type.

For example, gallium arsenide is a semiconductor material that requires different fabrication processes than those required for silicon. A walk-through survey of a facility where gallium arsenide is used to manufacture multiple components, i.e., light emitting diodes and microwave devices, is preferred over a survey of a facility that produces a single component. Likewise, a facility using silicon to produce both MOS and bipolar integrated circuits is preferred over a plant specializing in one component type.

Another factor considered in the facility selection for the walk-through surveys was the state-of-the-art of the technology used in a specific production line at a given facility. For example, integrated circuit production lines that were established in 1980 incorporate ion implantation and plasma processes that are not present on lines established a few years ago. Power transistors are fabricated using neutron transmutation doping, large area alloying, and other processes not applicable to integrated circuits.

5.1.3.3 Capacitors—

Capacitor production processes are classified in one industry SIC code because of their similar electrical application. However, their appearance and manufacturing processes are not similar. Although the wet-electrolytic, film, and mica capacitors do not encompass all capacitor types, they are sufficiently representative to serve as the basis of the hazard assessment. Plants that produce more than one type of capacitor were preferred to provide reasonable coverage of the diverse processes during the walk-through surveys.

The wet-electrolytic capacitor consists of a container for a viscous liquid electrolyte. A metal foil is immersed into a electrolyte which forms a thin dielectric coating on the foil. The coated metal foil forms one plate of the capacitor while the other plate may be a metal electrode in electrical contact with the electrolyte. The common tubular capacitor consists of thin sheets of metal and dielectric rolled into a tube with leads attached. The mica capacitor is a lamination of metal foil and natural mica molded into a capsule the size of a postage stamp. A variety of process operations are used to make the thick and thin layers of materials which comprise the film capacitor.

5.1.3.4 Resistors—

Power resistors may be several feet in length and operate at high temperatures. However, the small carbon composition resistors and variable resistors that are found in electronic equipment such as radios and televisions are more common. Resistors vary in form because they have a variety of functions. Resistors may be made from long lengths of high resistance wire, consist of thin spirals of metal films that are fired onto glass or ceramic tubes, or be made by mixing powders in various formulations and molding them to the required shape. The mechanical design of variable resistors varies from straight sliding contact power devices to high precision 10-turn potentiometers. The resistor industry is mature and the manufacturing processes have changed little in recent years; therefore, the hazard survey adequately covered the industry by visiting several multiproduct plants. Low- and high-power resistors as well as fixed and variable carbon composition, film, and wire-wound designs were studied. The focus is on encapsulants, high temperature processes, and coatings.

5.1.4 Facility Recommendations

The rationale for facility recommendations for each SIC grouping was presented to NIOSH. NIOSH reviewed the RTI facilities recommendation in terms of geographical location, extent of health and safety programs instituted, union organization, extent of operations (merchant or captive, multiple product output), product output in sales, plant age, technological application (state-of-the-art), and number of production workers employed. Plant selection often favored the larger plants because of their diversity in product lines and process technology.

Contract travel restrictions also influenced the choice of facilities and process operations that could be surveyed. Survey sites were grouped in close geographic proximity to optimize travel time and cost.

5.2 SURVEY FINDINGS

Walk-through surveys were conducted at 15 electronic component manufacturing facilities. Eight semiconductor (SIC 3674), three electron tube (SIC 3671 to 3673), two capacitor (SIC 3675), and two resistor (SIC 3676) manufacturing facilities were surveyed. Five of the manufacturing facilities were located in California, three in Massachusetts, three in the South (South Carolina and North Carolina), two in the East (New York and New Jersey), and two in the Mideast (Kentucky and Ohio). Table 5-2 describes the product lines at each of the surveyed facilities.

Table 5-2 also describes the workforce at each of the surveyed facilities. Three plants had 100 or less workers, three plants had 100 to 500 workers, five plants had 500 to 1,000 workers, and two plants had 1,000 to 2,000 workers at the time of the surveys. The production workers were unionized at five of the 15 surveyed plants.

A wide variety of medical, health, and safety programs have been instituted throughout the electronic components industry based on the information gathered during the 15 walk-through surveys. Tables 5-3 and 5-4 summarize the medical, safety, and health programs of each surveyed facility. Only 1 of the 15 surveyed facilities did not employ an industrial hygienist or have access to an industrial hygienist through their corporation, insurance company, and/or consultants. All but three of the facilities had a local physician on-call or on a retainer or used a local clinic or hospital for medical services. Ten of the facilities employed a full- or part-time nurse. At several plants, the physicians and nurses were certified by the American Occupational Medical Association and American Board of Occupational Health, respectively.

Thirteen of the 15 surveyed plants had safety committees. New employee medical examinations are performed at 13 of these plants, and medical surveillance programs were in operation at 10 of the 15 plants. Employee training in terms of equipment operation, job and chemical safety, and medical emergency response (first aid, CPR, and/or EMT) was conducted at all of the surveyed plants. Monitoring for chemical agents and physical agents were conducted at 11 and 9 of the 15 plants surveyed, respectively. Nine of the 15 plants allowed women to work in nonchemical areas during pregnancy if their physicians or supervisors approved the transfer. The remaining 6 plants did not have any specific policy.

Table 5-5 lists the 1980 workmen's compensation data for the plants surveyed. The number of recorded lost-time accidents ranged

TABLE 5-2. SURVEYED PRODUCT LINES AND WORKFORCE DESCRIPTIONS

Plant identifier (SIC code)	Product line surveyed	Number of workers employed by the surveyed process operation(s)	Union representation
A (3671)	Receiving electron tubes	370	Yes
B (3672)	Color television cathode ray electron tubes	NA	Yes
C (3673)	Travelling wave and klystron electron tubes	717[a]	No
D (3674)	Integrated circuits (microwave devices) and magnetron electron tubes	1,300	No
E (3674)	Integrated circuits (MOS, SOS, bipolar technology)	560	Yes
F (3674)	Integrated circuits (bipolar technology)	70	No
G (3674)	Transistors (alloy technology)	89	No
H (3674)	Integrated circuits (bipolar, MOS technology)	413	No
I (3674)	Integrated circuits (LED technology)	136	No
J (3674)	Integrated circuits (MOS technology)	8,500[a]	No
K (3674)	Integrated circuits (power devices)	NA	No
L (3675)	Capacitors (mica, AC oil)	610[a]	Yes
M (3675	Capacitors (electrolytic tantalum)	924	No
N (3676)	Resistors (wire-wound, thick film)	556[a]	No
O (3676)	Resistors (thin film)	100	Yes

SOS—Silicon on sapphire.
MOS—Metal oxide semiconductor.
LED—Light emitting diodes.
Bipolar—two N- and P-type, digital and linear.
NA—Data considered propritary by the surveyed company.
[a] Number of employees in surveyed plant or plant complex.

TABLE 5-3. SURVEYED MEDICAL PROGRAMS

Plant identifier (SIC code)	Health and safety staff			Medical program	
	Physician	Nurse	Industrial hygienist	Preemployment examinations	Medical surveillance testing
A (3671)	OC	FT	C	YES	PA
B (3672)	PT	FT, PT	C, IC	YES	PA
C (3673)	OC	NO	IC	NO	PA, CN
D (3674)	OC	FT, PT	IC,CS	NO	PA
E (3674)	PT	FT	C, IC, CS	YES	PA
F (3674)	NO	NO	NO	YES	NO
G (3674)	NO	NO	IC	NO	NO
H (3674)	OC	FT	C, IC	PA	CH
I (3674)	OC	FT	P, C, IC	YES	CH, PA
J (3674)	PT	FT	P, C	PA	CH, PA
K (3674)	NO	NO	IC, CS	YES	NO
L (3675)	OC	FT	CS	PA	NO
M (3675)	OC, C	FT	C, IC	YES	NO
N (3676)	OC	NO	C, IC	YES	PA, CH
O (3676)	OC	FT	C	YES	PA

OC = on-call.
PT = full-time.
FT = full-time.
C = corporate.
IC = insurance company.
CS = consultant.

P = plant industrial hygienist.
YES = plant provides service.
NO = plant does not provide service.
HC = hospital or clinic provides service.
CH = chemical or physical agent specific.
PA = process area or job specific.

TABLE 5-4. SURVEYED SAFETY AND HEALTH PROGRAMS

Plant identifier (SIC code)	Safety committee	Industrial hygiene sampling		Training		
		Physical agents	Chemical agents	Equipment	Safety	Medical (First aid, CPR, and/or EMT)
A (3671)	YES	YES	YES	YES	YES	YES
B (3672)	YES	NO	YES	YES	YES	YES
C (3673)	YES	YES, IC	YES, IC	YES	YES	YES
D (3674)	YES	YES, IC, CS	YES, IC, CS	YES	YES	YES
E (3674)	YES	NO	YES, CS	YES	YES	YES
F (3674)	NO	NO	NO	YES	YES	YES
G (3674)	YES	NO	NO	YES	YES	YES
H (3674)	YES	YES	YES	YES	YES	YES
I (3674)	YES	YES	YES	YES	YES	YES
J (3674)	NO	YES	YES	YES	YES	YES
K (3674)	YES	NO	NO	YES	YES	YES
L (3675)	YES	IC, CS	IC, CS	YES	YES	YES
M (3675)	YES	NO	YES	YES	YES	YES
N (3676)	YES	IC	IC	YES	YES	YES
O (3676)	YES	YES	NO	YES	YES	YES

C = corporate.
IC = insurance company.
CS = consultant.
Yes = plant provides service.
No = plant does not provide service.

CPR = Cardio-Pulmonary Resuscitation.
EMT = Emergency Medical Technician.

TABLE 5-5. WORKMEN'S COMPENSATION DATA SUMMARY FOR THE FACILITIES SURVEYED

Plant identifier (SIC code)	Data year	Number of lost-time accidents[a,b]	Frequency rate[c]	Severity rate[d]
A (3671)	1980	2	0.28	NA
B (3672)	1980	4	0.18	1.13
C (3673)	1980	15	11.83	168.45
D (3674)	1980	29	NA	NA
E (3674)	1980	2	0.58	8.4
F (3674)	1980	9	NA	NA
G (3674)	1980	NA	NA	NA
H (3674)	1980	NA	2.3	NA
I (3674)	1980	8	NA	NA
J (3674)	1980	173	NA	NA
K (3674)	1980	47	26.7	151.8
L (3675)	1980	6	4.8	45.6
M (3675)	1980	3	0.10	1.47
N (3676)	1980	5	0.77	6.0
O (3676)	1980	1	0.35	41.0

[a] Injuries and illnesses combined.

[b] Lost-time is cases which involve days away from work, days of restricted work activity, or both.

[c] Frequency rate is incidents per 100 full-time workers per year.

[d] Severity rate is lost workdays per 100 full-time workers per year.

NA = The data were not available in the proper format or units at the time of the survey.

from 1 to 173, the recorded frequency rate ranged from 0.10 to 26.7, and the recorded severity rate ranged from 1.13 to 168.45. Data were not available from several facilities due to the different formats and units used and required by the surveyed plants.

5.3 SURVEYED PLANT SUMMARIES

A survey summary for each plant is provided below by alphabetical designation. The summary discusses the plant size, number of workers, engineering controls encountered, and recommendations by the survey team. More detailed information may be extracted from the walk-through survey reports available from NIOSH.

Plant A (SIC 3671)

Approximately 300 types of receiving tubes are manufactured at Plant A. The plant operates one work shift and has a unionized (Allied Industrial Workers Union) workforce of 370 employees. The electron tubes are fabricated in four buildings with a combined floor area of 130,000 square feet. The part configurations vary among tube types, requiring essentially hand assembly of the components. Chemical operations are conducted in exhaust hoods and the chemical storage area is mechanically ventilated. The plant supplies the employee with safety glasses, gloves, aprons, smocks, and cotton work clothes. Chemicals are transported to the process area by an assigned operator. The RTI and NIOSH survey team recommended improvements of the ventilation system in two process areas. Otherwise the survey team did not note any serious deficiencies in the safety and health program at Plant A.

Plant B (SIC 3672)

Plant B manufactures 19-to-25 inch color television cathode ray tubes (CRT). The manufacturing operation is located in three interconnected buildings covering a floor area of 250,000 square feet. The plant employees are represented by the International Brotherhood of Electrical Workers. The CRT production line is highly automated to the extent that little worker chemical contact was observed during the survey. Engineering controls range from exhaust hoods to totally enclosed, ventilated process booths. The plant supplies the employees with safety glasses, goggles, aprons, gloves, and a yearly allowance for smocks, caps, and shoes. Chemicals are stored in an outside storage area and are piped or transported by the operators to the process area. At the time of the survey, the RTI and NIOSH team did not note any serious deficiencies in the safety and health program at Plant B.

Plant C (SIC 3673)

Traveling wave and klystron electron tubes are manufactured at Plant C. The plant operates a bench-scale job shop where each tube may take months to fabricate and consist of a couple thousand parts. The plant has a nonunion workforce of 717 employees and operates a swing shift. Tube fabrication occurs in six buildings with a floor area of approximately 270,000 square feet. Chemical operations are ventilated and personal protective equipment (gloves, safety glasses, dustmasks, aprons, laboratory coats, face shields, and armlets) is supplied to the employees. Chemicals are stored in an outside area and transported by trained chemical handlers to the process area. The RTI and NIOSH survey team did not note any serious deficiencies in the safety and health program instituted at the plant. However, the survey team recommended that (1) housekeeping in several process areas be improved, (2) personnel protection in one process area be improved, (3) the ventilation system in one process area be assessed, (4) floor fans be removed from all process areas, and (5) a general ventilation system be provided in one process area.

Plant D (SIC 3674)

Plant D manufactures gallium arsenide and silicon integrated circuits (IC), and low-power magnetron tubes with a workforce of approximately 1,300 nonunion employees. The walk-through survey concentrated on the gallium arsenide and silicon IC production areas. The plant's engineering controls range from chemical fume hoods to Class 100 clean rooms. Safety shoes, glasses, face shields, gloves, caps, booties, respirators, and laboratory coats are provided for the employees. Chemicals are dispersed by a control support group. Overall, the RTI and NIOSH team did not note any serious deficiencies in the safety and health program at Plant D.

Plant E (SIC 3674)

Silicon integrated circuits (IC) are manufactured at Plant E using high speed bipolar, CMOS (complementary metal oxide simiconductor), SOS (silicon-on-sapphire), and PMOS-bulk (positive charge metal semiconduc tor) technology. Approximately 560 union (International Union of Electrical, Radio, and Machine Workers) workers are employed on the surveyed IC production lines over 2 full and 1 skeleton shift. The processing areas use a combination of laminar flow rooms, laminar flow work stations, and clean room designs. Safety glasses, face shields, gloves, and laboratory coats are used in the production areas. Chemicals are dispensed to the equipment operations from a centrally located reception area. Overall, the RTI and NIOSH team did not note any serious deficiencies in the safety and health program instituted at Plant E.

Plant F (SIC 3674)

Plant F manufactures digital display drives, transistors, diodes, and simple and complex integrated circuits. The survey team concentrated on the silicon digital display drive fabrication operations using dielectric isolation and bipolar technology. The production area covers approximately 10,000 square feet and the plant employs 70 nonunion workers. Chemical processes are exhausted and employees are provided with laboratory coats, safety glasses or face shields, gloves, and half-mask cartridge respirators. Chemicals are stored in the shipping area and the operators are responsible for obtaining their daily supply. Overall, the RTI and NIOSH team did not note any serious deficiencies in the safety and health program instituted at the plant. However, the survey team recommended that (1) the chemical storage area be evaluated for fire safety, and (2) the local ventilation system be expanded into the chemical storage area.

Plant G (SIC 3674)

Plant G manufactures germanium pnp, pro-electron type, small signal, pnp mesa, and npn transistors using alloy technology. Much of the transistor fabrication work is done manually. This nonunion plant employs approximately 69 workers over one full and one skeleton shift. The production floor area is approximately 28,000 square feet. The chemical operations and furnaces are exhausted and personal protective equipment (eye and face protection, gloves, aprons, shoes, gowns, and ear plugs) are provided for the employee. The operators are responsible for obtaining their daily supply of chemicals from the storage areas. Overall, the RTI and NIOSH survey team did not note any serious deficiencies in the safety and health program at Plant G. However, the survey team recommends that (1) a routine maintenance program for the plant's general and local ventilation system be developed and implemented, and (2) the local exhaust ventilation system be expanded into the chemical storage area.

Plant H (SIC 3674)

Plant H manufactures silicon integrated circuits using bipolar and MOS (metal oxide semiconductor) technology in a production area of approximately 47,000 square feet. The plant employs 413 nonunion workers on two full and one skeleton shifts. Chemical operations are locally ventilated and monitored with state-of-the-art equipment. Chemicals and gases were piped, or carried by trained personnel to the process areas. The plant provided the employees with a full range of personal protective equipment. Overall, the RTI and NIOSH team did not note any serious deficiencies in the safety and health program instituted at Plant H. Documentation of plant and corporate safety and health information was excellent and the understanding and approach of the staff in controlling and evaluating the chemical and physical hazards of the process operations was progressive and innovative.

Plant I (SIC 3674)

Plant I manufactures gallium phosphide and gallium arsenic phosphide light emitting diodes (LED) in three buildings with a floor area of 161,000 square feet. The LED production area employs 136 nonunion employees. Chemical operations are locally exhausted. The plant provides the employees with safety glasses, safety shoes, gloves, dust respirators, aprons, arm guards, face shields, and self-contained breathing apparatus, depending on the work area and job category. Chemicals are dispensed to the process areas from an outside storage facility twice daily by trained personnel. Overall, the RTI and NIOSH team did not note any serious deficiencies in the safety and health program at Plant I. However, the survey team recommended that (1) the composition of the dust around the exit port of the passivation unit be determined, and (2) wipe samples be collected and analyzed as a means to assess the effectiveness of engineering controls and general housekeeping in the production areas, especially for agents presenting a potentioal dermal hazard.

Plant J (SIC 3674)

Plant J consists of 24 buildings where 9,000 different product lines and over 6 million units are produced per day. The plant employs approximately 8,500 nonunion workers. The survey concentrated on the silicon metal oxide semiconductor (MOS) production line, which is located in one building with a floor area of 110,000 square feet. Chemical operations are locally ventilated with personal protective equipment (gloves, arm guards, heat covers, laboratory coats, safety glasses and goggles, safety shoes, and respirators) are provided for the employees at the plant. Chemicals are transported to the process areas from an outside storage area by trained personnel. Overall, the RTI and NIOSH team did not note any serious deficiency in the safety and health program at Plant J. However, the survey team recommended that the plant (1) expand its respirator training program to include employees not presently required to wear respirators, and (2) develop and institute a respirator fit test program.

Plant K (SIC 3674)

Plant K manufactures several types of silicon control rectifiers in a floor area of 80,700 square feet. Chemical operations are locally ventilated or exhausted, and personal protective equipment (vinyl smocks, aprons, cotton coats, gloves, safety glasses, face shields, and respirators) is available for the plant personnel. Process operations ranged from completely automated units to those requiring hand-work. Operators collect process chemicals from the outside storage area, and transport them to each manufacturing department daily. Overall, the RTI and NIOSH team did not observe any serious deficiencies in the safety and health program at Plant K. However, the survey team recommended development of a maintenance program for the ventilation system, and written standard operating procedures for the process units.

Plant L (3675)

Plant L manufactures mica, AC oil, and filter capacitors in one building with a total floor area of 410,000 square feet. The plant employs 605 unionized (International Brotherhood of Electrical Workers) workers on primarily one shift. The RTI and NIOSH team surveyed only the mica and AC oil capacitor fabrication operations. The plant uses exhaust hoods on a variety of operations and a totally-enclosed, ventilated booth for one operation. Protective equipment provided to the employees included safety glasses, face shields, Welch dust masks, aprons, ear plugs, gloves, and protective hand creams. The chemical storage areas are inside the building and chemicals are transported to the work stations by the operators. The survey team did not note any serious deficiencies in the safety and health program instituted at the plant. However, the survey team recommended that (1) a safer material be substituted for the ground silica used in a capacitor coating operation, (2) protective equipment be supplied to the workers using the ground silica, (3) the ventilation system be evaluated in several process areas, (4) air sampling be conducted during the operation and maintenance of the degreasing, and zinc plating units, (5) protective equipment be supplied to the employees assigned to the degreasing operation, (6) the housekeeping procedures be reviewed in the chemical storage area, and (7) a substitute for barrier creams currently used at the facility be considered. Overall, the survey team noted three production areas where potential chemical hazards could exist in the plant.

Plant M (SIC 3675)

Plant M manufactures tantalum, ceramic, and film capacitors. The facility employs 924 nonunion production workers over 3 shifts. Capacitors are fabricated in three buildings with a combined floor area of approximately 255,000 square feet. The survey was concentrated in the tantalum capacitor manufacturing area. Chemical emissions from the process operations are controlled by local exhaust ventilation. Chemicals are stored in an outside area and transported to the process operations by trained personnel. Personal protective equipment is mandatory or available on request. The primary hazards associated with the manufacture of tantalum capacitors are potential exposure to tantalum dust, solvents, epoxies, acids, and soldering fumes. At the time of the survey, the RTI and NIOSH team did not note any serious deficiencies in the safety and health program instituted at the plant. However, the survey team recommended that (1) the emissions from the solder melt oven be characterized by area and personal sampling, (2) the operation of the local exhaust system installed to control fumes during hand-soldering be evaluated and/or redesigned to operate more effectively, (3) all new trial chemicals be reviewed by the health and safety department before procurement, (4) housekeeping and cleanup procedures in the tantalum process areas be reevaluated, (5) short-term exposures during maintenance operations be evaluated, and (6) impact noise levels in the sheaving operation be measured.

Plant N (3676)

Plant N manufactures wire-round, thick film, and network resistors in a production area of approximately 115,000 square feet. The plant employs 556 nonunion workers on basically 1.5 shifts. The majority of the manufacturing operations are conducted in an open production area and are automated. Chemical operations are locally ventilated and personal protective equipment (uniforms, aprons, boots, gloves, smocks, safety glasses, face shields, and respirators) is provided to the employees, depending on their job task. Volatile chemicals are stored outside and dispensed to the process area by specially trained material handlers. Trichloroethane is piped to the process areas from an outside tank. At the time of the survey, the RTI and NIOSH team did not note any serious deficiencies in the safety and health program instituted at the plant. The plant does recirculate exhaust air from several process units back into the production area to save energy. The survey team recommended that the recirculated air be sampled for process contaminants.

Plant O (3676)

Plant O manufactures thin film resistors in 35,000 square feet of production floor area. The plant employs approximately 100 unionized (American Flint Glass Workers Union) workers over 2 shifts. Exhaust ventilation is installed on a number of process units and personal protective equipment (safety glasses, smocks, gloves, and respirators) is provided for the employee. At the time of the survey, the RTI and NIOSH team did not note any serious deficiencies in the safety and health program at plant O. However, the survey team recommended that (1) chemical handling practices and engineering controls in one process area be improved, and (2) local exhaust ventilation be installed and/or improved in two process areas.

SECTION 6

LITERATURE REVIEW

6.1 INTRODUCTION

A large number of chemicals, many physical agents, and several ergonomic stresses are associated with the manufacture of electronic components. As part of the hazard assessment, a literature review was conducted to determine and review the chemical agents, physical agents, and ergonomic stresses in the industry. This review was not meant to be all encompassing as to the health effects of the various chemical and physical agents encountered but rather to give the reader an idea of what the potential health effects may be. If the reader wishes more detailed information about the potential health effects, he should then refer to the articles referenced.

The strategy of the literature review was to determine and review those materials and effects of exposure believed to be the most significant from an occupational health point-of-view. The review was concentrated on the following topic areas:

- Agents that historically have caused exposure problems in the electronic components industry. These agents were identified through reviewed NIOSH surveys, OSHA compliance inspection reports, published literature, and discussion with industry personnel during the 15 plant surveys conducted as part of this project.
- Effects of low-level chronic exposures and long-term effects of multiple acute exposures in the industry.
- Chemicals that are used throughout the industry in processes where exposure is likely to occur.
- The combined effects of exposure to mixtures of chemical agents used in the industry.
- Carcinogens, teratogens, and mutagens used in the industry.

The literature review did not attempt to cover all the materials and stresses encountered in electronic component manufacturing industry. To compile meaningful information on so many chemicals, physical agents, and stresses would have required more resources than were available in this assessment. However, information was collected on the chemicals, physical agents, and stresses that were (1) determined by the research team to pose the greatest potential health hazard to the industry workers, and (2) referenced in the available published and unpublished information relevant or related to the electronic component manufacturing industry. Secondary references were often used due to time and monetary considerations, e.g., summaries of foreign articles were used instead of full translations of the articles. These chemicals, physical agents, and stresses are reviewed in this section by generic class.

The lack of available information on the chemicals, physical agents, and ergonomic stresses in the industry was great. As a result, if a relevant data source could not be located for a given chemical, physical agent, or stress, the chemical, physical agent, or stress was not discussed in this section. However, this chemical, physical agent, and/or stress was usually referenced elsewhere in the report for future reference. Also, most of the cases of occupational exposures to the various chemicals, physical agents, and ergonomic stresses occurred outside the electronic component manufacturing industry. These cases are described in this review to indicate the potential hazards associated with the agents of interest not to indicate that these hazards do exist in the industry.

Injury and illness data for the industry were also reviewed, and these data are presented in Appendix B. The disabling injury indices for all of the segments of the electronic components manufacturing industry, except cathode ray television tubes, were much lower than the indices of the private sector or the manufacturing division (see Appendix B). Data from the California semiconductor industry show a decreasing illness index and an increasing injury index over the last two years for which data are available.[23]

Appendix C contains a compilation of the findings of 65 OSHA compliance inspections in the electronic component manufacturing industry. Appendix C reveals that the most frequently cited health hazards in the electronic components industry are caused from organic solvents, noise, and lead exposure. The most frequently cited safety violations resulted from flammable liquid handling procedures, and emergency facilities and equipment.

6.2 CHEMICAL AGENTS

6.2.1 Organic Liquids

6.2.1.1 Introduction—

A wide variety of organic liquids and liquid solutions are used in the electronic components industry. A large portion of these liquids are solvents. At a certain level of exposure, solvents can cause occupational dermatosis. A frequent response to contact with solvents is primary irritation of the dermatitis caused by the removal of the protective barrier of fats and oils that covers the skin.

Nonpolar organic solvents are popular cleaners and degreasers in the electronic components industry. Degreasing operations use volatile solvents because they facilitate drying.

A Russian study of a capacitor manufacturing plant stated at 40 percent of the workers had some degree of dermatitis from contact with solvents.[4] Polar and semipolar solvents such as water, aldehydes, ketones, and alcohols do not cause primary irritation dermatitis as frequently as nonpolar solvents; but multiple and prolonged contact will result in drying and cracking of the skin.

Many of the organic liquids can vaporize and cause respiratory tract irritation if the airborne concentrations are high. However, most vapors will cause systemic damage after prolonged exposure at concentrations below levels that cause mucous membrane irritation. Also workers may become sensitized to organic solvent vapors. If sensitization has occurred, the sensitive worker may experience severe respiratory tract irritation at airborne chemical levels that are generally viewed as being safe.

In general, aldehydes, ketones, higher molecular weight alcohols, and aromatic hydrocarbons are irritating to the respiratory tract. These types of chemicals are usually used in the electronic component manufacturing industry as solvents and cleaners.

Some general rules apply to the narcotic effect of the various classes of organic solvents. The lower molecular weight aliphatic and alicyclic hydrocarbons, excluding methane, ethane, and propane, cause narcosis characterized by headaches, blurred vision, and dizziness. These symptoms may increase the possibility of worker accidents. The narcotic effect diminishes with increasing molecular weight among the aliphatic and alicyclic hydrocarbons. Aromatic hydrocarbons, the aliphatic alcohols, and most of the cyclic and aromatic alcohols produce narcosis at high concentrations. Other alcohols, especially phenol, affect the central nervous system by causing respiratory stimulation followed by respiratory paralysis. Aldehydes and ketones also produce narcosis.[41]

Nonpolar organic solvents enter the body primarily by vapor inhalation, but some of these solvents may enter through the intact skin. Other solvents, such as trichloroethylene, methylene chloride, perchloroethylene, and 1,1,1-trichloroethane, probably do not penetrate the skin in toxic amounts in usual industrial situations.[72]

6.2.1.2 Glycol Ethers (Cellosolve, Methyl Cellosolve, and Butyl Cellosolve)—

Cellosolve (2-ethoxyethanol, ethylene glycol monoethyl ether) is used as a solvent in the electronic component manufacturing industry. EGME is a component of inks used in thick-film circuits, or it may be found in photoresist reagents. Pregnant rats were exposed to 100 ppm ethoxyethanol for 7 hours per day on gestation days 7 through 13 or 14 through 20. The ethoxyethanol-exposed offspring showed a significantly higher number of behavioral and neurochemical deviations than the control rat population. The significant (p • 0.05) behavioral effects included impaired neuromuscular ability, reduced physical activity, and reduced performance in conditioning tests. The neurochemical deviations included decreased norepinephrine levels and increased levels of acetylcholine and dopamine.[124]

Methyl cellosolve (ethylene glycol monomethyl ether) is another solvent used in the electronic component manufacturing industry. One study reviewed five case histories of workers exposed to high concentrations of methyl cellosolve in industries other than the electronic component manufacturing. The exposure levels ranged from 61 to 3,960 ppm in the area where five men worked. The workers presented symptoms of somnolence, tremors, anorexia, and lack of coordination.[77]

Another commonly used solvent is butyl cellosolve (ethylene glycol monobutyl ether). The 7 hour LC_{50} in mice is reportedly 700 ppm butyl cellosolve. At necropsy, the mice were found to have lung and kidney injury; but the kidney injury, in the form of conjestion, was more pronounced. Mice exposed to a concentration of 200 ppm butyl cellosolve 30 times for 7 hours per exposure were not injured, but hemeglobinuria was evident at levels above 100 ppm.[5]

NIOSH is currently involved in a comprehensive, industry-wide study of the glycol ethers. No results are currently available from the NIOSH study. In general, the glycol ethers have a low order of acute toxicity. The rat 4-hour LC_{50} is reportedly 4,000 ppm. Effects of acute exposure in animals include narcosis, pulmonary edema, and severe hepatic and renal damage. Fatigue, lethargy, anorexia, and tremor were observed in chronically exposed animals. In dogs, hematopoeitic damage in the form of slight decreases in hemoglobin and red blood cells, and a shift in white cells to more immature forms was observed after chronic exposure to ethylene glycol monoethyl ether. There have been reports of testicular atrophy in rats in long-term feeding studies using the alkyl ethylene glycol ethers. At inteaperitoneal doses above 100 ml/kg/day, a dose-dependent increase in skeletal malformations was observed in rat offspring. Inhalation exposure to 900 ppm ethylene glycol monoethyl ether for 7 hours per day during gestation days 7 to 13 or 14 to 20 caused 100 percent offspring mortality in rats, and similar exposure to 200 ppm caused approximately 25 percent mortality.

In humans, glycol ethers are mildly irritating to the skin, and they are somewhat more irritating to the eyes and mucous membranes causing temporary corneal opacity, conjunctivitis, and upper respiratory tract irritation. Central nervous system effects are the most prominent seen in human poisoning. In two cases of human ingestion of glycol ethers, the patients recovered fully.

6.2.1.3 Esters (Ethyl, Butyl, Amyl, and Cellosolve Acetates)—

Esters are commonly employed as solvents in many production facilities of the electronic component manufacturing industry. The acetates are common in industrial use, and the health problems encountered with them have been minimal. Ethyl, butyl, and amyl acetates may produce narcosis and anethesia. Butyl and ethyl acetates did not produce anesthetic symptoms in humans exposed to 100 to 600 ppm for 2 to 3 hours.[48]

Animal studies with cellosolve acetate (ethylene glycol monoethyl ether acetate) revealed no injury to dogs exposed for 120 days for 7 hours per day to a concentration of 600 ppm. Mice and guinea pigs demonstrated albuminurea after 8 to 12 hours of exposure to 450 ppm cellosolve acetate, whereas one rabbit and two cats died from kidney damage that resulted from the same exposure level.[5] Butyl carbitol acetate (diethylene glycol monobutyl ether acetate) was used as an insect repellent; however, no standard has been set for this substance because of its low toxicity and low vapor pressure.[5]

6.2.1.4 Ketones—(Acetone, Methyl Ethyl Ketone, and Methyl Isobutyl Ketone)—

Acetone is a ketone which is used in the electronic component manufacturing industry. Acetone exposure causes narcosis and will cause unconsciousness in severe exposures.[85] Workers chronically exposed to acetone concentrations of 1,000 ppm for 3 hours per day for 7 to 15 years had attacks of giddiness and asthenia.[86]

Methyl ethyl ketone and methyl isobutyl ketone are used as solvents in all segments of the electronics industry. Like acetone, these compounds principally exert a narcotic effect. Exposure in industrial situations to 100 ppm methyl isobutyl ketone or 300 ppm methyl ethyl ketone have caused complaints of headaches.[5]

6.2.1.5 Aromatics (Toluene, Benzene, Xylene, Phenol, Styrene, and Isocyanates)—

Toluene is often used as a solvent in varnish formulations. These varnishes are used in the electronic component manufacturing industry, especially in the manufacture of resistors. A study of the health of workers involved with toluene-based varnishes in an electronics manufacturing facility revealed a statistically significant increase in autonomic and peripheral nervous system disorders among the workers.[82] The airborne concentrations of toluene varied from 25 to 400 mg/m^3.

One report documents an incident where an optometrist exhibited cerebellar ataxia symptoms, including fatigue, clumsiness, and staggering, after being exposed to toluene vapors while cleaning eyeglasses and contact lenses. The levels of exposure were unknown. Cessation of exposure brought recovery in 1 month.[83]

Inhalation of toluene vapors at very high concentrations produces a state of euphoria. Several cases of occupational toluene abuse and habituation were reported in the literature.[83 84] Such long-term abuse of toluene can lead to permanent central nervous system damage.

Benzene is an organic solvent that has been implicated as a causative agent of leukemia, hematopoietic system depression, and other blood dyscrasia. The literature search and the plant surveys have not revealed a significant use of benzene in the electronic component manufacturing industry. However, one report stated that benzene contamination of xylene was suspected at a printed circuits manufacturing plant.[104]

In one study, rats were exposed to inhalation to 313 ppm benzene, 399 ppm toluene, or 230 ppm xylene for 24 hours per day from days 9 through 14 of pregnancy. In addition, more rats were exposed to toluene vapor at 399 ppm for 24 hours per day from days 1 through 8 of pregnancy, or 266 ppm toluene for 8 hours per day for the first 21 days of pregnancy. None of the solvents proved to be teratogenic, but an increase in skeletal anomalies (extra ribs and fused sternebrae) was observed from all three solvent exposures. Benzene and toluene also caused a significant retardation of fetal development in animals.[122]

Phenol in 10 or 20 percent solutions has been found to induce papillomas and epithelial carcinomas when applied to the skin of mice. Toluene is reported to be an enhancing agent in 7,12-dimethylbenz[a]anthracene-induced skin carcinogenesis.[123]

Xylene also increased the yield of tumors when it was painted on the skin of mice before a subcutaneous injection of urethane. The skin carcinogenicity of these compounds seems to be associated with their irritant properties and the resultant skin hyperplasia.[123] No references to systemic carcinogenicity of xylene, benzene, or toluene were found in literature written prior to 1978, except for the association of benzene exposure with leukemia.[123]

Styrene has been used in the manufacture of resistors. Styrene is polymerized around a number of resistive rods to facilitate subsequent operations such as sawing and etching. Workers exposed to styrene vapor levels in the range of 100 to 300 ppm at 8-hour time weighted averages and to peak concentrations of more than 1,000 ppm reported symptoms that included tiredness, sleepiness, and memory disturbances. Some of these styrene-exposed workers were also demonstrated to have an increased reaction time in comparison to age-matched controls.[94] Ninety-six male workers exposed to unknown levels of styrene for 0.5 to 14 years showed a higher than expected percentage of abnormal electroencephalograms.[95] Of 33 workers exposed to 5 to 175 ppm styrene for 1 to 21 years, 10 workers showed some evidence of neuropathology in terms of lowered sensory nerve conduction velocities and other parameters that are of unknown significance.[96] Lymphocyte examinations of workers who were exposed to approximately 100 ppm styrene in a styrene production plant in Finland revealed a significant increase in aberrant cells. The authors concluded that high concentrations of styrene appear to be capable of altering genetic material.[144] This conclusion was confirmed in a follow-up study where workers who were employed from 1 to 15 years were exposed to styrene concentrations that occasionally increased to 300 ppm.[145] Another study of three groups of workers who were exposed to styrene vapors did not reveal an elevated incidence of lymphocyte chromosome aberrations; however, a random sample of the most highly exposed workers yielded higher than normal percentages of abnormal lymphocytes. Airborne concentration levels were not given for any of the groups.

Toluene diisocyanate (TDI) is a very potent respiratory tract allergen and irritant. Inhalation of toluene diisocyanate can cause a severe asthma-like reaction in humans after a latent period.[5] In the past few years, diphenylmethane diisocyanate (MDI) and polymethylene polyphenyl isocyanate (PAPI) have been substituted for TDI. However, recent analyses have revealed that some solutions of these substitutes contain 21 percent TDI.[149] These isocyanates are a constituent of some insulating varnishes, such as those used in the manufacture of wire-wound resistors, and in some solder fluxes. The TDI can be released when the varnish and flux is heated.[149]

6.2.1.6 Polyaromatics (Chlorinated Compounds)—

Chloracne may result when an individual inhales, ingests, or directly contacts chloronaphthalenes, chlorobiphenyls, chlorodibenzodioxins, chlorodibenzofurans, chloroazobenzenes, and chloroazoxy-benzenes. The majority of skin eruptions associated with chloracne are confined to the face. Lesions may clear within a few months, or they may persist for as long as 15 years.[29]

The literature search and plant surveys revealed that halowax, used in the electronic component manufacturing industry, is capable of causing chloracne. Halowax is a tritetrachloronaphthalene used in the production of alternating current oil capacitors.[29]

6.2.1.7 Halogenated Hydrocarbons (Trichloroethylene, Trichloroethane, Perchloroethylene, Methylene Chloride, Chloroform, and Fluorocarbons)—

Trichloroethylene (TCE) is a solvent that is sued in the electronic components industry. Exposure to TCE has been associated with paralysis of the fifth cranial nerve, central nervous system depression, mental confusion, and fatigue.[23 79] NIOSH has observed overexposure to TCE during cleaning operations in a electronics facility manufacturing printed circuits.[80] In this operation, a worker cleaned a soldering machine with a rag soaked with TCE without the benefit of respiratory protection. This operation was performed at the end of each shift and required 20-30 minutes to accomplish.

Researchers exposed several species of animals to trichloroethylene vapors for 7 hours per day, 5 days per week for approximately 6 months. At 400 ppm trichloroethylene, rats showed an increase in liver and kidney weights, and the males showed significantly less growth. Rabbits and guinea pigs also showed an increase in liver weights. The maximum no effect level tolerated by each species was 400 ppm for monkeys; 200 ppm for rats and rabbits; and 100 ppm for guinea pigs. The principal response to chronic exposure to trichloroethylene was growth depression and liver and kidney changes.[5]

Trichloroethylene was given to mice by gastric intubation five times per week for 78 weeks, and the trichloroethylene-dosed mice showed a significantly increased rate of hepatocellular carcinomas. However, in a recent epidemiological study, workers who were exposed to approximately 30 ppm trichloroethylene showed no evidence of unusual cancer incidence. The periods of exposure were not given.[121]

Trichloroethylene administered by gastric intubation to mice produced hepatocellular carcinomas with some metastases to the lungs. Thirty of the 98 mice administered the low dose (1,200 mg/kg and 900 mg/kg for male and the female, respectively) developed the hepatic cancers, while only one of the forty control animals did so.[49] At the high dose level (2,400 mg/kg and 1,800 mg/kg for male and female mice, respectively), 41 of 95 animals developed hepatic cancer.[49]

Rats exposed to 200 ppm trichloroethylene for 6 hours per day for 4 days exhibited changes in behavior in open field tests, whereas rats exposed to 500 ppm 1,1,1-trichloroethane for the same length of time did not exhibit such behavioral changes.[74] A cohort of 22 female workers exposed for a mean period of 6.7 years to 1,1,1-trichloroethane at levels of 110 to 990 ppm showed no statistical difference from unexposed controls with respect to clinical features, neuronal conduction velocities, and psychometric data.[75]

The 1,1,1 and 1,1,2 isomers of trichloroethane are two popular solvents which are often not differentiated. The literature indicates that the 1,1,1 isomer is less toxic than the 1,1,2 isomer. The principal effect of exposure to either solvent is anesthesic.[73]

The 1,1,1 isomer of trichloroethane is corrosive to aluminum and other metals; therefore, a corrosion inhibitor is often added. The inhibitor may increase the toxicity of the solvent. Additives are in many of the widely used chlorinated solvents which are often applied in degreasing operations.[5 78]

Trichloroethylene has been found to be weakly mutagenic in E. coli test systems.[49] In the same study, trichloroethylene (300 ppm), perchloroethylene (300 ppm), 1,1,1-trichloroethane (875 ppm), and methylene chloride (1,250 ppm) was given through inhalation to rats and mice for 7 hours/day on days 6-15 of gestation. These exposures did not cause significant maternal embryonal or fetal toxicity and were not teratogenic.[49]

Perchloroethylene has not been found to be carcinogenic in inhalation studies with rabbits, mice, rats, guinea pigs, and monkeys. Perchloroethylene was also found not to be mutagenic in a bacterial mutation experiment,[49] but perchloroethylene has been shown to be mutagenic in yeast cell cultures.[126]

Perchloroethylene (tetrachloroethylene) and methylene chloride (dichloromethane) are two solvents frequently used as degreasers in all segments of the electronic components industry. Rats exposed 6 hours daily for 4 days to either 200 ppm perchloroethylene or 500 ppm methylene chloride exhibited significant solvent accumulation in the fat and brain with marked effects on behavior and brain protein metabolism.[76] Methylene chloride also causes carboxyhemoglobin formation. One surveyed plant required workers with potential exposure to methylene chloride to have periodic tests for carboxyhemoglobin levels.

In one study, rats and mice were intubated with one of several halogenated hydrocarbons on a chronic basis, that is, five days per week for 78 to 90 weeks. The chloroform exposed animals showed a significant increase in the rate of both hepatocellular and kidney neoplasms at doses of 180 to 500 mg/kg. Trichloroethylene (1,000 to 2,400 mg/kg), tetrachloroethylene (1,000 mg/kg), and 1,1,2-trichloroethane (100 mg/kg) were demonstrated to also produce liver cancers. At the tested dose level (1,500 mg/kg), 1,1,1-trichloroethane did not cause an increase in any types of tumors.[125] In yeast cell cultures, methylene chloride, chloroform, and trichloroethylene were shown to induce mitotic gene convertants, recombinants, and, to a lesser degree, gene revertants.[126]

Rats and mice intubated with from 180 to 480 mg/kg chloroform for 5 days per week for 78 weeks developed a significant number of kidney tumors and hepatocellular carcinomas. Inhalation of chloroform at doses of 300 ppm for 7 hours per day on days 6 to 15 of gestation resulted in a significant increase in fetal resorptions, a decrease in fetal weight and length, and a reduction in the conception rate from 88 percent to 15 percent.[49]

Fluorocarbons have the potential to produce bronchoconstriction, reduce pulmonary compliance, depress respiratory minute volume, reduce mean blood pressure, and accelerate the heart rate in dogs. Freon 11 ($CFCl_3$) was found to be the most toxic fluorocarbon tested; it caused all the aforementioned effects except bronchoconstriction and reduction in pulmonary compliance.[49]

Four fluorinated hydrocarbons (octafluorocyclobutane, trifluoromethane, 1,1-difluoroethane, and perfluorobutene-2) were tested for mutagenic potential using Drosophila melanogaster. All four fluorocarbons produced significant mutation rates.[45]

Many halogenated organic solvents can cause the heart to become sensitized to epinephrine. If a worker is sensitized to epinephrine, a sudden fright may trigger the adrenal glands to release large quantities of epinephrine into the bloodstream which will cause the heart to begin ventricular fibrilation.[41]

Halothane, a fluorocarbon which is used as an anesthetic, has been suspected of causing cardiac arrhythmia.[105] In an experiment with dogs, the lowest level of fluorocarbon exposure capable of inducing cardiac arrhythmia was 0.5 percent (5,000 ppm) for 10 minutes. In addition, sensitization of the myocardium to epinephrine was only a temporary effect. An epinephrine injection given 10 minutes after exposure did not result in arrhythmia during these experiments.[106] Little or no problems seem to exist in the electronic component manufacturing industry with regard to cardiac sensitization because exposure levels of halogenated hydrocarbons are usually well below the high levels used in these experiments.

6.2.1.8 Alkyl Nitrites (Dimethylformamide)—

Dimethylformamide (DMF, DMFA) is an aprotic solvent for a wide range of organic substances, and it has a relatively slow evaporation rate. DMF inhalation or skin contact may cause abdominal pain, anorexia, nausea, constipation, vomiting, diarrhea, elevated blood pressure, hepatomegaly, and other signs of liver damage. The chemical has produced kidney damage in experimental animals.[14]

6.2.1.9 Aldehydes (Formaldehyde)—

NIOSH issued a Current Intelligence Bulletin in 1980 that presented evidence on the carcinogenicity of formaldehyde. NIOSH states that the evidence for animal carcinomas of the nasal turbinates is very strong, and that formaldehyde exposure should be reduced to the lowest feasible limit.[54] Formaldehyde may cause respiratory tract sensitization, and it may cause pulmonary edema if inhaled in high concentrations.[14]

Formaldehyde is a pyrolysis product of colophony soldering flux. In bacterial studies, formaldehyde has been consistently shown to be a weak mutagen. At this time, the data are inadequate to demonstrate whether or not formaldehyde is teratogenic.[55]

6.2.2 Gases

6.2.2.1 Introduction—

Numerous gases are used in the electronic components industry. There is little information available on the chronic toxicities of many of these gases. Since most of the more unusual gases are used in closed systems, their primary occupational hazard appears to stem from accidental release and acute exposure rather than chronic, low-level exposure.

Many of these gases can cause severe respiratory tract damage. The respiratory irritant gases can have both an acute and chronic effect on the tissues of the respiratory tract. The gases that affect the respiratory tract can be divided into two groups: upper and lower respiratory tract irritants.

Upper respiratory irritant gases used in the industry include ammonia and the halogen acid gases (hydrogen chloride and hydrogen fluoride). Although these gases are highly toxic, their irritant properties give warnings of their presence. For example, trichlorosilane, which is used in the semiconductor industry, decomposes in water to form hydrogen chloride, a known irritant.[81] Under most circumstances, irritation caused by these materials will force people to leave an area before dangerous concentrations accumulate.[41] These gases are highly soluble in water which is one reason for their intense, immediate irritation of the moist membranes of the upper respiratory tract. If a person becomes tolerant to the upper respiratory irritant effects, the possibility of deep lung irritation during exposure to higher concentrations is greatly increased. Hypersensitive persons may exhibit an asthma-like response to inhaling concentrations that are not irritating to the unsensitized people.[41]

The lower respiratory tract irritant gases may produce the acute effect of pulmonary edema, and some of these gases may cause chronic pulmonary fibrosis. These gases have low but appreciable solubility in water, and they may hydrolyze in water to produce a material that is a strong irritant. A mild irritation immediately results from inhalation of these gases. Because there is little or no irritation during exposure to low but toxic concentrations, these gases are quite hazardous. The pulmonary edema resulting from exposure to deep lung irritant gases is often delayed for several hours. Phosgene and the oxides of nitrogen are the more commonly encountered lower respiratory tract irritant gases.[41]

Another class of gases has the properties of being both upper and lower respiratory tract irritants. Halogen gases and germane, which are found throughout the electronic component manufacturing industry, are immediately irritating and can cause delayed pulmonary edema.[41]

Byproduct or secondary gases are theoretically possible but difficult to detect in electronic component manufacturing facilities. Ozone may be inadvertently formed near electrical discharges such as those from welders' arcs and X-ray generators. Ultraviolet light also causes the conversion of small amounts of ambient oxygen to ozone. Carbonyl chloride (phosgene) and carbonyl fluoride can be produced if chlorinated or fluorinated hydrocarbons are exposed to heat or flame. Therefore, welding, soldering, or brazing should not be performed on an object that has chlorinated solvent degreasing residue. Nitric acid is used extensively in the industry. When this acid mixes with organics, especially wood, nitrogen oxides will evolve. Exposure to nitrogen oxides can result in delayed pulmonary edema and concomitant heart failure.[14]

6.2.2.2 Boron (Boron Trichloride, Diborane, and Boron Tribromide)—

Boron trichloride, diborane, and boron tribromide are used as dopants in the semiconductor industry, and are respiratory tract irritants. Dopants are gases that are allowed to diffuse into the semiconductor crystal to modify its electronic properties. These dopant gases are provided in pressure cylinders and are used in closed systems. In chronic inhalation experiments, several species of animals exhibited marked pulmonary congestion, edema, and focal hemorrhage when they were exposed to 1 to 6 ppm diborane.[50] Boron trichloride forms hydrogen chloride on contact with the moist surfaces of the respiratory tract. The acute symptoms of diborane exposures are stated to be similar to those of metal fume fever, i.e., chills, fever, and tremors. Chronic exposure to diborane can result in wheezing, dyspnea, tightness in the chest, and a dry cough. Chronic diborane exposure of workers has also been known to cause hyperventilation which persisted for several years after the termination of exposure. Central nervous system effects were also reported from exposure to diborane.[14 41]

6.2.2.3 Metal Hydrides (Arsine and Germane)—

Arsine and germane are used in the semiconductor industry as dopant gases. In acute exposures, arsine and germane cause rapid hemolysis of the red blood cells (erythrocytes) and in many cases electrocardiographic changes are noted.[98]

The published literature revealed one instance of acute arsine exposure related to the electronic component manufacturing industry, but the exposed worker was employed by a specialty gas supplier as a deliveryman.[97] In another industry, one individual of an acute arsine exposure had evidence of bone marrow depression, and another person were still severly disabled 6 months after an acute arsine exposure.[99]

Hepatotoxicity has been reported as another result of arsine exposure.[115 116 117] In acute arsine exposures, there is usually a delay of 2 to 24 hours between exposure and the onset of symptoms of abdominal pain and bloody urine.[97] One case report describes renal damage with no other symptoms after an acute low-level arsine exposure.[118] This report recommends that workers who may be exposed to arsine have periodic urine examinations for arsenic and have routine blood and urine tests to detect renal damage.

Another report cited evidence of a cumulative damaging effect on the blood caused by chronic, low-level arsine exposure.[100] This damage has not been noted in the semiconductor industry. Previous exposure to trace amounts of arsine was documented but airborne arsine levels were not measured.[100 101] When arsine is inhaled, it breaks down to inorganic arsenic in the blood. Changes in cardiac performance have been reported after chronic arsenic exposure.[102]

Although no reports were located concerning chronic exposure-central nervous system effects, one report details the manifestation of reversible polyneuropathy and a mild psychoorganic syndrome following an acute arsine exposure. The symptoms appear after a latency period of 1 to 6 months.[90] In a separate incident of acute arsine poisoning, the recovered worker had evidence of a peripheral neuropathy 6 months after exposure.[91]

6.2.2.4 Asphyxiants (Simple Asphyxiants, Carbon Monoxide, and Cyanides)—

Many gases that are used in the electronic components industry have a very low inhalation toxicity or are physiologically inert, and exert their principal effect by dilution of oxygen in the inhaled air. These gases are often used to provide an inert atmosphere for some operations and to flush lines and vessels containing reactive gases.

Many simple asphyxiants are flammable and my be used as fuel. Some of these flammable gases are butane, cyclopropane, ethylene, ethane, isobutane, methane, propane, and hydrogen. The nonflammable simple asphyxiants include argon, helium, krypton, neon, nitrogen, sulfur hexafluoride, and xenon.

Carbon monoxide may accumulate to hazardous levels where internal combustion engines are operating in a confined space. Gasoline driven engines produce large amounts of carbon monoxide. Diesel and liquid petroleum engines produce less carbon monoxide than gasoline driven engines. The management at one electronics plant was concerned that carbon monoxide levels in an indoor loading dock facility were presenting a health hazard,[103] but ambient air measurements showed that the carbon monoxide levels were within the OSHA exposure standard. The suspected source of carbon monoxide was diesel forklift truck exhaust.

Plating operations are often used in the electronic component manufacturing industry. Several references were reviewed concerning potential cyanide exposures from plating processes.[104 165 166] Toxic concentrations of hydrogen cyanide, which forms when cyanide and acids are mixed, can result from electroplating operations.[5] Hydrogen cyanide gas may enter the body through inhalation or through the skin. This gas immediately stops basic cellular oxidative processes, and death results quickly from exposures above 250 ppm.[1] Procedures should ensure that cyanide dips or plating vats are maintained in the alkaline pH range and are protected from accidental mixing with any acid. Bulk acids and cyanide should never be stored in proximity to each other.

In one study, three factories using electroplating processes were surveyed, and cyanide concentrations in the breathing zones of the workers ranged from 4.2 to 12.4 ppm. Neurological symptoms reported by the exposed workers included headache, giddiness, weakness, and changes in their sense of taste and smell. Two workers in the most highly exposed group suffered from psychotic episodes. When removed from exposure, the workers recovered within 48 hours.[93]

6.2.2.5 Silicon (Silane, Dichlorosilane, Trichlorosilane, and Chlorosilane)—

Silane and silicon halides, including dichlorosilane, trichlorosilane, and chlorosilane, are gases at normal ambient temperature. These gases are used by the semiconductor industry in epitaxial growth and passivation processes. They are severely irritating to the skin and mucous membranes. The acute effects of breathing any of these silicon gases is lung irritation and possible pulmonary edema.[81] No information could be located that dealt with the chronic effect of exposure to these gases. Silane presents a severe fire hazard as it ignites spontaneously on contact with air. Trichlorosilane has a flash point of 7 ° F and a lower flammable limit in air of 0.1 percent, but it is acutely much less toxic than silane.[81]

6.2.2.6 *Phosphine, Phosgene, Nitrogen Oxides, and Ozone—*

Phosphine is a semiconductor dopant gas. Various effects of acute exposures have been reported, but no information on effects of chronic exposure was located.[14 51 52] A worker acutely exposed to phosphine experienced numbness of the fingers. This numbness was attributed to cervical spondylosis, which may be caused by the edema produced by acute phosphine exposure.[92] After an acute phosphine exposure, the victim may develop chronic hepatitis.[92] One source indicated that a survivor of an acute exposure to phosphine exhibited electrocardiographic and echocardiographic signs of myocardial injury.[52]

Phosphine is produced when phosphorus comes in contact with nascent hydrogen. The production of this gas usually requires a metal surface for the reaction to occur. Aluminum is especially efficient in promoting this reaction.

Phosgene and nitrogen oxides, which are represented in the electronic component manufacturing industry by nitric oxide and nitrogen dioxide, are capable of causing both acute and chronic pulmonary disorders. Both phosgene and nitrogen oxides cause delayed pulmonary edema if acute exposure is sufficient. If a victim of acute exposure to nitrogen oxides survives, a debilitating fibrogenic condition of the lungs may develop.[1] This condition is called bronchiolitis fibrosa obliterans, and victims may develop chronic,severe dyspnea accompanied by fever and cyanosis. Phosgene and nitrogen oxides were not used as process gases at any of the surveyed plants, but a potential for exposure exists via generation of these gases as byproducts of certain processes. Nitric acid is used by all segments of the electronics industry, and nitric acid reacts violently with organics, especially wood, to produce nitrogen oxides. Phosgene may be inadverdently produced by thermal decomposition of chlorinated solvents.

Chronic exposure to low levels of nitrogen oxides may produce symptoms suggestive of emphysema.[53] Evidence shows that exposure to nitrogen dioxide over-time causes a reduction in the elastin content of the lung. A study revealed that the elastin levels in hamster lungs did not return to normal until exposure at 30 ppm nitrogen dioxide for 22 hours per day for 3 weeks was terminated; however, this is a very high dose level.[53]

Ozone may be generated by high voltage electrical discharges and by ultraviolet light. High intensity mercury vapor lamps are used as a light source in some photolithography processes. The amounts of ozone generated are small.[1]

Aside from the serious effects of acute ozone exposure, chronic toxicity may occur at low exposure levels. Prolonged animal exposures to 1 ppm of ozone resulted in terminal airway passage thickening, narrowed air passages, and fibrotic tissue formation.[5] Two air samples taken in a semiconductor plant revealed ozone concentrations of 2.04 and 0.82 ppm in an area where diffusion operations were being conducted, and in another room containing an unknown operation.[56] When ozone enters biological tissue, it acts as a bi-free radical and ionizes nearby chemicals. The widespread consequences of this action result from what has been termed the radiomimetic properties of ozone.[41]

Some of the signs and symptoms of ozone overexposure are similar to those associated with exposure to ionizing radiation. Ozone reacts with DNA and RNA inside the cells and causes an alteration of the genetic makeup of the cell.[41] The mutagenic effect of ozone has been observed in bacteria, chick fibroblasts, human lymphocytes in vitro, and hamster lymphocytes in vivo. The hamsters were exposed to 0.2 ppm ozone for 5 hours. In another study, humans exposed to 0.5 ppm ozone for 6 and 10 hours did not have any evidence of lymphocyte chromosome aberrations, but a higher frequency of achromatic and chromatid lesions was observed. Observation of these lesions suggests that ozone has an effect on chromosomes which has been interpreted as the consequence of an unrepaired DNA single polynucleotide strand break. Exposures of humans to an environment containing ozone at concentrations of 0.5 ppm for 6 to 10 hours may be sufficient to produce subsequent persistent chromosomal aberrations in a significant number.[129]

6.2.3 Metals and Metallic Compounds

6.2.3.1 *Introduction—*

Many metals and metallic compounds are used in the manufacture of electronic components. Skin contact may result from direct handling of the bulk metal or from exposure to airborne metal in the form of dusts, fumes, or mists. Metal dusts may be generated by grinding, sawing, or other machining processes of metal parts, and fumes may be generated by hot processes such as welding, brazing, and soldering. Liquid mists that contain metallic atoms may be generated by plating baths if the baths are sufficiently agitated by stirring devices or when plated articles are removed from the bath.

A study conducted in the United States from 1968 to 1970 determined that nickel, mercury, and potassium dichromate were common skin sensitizers for man.[7] These substances are commonly used in the electronic component manufacturing industry. Nickel and chromium are frequently used in plating operations where worker exposures to these metals may occur.

In brazing and welding, fluxes are not the common source of fume evolution; the fume produced in these operations usually comes from the base or filler metal. These metal fumes can cause adverse health effects such as the common metal fume fever or "Monday morning sickness." Metal fume fever is characterized by fever, chills, shakes, and a general feeling of malaise. The fever is transient and most workers become acclimatized to the extent that they do not experience significant symptoms. However, a brief period without exposure, such as a weekend away from work, will cause the symptoms to reappear with the next exposure. Recently it has been postulated that metal fumes, composed of the oxide of the volatilized metal, must combine with carbon monoxide to produce the fever and weakness associated with the fever.[167] This metal oxide/carbon monoxide combination can occur in the heat of the welding arc or flame. The majority of the metals associated with brazing and welding are agents of metal fume fever.

Some metals used to manufacture electronic components are toxic even if they are not converted to the metal oxide. Chromium, nickel, and cadmium are examples of toxic metals which are frequently welded or brazed.[78] Beryllium, a potential carcinogen,[14] is an ingredient in some alloys.

6.2.3.2 Lead—

Some workers in the electronic components industry may be exposed to lead dust or fumes as a solder component. The first effects of excessive lead exposure include digestive symptoms (particularly constipation) and abdominal pains. If exposure continues, lead colic may develop. Lead colic is characterized by an intense periodic abdominal cramping associated with constipation and possible nausea and vomiting. Long-term exposure to lead can damage the kidneys with loss of renal function and progressive azotemia. Persons potentially exposed to lead should receive periodic evaluations of renal function.[14]

Lead is frequently used as an ingredient of solders, and soldering is widespread in the electronics industry. A Russian study states that, although the gross manifestations of lead poisoning, such as encephalopathy, nephropathy, sterility, and behavioral aberrations, have virtually disappeared from modern industry, effects such as mild anemia are still frequently encountered.[21] This study reports that small concentrations (approximately 0.01 mg/m^3) of lead in the workplace air can cause mild anemia evidenced by symptoms of fatigue and dizziness, and signs of decreased erythrocyte counts and reduced hemoglobin levels. However, a study of long-term hand solderers, using a 40-percent lead and 60-percent tin solder revealed that the solderers' lead blood levels were not statistically different from the blood lead levels of a control group that had no known lead exposure.[87]

Lead is a suspect carcinogen, but the evidence at this time is inconclusive.[41] In mice, 22 ppm lead administered in the drinking water resulted in loss of the strain in two generations with many abnormalities. In rats, lead was very toxic, resulting in many early deaths and runts.[140] Lead is reportedly toxic to the male reproductive systems,[134] and lead exposure may pose dangers to the developing human fetus.[138] A recent report stated that the average rate of spontaneous abortions was higher for women involved in the production of radios and televisions and their components than for all women taken as a a group.[133] Women involved in these occupations may be exposed to lead dust and fume during their pregnancy, but the actual causative agent has not been identified since other chemical agents were also present. Another source states that lead is suspected of involvement in stillbirths, sperm abnormalities, chromosome aberrations, decreased libido, atrophy of the testes, menstrual disorders, and teratogenesis.[131]

6.2.3.3 Gallium, Indium, and Antimony—

Two new semiconductor materials are gallium arsenide and indium antimonide. The major industrial use for gallium arsenide has been for light emitting diodes.[44] Indium antimonide may be employed as the semiconductor material in several component devices, and indium is an ingredient of some solders. One study that involved administering powdered gallium arsenide and indium antimonide into the lungs of laboratory animals reported that lung changes were noted on necropsy. The same study stated that when indium compounds were administered intracheally,[45] they caused inflammatory destructive changes as well as the development of fibrosis of the lung tissue.

In a large study, gallium citrate was subcutaneously injected into several animal species. The effects of these injections included an increase in blood urea nitrogen and nonprotein nitrogen, elevated blood sugar levels, diminished carbon dioxide transport capacity, and lowered pH of the whole blood. The study suggested that the major effect of gallium intoxication was kidney damage.[12] Radioactive gallium citrate was tested on human patients as a possible cancer treatment. The dosages were not given, but side effects were reportedly mild anorexia, malaise, and a significant lowering of the leukocyte and red cell values.[11]

A recent Russian article recommends a TLV of 2 mg gallium arsenide per cubic meter of air.[88] In white rats and guinea pigs, continuous inhalation of 4.2 mg/m^3 gallium arsenide for a 4 month period caused a decrease in erythrocyte count and body weight, and an increase in the summation-threshold index. After cessation of exposure, the weights and hematocrit returned to normal. Upon necropsy, animals exposed continuously for 4 months to 12 mg/m^3 gallium arsenide exhibited lung damage in the form of plasma fusion, homogenization of the vascular walls, and fibrosis of the interalveolar septa. The exposed animals also exhibited other toxic effects including vacuolar and granular degeneration of the epithelium of the convoluted tubules and fatty degeneration of the liver cells. Gallium arsenide ointment (75 percent) was applied to the skin of guinea pigs and rabbits for 30 days, and no adverse effects were observed. The compound was shown to be an ocular irritant after application of 50 mg of powder to the conjunctival sac.

Gallium and indium were injected into pregnant hamsters. Gallium was essentially negative for teratogenesis, but an indium dose of 1 mg/kg caused a 72 percent incidence of digital malformation. One percent of the gallium exposed embryos showed mild malformations consisting of limb bud abnormalities, spina bifida, and mild enencephaly.[139]

Antimony trioxide is a solid compound used as a semiconductor dopant. It is first evaporated from the bulk solid or powder form to produce a diffusable vapor. Inhalation of dusts or fumes of this material will cause severe respiratory tract irritation. Antimony trioxide was administered to guinea pigs in a chronic inhalation study and levels of 45 mg/m^3 resulted in fatty degeneration in some of the animal livers and extensive pneumonitis in all of the animals exposed.[48] However, rats exposed by inhalation to 1,700 mg/m^3 of antimony trioxide for 1 hour every 2 months for one year showed no pulmonary response.[48]

6.2.3.4 Cadmium—

Cadmium is an ingredient of solders, and metals which are used as fillers in brazing. Cadmium compounds are also used as phosphors in television picture tub manufacturing operations. Exposure to cadmium dusts or fumes may cause respiratory irritation.[46] Sixty-one rats were exposed to cadmium oxide fumes for 30 minutes at a concentration of 60 mg/m^3. Twenty-seven of the rats died from pulmonary edema within 3 days, and the remaining rats were observed for a period of 1 year. Upon examination, the exposed rats had a highly significant increase in the incidence of seminiferous tubule degeneration.[119]

The most common abnormality observed in workers chronically exposed to cadmium is proteinuria. Eighty-one percent of 43 workers exposed to cadmium for an average of 20 years in an alkaline storage battery plant had proteinuria. In another study, proteinuria was not found in workers exposed to cadmium for less than 2 years but was found in workers exposed to cadmium for 25 years or longer. Environmental levels were not reported in these two studies. Chronic cadmium exposure has also been associated with the formation of renal stones.[48] Chronic inhalation of cadmium oxide dust has been reported to cause pulmonary emphysema.[48] However, a study of workers exposed to cadmium sterate dust at concentrations ranging from 0.02-0.7 mg/m^3 for 1 hour per day showed no pulmonary effects. The length of exposure was not given. Moderate anemia has been noted in workers chronically (5 to 30 years) exposed to cadmium oxide dust and fume. Storage battery workers exposed to cadmium oxide dust exhibited symptoms of back and extremity pain, and walking difficulty. Itai-itai ("ouch-ouch") disease in Japan has been attributed to a high dietary cadmium intake due to pollution of water and crops by industrial wastes. The signs as revealed by radiography were similar or identical to those of osteomalacia, with painful joints and bones particularly in the back and legs.[48]

In mice and rats, 10 ppm cadmium administered through the drinking water caused loss of the strain within two generations due to fetal toxicity and teratogenesis.[140] Cadmium powder injected intramuscularly into rats induced injection-site fibrosarcomas in 60 percent of the animals.[136]

6.2.3.5 Yttrium—

Europium-activated yttrium orthovanadate is a cathodoluminescent phosphor used in color television picture tube manufacturing operations. In one plant, a material balance study revealed that every day 3 kilograms of this phosphor was released into the workroom environment during application of the phosphors to the picture tube. An increased rate of tracheobronchitis was observed among the workers exposed to these yttrium orthovanadate phosphors. During an observation period of 5 years, no permanent damage was noted among the 3,000 exposed workers. The airborne levels of the phosphor reportedly ranged from 0.02 to 3.2 mg/m^3, with a mean value of 0.844 mg/m^3.[47] In another study, mice were fed 5 ppm yttrium in drinking water for life. Yttrium was found to be carcinogenic and to enhance malignant disease in this study. The sites of the cancer were not given in the article.[132]

6.2.3.6 Silver—

Silver is a metal that is used throughout the electronic component manufacturing industry because of its superior electrical conductivity. Exposure to silver can cause a pigmentation aberration known as argyria. Silver exposure may result from soldering or brazing fumes or plating acid mist. Exposure to silver solutions or fine particles of silver can cause argyria. Inhalation of silver or skin contact with silver particles causes a permanent bluish discoloration of the skin. The nasal septum, eyes, and throat are among the first areas of the body to exhibit discoloration.[14]

Thirty employees of an industrial plant that manufactures silver nitrate and silver oxide were examined for signs of ocular argyrosis. Twenty of the 30 examined workers presented signs of conjunctiva pigmentation, and corneal pigmentation was present in 15 workers. Ten workers with the most significant levels of pigmentation reported decreased night vision, but electrophysiologic and psychophysiologic studies demonstrated no functional defects. Gross photoreceptor or conduction defects were not noted among the workers. However, although a significant functional deficit related to ocular silver deposition could not be documented, the possibility of subtle visual changes or future deficits could not be ruled out.[169]

Fine particles of silver were intramuscularly injected into rats to determine carcinogenicity, and silver was found not to be carcinogenic under the conditions of the experiment.

6.2.3.7 Beryllium—

Beryllium oxide is used as a getter material in electron tubes. Beryllium and its compounds are toxic materials. The acute systemic effects of beryllium inhalation are characterized by a nonproductive cough, substernal pain, moderate shortness of breath, and weight loss. Berylliosis is the chronic phase resulting from exposure to beryllium. Berylliosis is characteristed by granulomatous chest radiographic changes along with decreases in pulmonary diffusing capacity. The deterioration of the lung tissue may progress until a severe oxygen deficiency is evident. Death from berylliosis is usually caused by pulmonary insufficiency or right heart failure. The onset of the symptoms of berylliosis is commonly delayed for 5 to 10 years following the last beryllium exposure.[14] Beryllium is also a suspect carcinogen, but the evidence for carcinogenicity is inconclusive.[41].

6.2.3.8 Platinum—

Platinum is used in the semiconductor metallization process. The acute toxic symptoms of platinum poisoning in animals include vomiting, diarrhea, and bloody stools.[48] A specific Type I allergy to platinum chloride has been demonstrated in workers exposed to this material. The sensitization is very strong and exposure to very low levels produces dermatitis, bronchial asthma, rhinitis, and conjunctivitis.[147] Reportedly, 60 percent of people working in the platinum industry experience bronchial asthma.[147]

6.2.3.9 Gold—

Gold is an extremely conductive metal that is widely used in electronic component manufacturing industry. Skin and nail lesions have resulted from worker exposure to gold plating solutions in an electronics firm. The affected worker was exposed to gold potassium cyanide while cleaning gold electrode contacts. The dermatitis could have resulted from contact with the gold compound or an associated oxidizing agent such as meta-nitrobenzene sulfonic acid. The report did not indicate whether the dermatitis was a primary irritation or sensitization type.[15] Most of the metallic cyanides are skin irritants.

A study was performed to determine the carcinogenic potential of gold when injected intramuscularly into rats. Gold was determined not to be carcinogenic in this experiment.

6.2.3.10 Tantalum—

Tantalum and its compounds are used extensively in the capacitor industry. Tantalum may be found in slug or powdered form. Tantalum is possibly one of the most physiologically inert substances known. Inhalation of gross amounts of tantalum dust may produce a mild, reversible bronchitis or pneumonitis. Tantalum has been used for over 25 years in surgical implants without any evidence of pathogenesis.[48]

6.2.3.11 Mercury—

Some evidence indicates that a single brief exposure to a high concentration can cause chronic mercury poisoning symptoms that may last for several years. Six workers were exposed to a maximum of 44.3 mg of mercury vapor per cubic meter for about 8 hours. All six workers reported some symptoms 4 to 8 years after exposure. The symptoms included lack of motivation and sexual desire, asthenia, and shortness of breath.[89]

Another study noted an increased rate of spontaneous abortions among women involved in the production of radios and televisions. This study indicated that exposure to mercury may have been a contributing factor to the elevated spontaneous abortion rate, noting the women in this study may also have been exposed to lead, colophony, and other agents.[133] Another report also stated that mercury may present a hazard to the developing human fetus.[138]

6.2.3.12 Nickel—

Nickel is used as a cathode in electron tubes, and in electroplating solutions. Nickel is also used in the metalization of certain semiconductor devices. According to one report, 35.5 percent of all deaths among nickel workers in a nickel carbonyl refinery during the years 1938 to 1956 resulted from cancers of the lung and nose. The reported incidences of lung cancer among the nickel workers have ranged from 2.2 to 16 times the normal value.[137]

Three generations of mice and rats were administered 5 ppm of nickel in drinking water to determine the reproductive effects of nickel exposure. Nickel was classified as moderately toxic and resulted in many early deaths and runts.[140] Nickel is reportedly toxic to the male reproductive system.[134]

Nickel is also a cutaneous sensitizer and it causes a very irritating form of dermatitis known as nickel itch. [41] A recent study in England revealed that 10 to 14 percent of the population is sensitive to nickel sulfate,[7] but another study stated that the observed nickel sensitivity rates probably resulted form contact other than that resulting from occupational exposure.[9] This result is not surprising because some jewelry contains nickel. In 1968, two physicians reported 17 cases of nickel earlobe dermatitis treated in a 12-month period. In all 17 cases, the patients had been wearing pierced earrings containing nickel.[10]

6.2.3.13 Arsenic—

Arsenic is used in the electronic component manufacturing industry as a semiconductor dopant and component material. An article stated that arsenic may pose dangers to the developing human fetus,[138] and 5 ppm arsenite administered to rats and mice via the drinking water resulted in an abnormally high male to female ratio.

For many years, skin cancer has been associated with arsenic exposure, and multiple cancers of the internal organs have also been reported to result from arsenic exposure.[102] One report reveals an increased incidence of respiratory cancers among workers exposed to arsenic, but arsine exposure was not involved and the authors state that the effects of other chemical exposures could not be discounted.[130]

6.2.3.14 Tellurium—

Tellurium is a metal used in the manufacture of electronic components. Diethyltelluride

(DET) is used as a dopant, and tellurium has been implicated as a cause of polyneuritis of the peripheral nervous system.[81]

6.2.3.15 Tin—

In some semiconductor manufacturing facilities where electroplating processes are used, exposure to tin fumes and dust may occur. Tin exposure has resulted in dermal lesions such as acute localized burns or subactute irritation.[5]

6.2.3.16 Barium—

Barium sulfate has been found to be responsible for a benign pneumoconiosis in workers exposed to its finely ground dust. Barium carbonate has caused respiratory irritation in humans, and barium oxide dust may cause dermal and nasal irritation. Chronic exposure to barium or its compounds may affect the central nervous system. Bronchogenic carcinoma developed in rats that were intratracheally administrated particles of radioactive barium sulfate (^{35}S). Barium compounds are used as getters in some types of electron tubes.[48]

6.2.3.17 Cobalt—

An approximate LD_{50} of 20 mg/kg was determined in several animal species by intratracheal, intraperitoneal, and intravenous injection of cobalt chloride. Under conditions where cobalt or its salts cannot be eliminated as rapidly as they are absorbed, these materials appear to have a cumulative toxic action. The earliest sign of cobalt intoxication is the production of increased amounts of serium alpha globulins. Moderately high levels (1 to 5 mg Co/kg, as soluble salt by mouth) of cobalt intake cause polycythemia and higher levels cause destruction of the alpha cells in the pancreatic islets of rabbits. Chronic exposure to cobalt sulfate in humans has been shown to cause serious myocardial lesions. This chronic exposure was observed in excessive beer drinkers when cobalt sulfate was used as an anti-foaming agent. Cobalt metal dust is a bronchial irritant, and it has caused bronchial adenomastosis and adenocarcinoma in exposed rats. Allergy to cobalt has been reported.[48]

6.2.4 Particulates and Fibers

6.2.4.1 Introduction—

Several particulates and fibers are used in the electronic component manufacturing industry. Information from the literature search does not suggest these particulates and fibers present a hazard in the industry. However, a potential health hazard may be associated with these materials; therefore, their toxic properties and uses were reviewed.

6.2.4.2 Resin Dust—

Phenolic and epoxy resins are used as potting or encapsulating agents in the industry. After molding, some components are machined to remove excess resin. Both phenolic and epoxy resin dusts are considered physiologically inert if the resin is thoroughly cured. However, some workers may be sensitized to these dusts and exposure can result in asthma.[26] [33] Use of wetting agents during the machining of these substances will almost eliminate any dust problem.

6.2.4.3 Fibrous Glass—

In the reviewed literature concerning dusts and dermatitis, a frequently encountered problem involves exposure to glass fibers. Glass fibers are primary irritants that cause dermatitis by mechanically piercing the skin. Fibers responsible for one dermatitis outbreak reportedly originated from the filtering and insulating materials used in the heating and ventilation systems.[16]

Fibrous glass is used as a filler in some potting mixtures, and it is also used in the extensive particulate filtering systems that are employed in clean rooms of semiconductor manufacturing facilities. An epidemiologic study of retired fibrous glass workers showed that overall mortality was low. Although the study did not reveal any unusual health hazards among fibrous glass workers, it showed that an excess chronic bronchitis incidence may exist among these workers.[38] Because the sample size was small, the increased incidence of chronic bronchitis is inconclusive.

A study was conducted on 1,448 workers who were exposed to fibrous glass dust while employed in the manufacture of fiberglass construction products. In this group, a significant increase in deaths caused by nonmalignant respiratory disease was observed.[39] These workers had been employed from 5 to more than 30 years, and glass fiber airborne concentrations varied from 0.1 to 1.0 mg/m^3. The mean fiber length was 28 μm and the mean fiber diameter was 1.8 μm. No excess of malignant disease was found among these workers, including those who had worked 20 years after the onset of exposure. However, a case control study among the same population of employees who worked with smaller diameter glass fibers showed a marginally significant increase in malignant respiratory diseases. Furthermore, animal studies in which glass fibers were administered intrapleurally and intraperitoneally have produced both fibrosis and cancer.[39] Glass fibers of approximately 0.5 mm diameter were found to be highly carcinogenic when applied to the pleura of rats, and fibers of this diameter can be found in some fiberglass insulation.[40] Glass fibers are known to be respiratory tract irritants in humans, and pulmonary fibrosis has resulted in animal studies through both intrapleural and intraperitoneal administration.[39 40]

6.2.4.4 Silica—

Crystalline silica is often used in powder form as an ingredient in potting mixtures. Silica levels measured in the production area of one facility were reportedly below the level of detection.[34]

The literature search revealed some evidence that amorphous silica dust can cause fibrotic and granulomatous pulmonary disease. One study reported that 11 of 40 workers engaged in the production of silicon demonstrated definitive radiographic evidence of fibrosis and granulosis, but that three workers who were examined further did not exhibit any decrease in lung function. The workers had been exposed to unknown levels of amorphous silica dust for 11 to 18 years. The dust particles were reported to be opaque, round, and smooth and they ranged from 0.05 to 0.75 micrometers (mm) in diameter.[36] NIOSH states that some amorphous silica dusts possess the potential for inducing fibrotic pulmonary response following inhalation of sufficient quantities of material.[36] A white powder observed on the walls and rafters of one semiconductor facility was generated by the siemens decomposition process. The powder was reported to contain amorphous silica.[37]

6.2.4.5 Portland Cement—

Portland cement is used in small amounts as a potting compound in the manufacture of wire-wound resisters. Many of the Portland cement particles can be dispersed as a dust and are small enough to be inhaled deep into the lung.[41] The dust can be quite irritating to the lung tissue because of its highly alkaline nature.[41] A case report of a 57 year-old man who was exposed to unknown levels of Portland cement dust for 28 years while working in a cement plant was reviewed. The worker exhibited signs and symptoms of restrictive pulmonary disease of a granulatomatous nature. This worker was also found to have a granulatomatous hepatic disorder. At necropsy, Portland cement was identified in both the hepatic and pulmonary lesions.[42]

6.2.4.6 Mica—

Mica is another material from which a toxic dust can arise. Mica is used as a filler in some encapsulating compounds and as a dielectric in capacitors. Mica dust may contain significant amounts of crystalline silica, which may account for its toxicity.[42] A case was reviewed concerning a 46 year-old woman who had worked for 7 years grinding mice-bearing materials. At necropsy, the woman was found to have a granulamatous disorder of both the lungs and the liver. The lesions of both organs were found by histochemical and X-ray diffraction techniques to contain abundant inclusions of mica.[42]

6.2.5 Acids, Alkalies, and Oxidizers

6.2.5.1 Introduction—

A large number of acids, bases, and other corrosive materials are used in the electronic component manufacturing industry. These materials are often used as etchants and/or cleaners. When parts to be etched or cleaned are transferred from these baths, corrosive mists may be generated.[67] There is also the possibility of direct contact with the liquid acid or base, or the evolution of an irritant vapor. All of these corrosive materials primarily affect the skin, eyes, and upper respiratory tract of the worker.

Acids and alkalis are classified as primary irritants because of their corrosive chemical action on the skin. Irritation caused by acids or bases increases proportionately with the concentration of the solution. For example, vinegar is a dilute solution of acetic acid. Vinegar is not very irritating to the skin, but concentrated (glacial) acetic acid causes immediate and severe tissue corrosion. Although skin sensitization to acetic acid is rare, it has been observed.[5] The literature search revealed that citric acid along with acetic acid are two organic acids used in the electronic component manufacturing industry. Citric acid is weak and no skin irritation problems have not been reported.[5]

Inorganic acids used in the electronic components industry include hydrochloric, hydrofluoric, chromic, dichromic, nitric, fluoroboric, boric, sulfamic, perchloric, phosphoric, and sulfuric acids. Sufficient concentrations of each of these acids will cause damage to exposed skin. Boric, dichromic, and phosphoric acid are the least corrosive and irritating of the inorganic acids.[5]

Strong alkaline materials associated with the industry include sodium hydroxide, potassium hydroxide, calcium hydroxide, ammonia, and ammonium hydroxide.[6] In a concentrated solution or in solid form, these alkalis are more corrosive to the skin than are most acids. The hydroxides of sodium and potassium can produce deep and painful injury by gelatinizing body tissues.[5]

Several chemicals that are used in the manufacture of electronic components were tested for mutagenic properties using the bacterium Escherichia coli. Sulphuric, phosphoric, nitric, and hydrochloric acids did not increase mutation rates in Escherichia coli under the conditions of this experiment. Boric acid was the only tested inorganic acid that give positive mutation results. Ammonia, ammonium chloride, and hydrogen peroxide showed definite mutagenic activity, and acetic acid, formaldehyde, and phenol also proved to be mutagenic in Escherichia coli.[150]

6.2.5.2 Sulfuric Acid—

When sulfuric acid is used in the electronic component manufacturing industry, acid mist exposures may be present. In a teratology study involving mice and rabbits, sulfuric acid mist was not teratogenic in either species. The pregnant animals were exposed for 7 hours per day to 5 or 20 mg/m^3 of sulfuric acid mist on gestation days 6 through 15 and 6 through 18, respectively.[146]

6.2.5.3 Chromium Acids—

Both chromic and dichromic acids are used in the electronic component manufacturing industry as cleaners and in some photolithography processes. A mutagenicity study using Bacillus subtilis to test 127 metal compounds determined that the potassium salts of chromic acids are mutagenic.[135] Introduction of the chromate or dichromate ion into the blood through inhalation can cause methemoglobinemia.

6.2.5.4 Hydrogen Fluoride (Hydrofluoric Acid)—

Hydrogen fluoride is a gas and hydrofluoric acid is an aqueous solution of hydrogen fluoride. Hydrofluoric acid is unique because the fluoride ions can penetrate the skin and produce painful ulcers that heal slowly. Any area of the skin contacted with hydrofluoric acid should immediately be thoroughly washed with water and allowed to soak in water for a prolonged period. After soaking, the affected area should be treated with a magnesium oxide in glycerin ointment. In the case of severe skin contact, a physician should be consulted immediately to provide other treatments to stop the spread of the fluoride ion.[5]

One article reported a case of assumed chronic hydrogen fluoride intoxication. The exposed worker reported rectal incontinence with diarrhea after 1 to 2 years of hydrogen fluoride exposure primarily due to the inhalation of hydrogen fluoride gas. The worker was also troubled by severe headaches, weakness, and lower back pain. These symptoms diminished during time away from work, but later they became chronic. The back pains gradually extended down both legs, the worker's handwriting became illegible, and a decrease in intellectual power, especially loss of memory, became evident. After 10 years of what appeared to be gross over-exposure to hydrogen fluoride from flushing waste hydrofluoric acid down a drain, the worker's back and leg pains rendered him unable to continue working. Five years later his condition was not improved.[168]

6.2.5.5 Sodium Hydroxide—

A study involved a cohort of 291 workers who were employed in a plant producing sodium hydroxide and were exposed to sodium hydroxide dusts. The length of exposure ranged from less than 1 year to more than 21 years. The airborne dust levels were estimated to be between 0.5 and 2.0 mg/m^3. No significant increase in mortality could be found in relation to the duration or intensity of exposure.[43]

6.2.5.6 Hydrogen Peroxide—

Hydrogen peroxide is employed as a cleaner, especially in semiconductor processes.[28] Hydrogen peroxide is characteristic of all strong oxidizers, in that, sufficient concentrations of the compound will chemically corrode the skin.

6.2.6 General Manufacturing Materials

6.2.6.1 Epoxy Resin Systems—

Exposure to vapors and liquid epoxy resin system components may occur during application or curing of epoxy coated components such as diodes and transistors. Machining cured epoxies produces a dust that is relatively inert. However, any of the components of the resin system may be volatilized and released if machining feeds or speeds are too rapid or if tools are blunt.[26] The amount of compound volatilized may be very small, but even minimal exposure can cause serious reactions in sensitized persons.[41] During the walk-through plant surveys, epoxy resin systems were found to be commonly used in the electronic components industry, but the exact formulations employed were generally regarded as proprietary information.

Both the resins and the hardeners of some epoxy systems are irritants and sensitizers.[48] A recent NIOSH report stated that 37 percent of all workers in a electric generator manufacturing plant area where epoxies were used had some type of reaction to an epoxy patch test, and 2 of the 19 workers tested had reactions that were diagnosed as sensitization.[18] Approximately 90 percent of all unmodified epoxy resins used in industry are based on epichlorohydrin and bisphenol A (sometimes called diphenylol propane). The novolac resins are another type of epoxy resin that may be used in the electronic component manufacturing industry as electrical laminates, encapsulants, and molding agents. The novolac resins account for about 4 percent of the total production of unmodified epoxy resins, and they are composed of polyglycidil ethers of phenol-formaldehyde or cresol formaldehyde resins.[19]

Polyamines and polyamides are the two types of curing agents commonly used in epoxy resin systems. Polyamines are very aggressive compounds that are extremely irritating to the skin and mucous membranes. Some workers may become sensitized to these compounds.[68]

Polyamine curing agents include diethylene triamine, triethylenetetramine, 3,3-diaminodipropylamine, tetra ethylenepentamine, ethylene diamine, diethyl triamine, and diethyl amine. In contrast to the polyamines, polyamides are mildly irritating. Excess polyamine curing agents are sometimes reacted with a low molecular weight uncured epoxy resin to produce a polyamine adduct curing agent. The advantage of the adduct system is that there is much less free amine volatility and therefore much less potential for skin and eye irritation.[20 48]

Epichlorohydrin can cause a very serious dermatitis accompanied by severe pain in the subcutaneous layers of the skin. However, it is extremely unlikely that any unreacted epichlorohydrin would remain in the epoxy resin because modern manufacturing processes are purposely designed to eliminate this problem.[22]

The curing agents, diethylenetriamine and triethylenetetramine, are volatile substances, strong primary irritants, and potent sensitizers.[22] A NIOSH report states that the curing agent dodecyl succinic anhydride is less irritating and sensitizing than many other curing agents used in industry.[23] One report documents two cases of sensitization dermatitis from occupational exposure to the curing agent isophoronediamine (IPD).[24]

Resins and hardeners are not the only constituents of some epoxy systems. Modifiers such as polyamides, amino resins, phenolic resin furanes, and polysulfide liquid polymers occasionally are added to the basic resin-hardener system to alter the physical properties of the system. Polyamides and polysulfide liquid polymers are weak primary irritants on rabbits. Uncured amino and phenolic resins and uncured furanes can produce both irritant or allergic contact dermatitis.[25]

Other components of epoxy resin systems are plasticizers such as dibutyl phthalate and tricresyl phosphate; and reactive diluents such as phenyl glycidyl ether, allyl glycidyl ether, butyl glycidyl ether, styrene oxide, acetonitrile, and aliphatic diepoxide. Many of these substances may be irritants or sensitizers.[25]

Since hundreds of epoxy resins may exist, irritability and sensitization data for many of the compounds is sparse or nonexistent. Because of this lack of data, the irritability and skin sensitization potential of some compounds may be estimated on the basis of structural similarities to compounds that have been thoroughly tested. Such estimations are usually inaccurate.[27]

With epoxy resin systems, the possibility exists of worker exposure to vapors of the uncured resin, hardener, or curing agent. The amine hardeners of epoxy resin systems may cause respiratory tract sensitization in workers.[68] Six workers with asthma and one worker with chronic bronchitis were tested using bronchial provocation methods. The workers were exposed to various epoxy resin systems at work, and the provocation tests showed that asthmatic responses could be produced by inhalation of the hardeners triethylene tetramine fume, phthalic acid anhydride as fume or powder, and trimellitic anhydride. The tests also showed asthmatic reactions to uncured epoxy moulding powder fume.[69]

A separate study of epoxy resin workers revealed that exposure to the amine hardener 3-dimethylamino propylamine (3-DMAPA) causes significant decreases in pulmonary function. Functional deficits were found only in a subgroup with exposure levels of 0.55 to 1.38 ppm; no adverse effects were seen in another subgroup exposed to levels of 0.41 to 0.55 ppm. The pulmonary function decrease was caused by irritation rather than sensitization.[70]

Several of the epoxy monomers have demonstrable carcinogenic potential in mice. Although no effects resulted from tests of some of the monoepoxides, many of the more complex epoxides produced skin cancer in mice.[27] Epichlorohydrin, a common epoxy monomer, causes chromosomal aberrations in human lymphocyte cultures.[141] Another report contains the positive and negative results of animal carcinogenicity experiments with epoxies.[142]

In 1978, NIOSH issued a Current Intelligence Report which stated that epichlorohydrin should be handled in the workplace as if it were a human carcinogen. This recommendation was based on a long-term epidemiologic study that showed a significant increase in respiratory cancer in exposed workers and an inhalation study that showed an increased rate of nasal carcinomas in rats. Data on exposure levels were not available for the human study, but the levels for the animal study were given as 100 ppm epichlorohydrin vapor inhalation for 6 hours per day for 5 days per week during a 30-day period.[143]

At least one study reports that the pyrolysis products of epoxy resins are toxic. The one hour LC_{50} for rats has been determined to be 3.2×10^5 mg/m^3. No deaths were observed when the animals were exposed to this concentration of epoxy resin combustion products. The primary effect of exposure to the pyrolysis products was pulmonary edema. Lesser effects included histotoxic anoxia, and systemic renal and hepatic damage.[148]

6.2.6.2 Flux Fumes—

In one electronics factory surveyed by NIOSH, at least 20 percent of the workers who were solderers or worked in the vicinity of soldering operations exhibited the clinical symptoms of occupational asthma—an allergic reaction of the respiratory tract.[57] Asthma is characterized by coughing, shortness of breath, wheezing, and chest pain.

Many solders and fluxes are used in the electronics industry and many of the health problems associated with soldering are caused by inhalation of colophony fumes. Colophony consists of about 90 percent resin acid, which is mostly abietic acid with 10 percent neutral materials such as stilbene and various hydrocarbons. Pyrolysis products include aliphatic aldehydes such as formaldehyde.[58 59] Colophony fluxes are extensively employed in the electronic component manufacturing industry because they are noncorrosive and electrically nonconductive. When colophony fumes are inhaled, the exposed person may develop an allergic sensitivity.[60] Colophony sensitization and its symptoms develop over a period that varies from a few months to 16 years of exposure. The mean exposure period before symptoms develop is 4 years.[46] The worker experiences wheezing and breathlessness earlier in the work shift as the length of employment increases, and the symptoms may continue for many hours after the employee's work shift is finished.[46 61]

A study using bronchial provocation tests revealed that all of the 21 asthmatic solderers examined showed a strong respiratory reaction to colophony fumes.[62] Another report suggests that solders using colophony flux have a high incidence of occupational asthma and that colophony is the chief cause of morbidity and labor turnover in this occupation.[63]

Other soldering fluxes may also cause occupational asthma. Polyurethane fluxes may be coated on the soldering filler wire or may be applied over an entire circuit board before soldering operations.[26] Conclusive evidence shows that concentrations of diisocyanates and/or cyanides are present in the breathing zone of workers soldering with polyurethane flux. Measurements indicate that the concentrations of these two contaminates often accumulate to several times the allowable OSHA exposure limits.[26] Another flux that may cause occupational asthma is composed of 95-percent alkyl aryl polyether alcohol and 5-percent propylene glycol. Experimental tests with this flux fume produced considerable respiratory distress in one occupational asthma patient.[64] Other researchers report cases where inhalation of aminoethyl-ethanolamine, a flux used with aluminum, caused occupational asthma.[58]

A recent British article describes a procedure for the diagnosis of occupational asthma caused by inhalation of colophony fumes using peak expiratory flow rate records (PEFR).[65] The PEFR might also be used to diagnose mild to moderate asthma cases caused by the other flux fumes. The procedure uses measurements taken at work and at home to allow a distinction between asthmas of occupational and nonoccupational origin.

Control of occupational asthma caused by inhalation of solder flux fumes would be best accomplished by substitution of other fluxes that do not cause respiratory tract sensitization. However, suitable substitutes from a medical and process requirement standpoint may be difficult to locate and costly to implement. Adequate, properly maintained local exhaust ventilation systems for soldering operations are one method of control. One aspect of control that is often neglected is housekeeping. If dust and fumes from soldering operations are allowed to accumulate on surfaces in the work area, concentration in the workroom air will increase because of air movement resuspending the particles.[66]

6.2.6.3 Cutting Fluids—

Cutting oils and fluids are one of the major causes of contact dermatitis. Cutting fluid dermatitis is usually a primary irritation because it results in defatting of contacted skin; sensitization is rare. There is impetus to replace cutting fluids with soap water to eliminate irritation resulting from cutting fluids. Some of the soaps employed as cutting fluid substitutes contain colophony—the residue that remains after distillation of turpentine from pine resin. The soap substitutes that contain colophony may cause an allergic type dermatitis because colophony is a sensitizer.[30]

In one of the surveyed resistor plants, generation of an oil mist in the lead heading operation was observed. The mist was generated by the violent mechanical action of the highly lubricated components of the lead heading machine. Several types of cutting and grinding fluids are used in the electronic industry. Napthenic and paraffinic mineral oils may be used in their natural state, but these oil applications are limited. More often, additives of various types are blended with the mineral oils to produce cutting fluids that have a wider variety of applications. Additives may consist of vegetable, animal, and marine fats and fatty oils; esters and alcohols; or other chemicals such as sulfur, chlorine, and phosphorus. Water may be added to a mineral oil to produce a soluble cutting fluid. The soluble fluids also contain an emulsifying agent, additives, and preservatives. Other fluids, which contain no mineral oil, are termed chemical or semichemical fluids. Some of these chemical and semichemical fluids contain nitrites, nitrates, and amines, which can react to form nitrosoamines.[127]

Epitheliomas of the hands, arms, and scrotum were found in an epidemiological survey among machine tools operators in England, and one soluble cutting fluid was carcinogenic to three different strains of mice when it was applied to the skin.[128]

One recent epidemiological study surveyed 2,485 white males who worked 5 or more years in jobs that exposed them to oil mists. This study concluded that there was no evidence of an increased cancer rate in the 15 anatomical sites studied for cancer. A mildly elevated incidence of cancers occurred in the stomach and large intestine, and a two-fold incidence was evident after 20 years in men with 5 or more years of exposure. Exposures in this study included soluble and insoluble mineral oil mists.[127] Another epidemiological study of 5,189 white males who were employed in machining operations and experienced an oil mist exposure for at least 1 year produced results similar to the previously mentioned study. No increased incidence of cancer was evident except for possible cancer of specific digestive sites. The workers in this study had mixed exposure to insoluble and soluble mineral oils and to synthetic cutting fluids.[128]

6.2.6.4 Nonacid Etches—

Several nonacid etchants are used throughout the electronic component manufacturing industry. Ferric chloride, one of the major etchants, is a skin irritant, but industrial experience has indicated that ferric chloride does not produce significant skin problems. Some of the newer alkaline etchants are based on ammonium hydroxide and sodium chlorite. Ammonium hydroxide is not considered to be hazardous because ammonia vapors are so irritating that workers usually do not remain in contaminated areas. Sodium chlorite solution is an alkaline corrosive which is a hazard in dry form (dried sodium chlorite can explode).[26]

6.2.6.5 Fluoride Compounds—

A variety of fluoride compounds are used in the electronic component manufacturing industry. Hydrogen fluoride, hydrofluoric acid, ammonium fluoride and bifluoride, and boron trifluoride are all potential sources of fluoride exposure to the worker. Fluoride is also a component of some welding, brazing, and soldering fluxes. The effects of chronic exposure to fluorides from either dusts or vapors are uncertain. Fluorides are retained preferentially in the bone, and excessive intake of fluorides may result in an osteosclerosis which is detectable by X-ray. The first signs of skeletal fluorosis appear as changes in density of the lumbar spine and pelvis. Recent investigations suggest that skeletal fluorosis may exist in workers without any significant health effects.[14] Breathing the vapors of ammonium fluoride or ammonium bifluoride is also extremely irritating to the respiratory tract.[5] [14]

Fluorides combine with serum proteins to produce an antigen. Many cases of allergic contact dermatitis have been reported as the result of skin contact with fluoride and fluoride compounds.[31] [32] The relation between fluoride and cancer is controversial. Fluoride warrants a high priority for study as an evironmental carcinogen. Fluoride's ubiquity in air, food, and water, high physiological reactivity, and tendency to accumulate in the body make it a prime candidate for the induction of malignant disease.[151]

6.2.6.6 Phosphorus Compounds—

Phosphorus compounds such as phosphorus oxychloride, phosphoric acid, gallium phosphide, and gallium arsenide phosphide are used throughout the semiconductor industry. The toxicity of the metallic phosphorous compounds are generally the same as the toxicity of their parent metals. Both phosphoric acid and phosphorous oxychloride are primary irritants. Phosphoric is only mildly irritating while oxychloride can cause severe skin and respiratory tract corrosion. Exposure to oxychloride results from direct contact with the liquid or from breathing the vapor.[5] [14] [48]

6.2.6.7 Hexamethyl Disilizane—

Breathing the vapors of hexamethyl disilizane can be extremely irritating to the respiratory tract. No cases of sensitization to hexamethyl disilizane have been reported.[5] [14]

6.2.7 Chemical Combined Effects

Simultaneous industrial exposure to more than one toxic agent seems to be the rule rather than the exception, and this rule applies to the electronic component industry. Some of the signs and symptoms that are indicative of the presence of combined occurrence include effects greater than expected for a suspected single agent exposure, an atypical symptomology in the correct organ or tissue for the single agent suspected, or involvement of other organs or tissues other than those that would be ordinarily affected by exposure to the single agent.[152] As is the case in most industries, many of the combined exposures found in the electronic component manufacturing industry have not yet received sufficient investigation.

One of the most thoroughly researched combined effects is that of ethanol intake with concomitant exposure to industrial solvents. Studies showed that ethanol intake can significantly increase the toxic action of some commonly employed industrial solvents. However, in many cases, additive effects were not evident.

In one study, mice were orally administered 25 percent ethanol at the rate of 5 g/kg/day for periods ranging from 12 hours to 15 days before they were subcutaneously administered a 1.6 percent solution of chloroform. The researchers concluded that pretreating mice with both single and multiple intoxicating doses of ethanol resulted in increased incidence of abnormal liver function from a single minimally hepatotoxic dose of chloroform. The authors also suggested that these findings resulted from an ethanol-induced increase in liver lipids.[153]

Xylene is a solvent that is extensively employed in the electronic component manufacturing industry, especially in photolithography processes. A study was conducted in which rats were exposed to 300 ppm xylene vapor with simultaneous ethanol ingestion for 5 to 18 weeks. The behavioral effects in the combined exposure group were different from those in any of the single agent exposed groups. Preening frequency decreased in the ethanol and in the xylene exposed groups, whereas increased ambulation occurred only in the xylene-ethanol groups. In addition, the authors state that the increased brain protein destruction observed in the combined exposure group might reflect a toxic interaction of ethanol and xylene in the brain.[154]

In another study, male rats were administered a single oral dose of ethanol at a rate of 5 g/kg of body weight. Sixteen to 18 hours after the dose of ethanol, the rats were exposed for different time periods to various concentrations of the halogenated solvents carbon tetrachloride, trichloroethylene, 1,1,1-trichloroethane, and perchloroethylene. Ethanol potentiation, as measured by serum enzyme response, could be demonstrated only after exposure of rats to carbon tetrachloride or trichloroethylene.[155]

Rats exposed to 300 ppm isopropanol vapor for 5 days per week, 6 hours per day for 5 to 21 weeks simultaneously administered 5 percent ethanol in their drinking water. Although the ethanol treatment caused a marked synergistic narcotic effect during early exposure, it was concluded that the effects of isopropanol on the central nervous system might not be potentiated by simultaneous intake of ethanol.[156] It has been speculated that humans may have a lowered tolerance to ethanol or an increased consumption rate of ethanol because of the solvent exposure. A study was undertaken to determine if exposure to styrene vapors was associated with increased alcohol consumption or a reduced tolerance to alcohol. This epidemiological study consisted of interviews with 98 male workers who were occupationally exposed to styrene. Neither the duration of styrene exposure nor the degree of exposure, measured as mean mandelic acid concentration in the urine, was statistically significantly related to alcohol consumption, changes in the consumption or lowered tolerance.[157]

A study with mice was conducted to determine the synergistic effects of pretreatment with isopropyl alcohol and acetone on the hepatoxicity of several chlorinated solvents. Acetone or isopropanol was administered by gavage at a dose of 2.5 mL/kg as a 25 percent volume per volume solution 18 hours prior to an interperitoneal injection of different amounts of various chlorinated hydrocarbons. After 24 hours, blood samples were taken, and serum glutamicpyruvic transaminase (SGPT) activity was determined and used as a measure of hepatotoxicity. The most marked synergism occurred between chloroform and both acetone and isopropanol. Trichloroethylene also exhibited statistically significant toxic potentiation with acetone and isopropanol, and 1,1,2-trichloroethane showed potentiation with both these solvents. Toxicity from 1,1,1-trichloroethane was not found to be increased by acetone or isopropanol. The authors concluded that the ability of acetone or isopropanol to enhance the hepatotoxic response caused by exposure to chlorinated hydrocarbons varies proportionally with the basic hepatotoxicity of the solvent—the more hepatotoxic solvents are the most potentiated.[158]

An epidemiologic investigation of brazers in a naval shipyard reported that nitrogen dioxide gas may combine with cadmium oxide fumes to produce pulmonary edema in acute exposures.[159] If a brazing filler metal contains cadmium, the respiratory irritant effects of the cadmium fume and nitrogen oxides may enhance each other. Soldering and brazing using a oxyacetylene torch are processes found in the manufacture of electron tubes.

Methyl ethyl ketone (MEK) and methyl n-butyl ketone (MBK) are two organics used in the electronic component manufacturing industry. In one study, rats were exposed to MEK at 1,125 ppm and MBK at 225 ppm for 24 hours per day. The combination of MEK and MBK was found to be considerably more toxic than MBK or MEK alone. Animals exposed to the combination showed clinical paralysis after 25 days of exposure. Animals exposed to only MBK did not develop paralysis until 66 days after exposure. After 55 days of exposure, no peripheral neurotoxicity was observed in animals exposed to MEK. Additional studies were also carried out for 5 months, and no abnormalities were observed in the MEK-exposed animals.[160]

An extremely complex experiment in which rats were intubated with 27 industrial chemicals in all possible pairs indicated that tetrachloroethylene and butyl ether in combination was 2.76 times more toxic than would be expected if the combined effects were simply additive. Furthermore, tetrachloroethylene exhibited the tendency to produce greatly magnified toxicities in combination with other chemicals more often than any other chemical tested. However, with the exception of butyl ether, the chemicals which produced enhanced toxicity when they were paired with tetrachloroethylene are not employed in the electronic component manufacturing industry.[161]

In one study, the irritant properties of sulfur dioxide on lung tissue were enhanced by a high relative humidity and concomitant exposure to sodium chloride aerosol. This study measured pulmonary flow resistance in guinea pigs after exposure to 0.1 ppm sulfur dioxide and 900 to 1,000 mm/m^3 sodium chloride aerosol.[162] Sulfur dioxide may be released from sulfuric acid etches. Relative humidity may be an important variable in the physiological response to aerosols that are capable of absorbing atmospheric water vapor at relative humidities below 95 percent.[162]

One study demonstrated the combined effects of hydrogen fluoride and sulfur dioxide on pulmonary, liver, and brain toxicity in rats. This study indicates that the effects of hydrogen fluoride and sulfur dioxide should be considered additive.[163]

The effects of more than one solvent vapor in the workplace atmosphere, when they act upon the same organ system, should be considered additive.[214] In the electronic components industry, more than one vapor may be present. The allowable exposure limit in this situation should be calculated using the following equation.

$$\frac{C_1}{S_1} + \frac{C_2}{S_2} + \ldots \frac{C_x}{S_x} = A$$

where:

C = contaminant concentration, and

S = standard for the contaminant.

If A equals one or more, a noncompliance exposure is evident.[164] However, a health hazard may exist even though the sum of the equation is less than unity because combined effects may be synergistic instead of simply additive. The toxicity of two agents that exhibit synergism would be greater than this simple addition would predict.

6.2.8 Chemical Substitutes

Carbon tetrachloride has been suspected of causing hepatitis outbreaks in the electronics industry through nonintentional use. This solvent is a contaminant in many organic fluids, and as a contaminant, it is the suspected causative agent of at least one hepatitis outbreak.[107 108 109] Solvents found or suspected of contamination with carbon tetrachloride should be substituted with a safer chemical immediately.

Substitutions for organic solvents or any other process chemical should be chosen carefully. Chemical toxicity, flammability, vapor pressure, and the biological half-life of the material should be given prime consideration. The biological half-life becomes very important when nonstandard workweeks are in effect. Many workers in the electronic component industry work more than 40 hours per week, and many work more than 5 days of any given week. These schedules may result in a higher exposure to chemical agents at the workplace.

As an illustration of the importance of the biological half-life, consider the two solvents trichloroethylene and perchloroethylene. Trichloroethylene has a biological half-life of 8.7 hours; the half-life of perchloroethylene is 71.5 hours. The change from a 5-day, 40-hour workweek to a 6-day, 48-hour workweek would not cause an increase in the level of trichloroethylene in the body. The same change to a 6-day workweek will increase the body burden of perchloroethylene by nearly 9 percent after 2 weeks.[110]

Fluorocarbons are good substitute solvents in degreasing operations if their chemical and physical characteristics are compatible with process requirements. These solvents are only slightly toxic when inhaled even for extended periods, have very little effect on the skin, and are nonflammable.[111] However, prolonged exposure to high concentrations of fluorocarbons can cause cardiac sensitization to epinephrine,[14 112] and pyrolysis products may include carbonyl fluoride.

Substitute solvents for trichloroethylene include 1,1,1-trichloroethane and methylene chloride. Both these solvents have little or no toxic effects on the liver and kidney. However, exposure to methylene chloride can cause the formation of carboxyhemoglobin.[41] The 1,1,1 isomer of trichloroethane should not be confused with the 1,1,2 isomer, which is considerably more toxic than 1,1,1-trichloroethane.[72] Two recent studies of workers exposed to 1,1,1-trichloroethane and methylene chloride revealed no clinically pertinent findings associated with exposures to these chemicals for prolonged periods of time.[113 114]

6.2.9 Allergens, Carcinogens, Mutagens, Reproductive Hazards, Sensitizers, and Teratogens

The materials listed in Table 6-1, Table 6-2, and Figure 6-1 are carcinogens, mutagens, teratogens, allergens, or hazardous to the fetus or reproductive system. These chemicals are used in the manufacture of electronic components but are not meant to be inclusive of all the process chemicals exhibiting the above hazards.

Table 6-1 lists a number of confirmed and suspected carcinogens used to manufacture electronic components and the respective target organs or systems. The confirmed carcinogens have been proven to cause cancer in humans by extensive and conclusive epidemiological research. The suspected carcinogens are substances which are suspect of inducing cancer in man based on limited epidemiological evidence or by demonstration of carcinogenesis in one or more animal species.[214]

Table 6-2 is a listing of chemicals used to manufacture electronic components that may have adverse effects on the reproductive system. Figure 6-1 is a list of chemicals used in the electronic components industry that may cause allergic reactions. The materials listed in Figure 6-1 are called allergens or sensitizers. The worker must be in contact with an allergen at least twice, and usually several times, over a period of several months or years, before a reaction will result. The initial exposures serve to prime or sensitize the immune system. The allergic reaction may be in the form of or in any combination of contact dermatitis, bronchial asthma, lacrymation, and/or anaphylactic shock.

6.2.10 Recommended Chemical Exposure Limits

Table 6-3 contains the Occupational Safety and Health Administration (OSHA) permissable exposure limits, the American Conference of Government Industrial Hygienists (ACHIH) threshold limit values, and the NIOSH recommended standards for the major chemicals in use in the manufacture of electronic components. The chemicals listed in Table 6-3 are not inclusive of all the chemicals used to manufacture electronic components that have OSHA, ACGIH, or NIOSH exposure limits. Rather, the chemicals listed are those most commonly encountered in the hazard assessment. The exposure limits listed in Table 6-3 are currently in use but may change after publication of this report.

Solvents

- Aniline
- Formaldehyde
- Isopropyl alcohol
- n-Butyl acetate
- Toluene diisocyanate

Metals and Metallic Compounds

- Aluminum silicate
- Arsenic trioxide
- Chromic acid
- Chromium
- Dichromic acid
- Gold
- Nickel
- Platinum salts
- Potassium dichromate
- Sodium dichromate

Other

- Colophony
- Epoxy resins and hardeners
- Fluorides
- Ammonia
- Sulfur dioxide
- Polyruethane fluxes

Figure 6-1. List of sensitizers associated with the manufacture of electronic components.[71]

TABLE 6-1. CONFIRMED AND SUSPECTED ANIMAL CARCINOGENS USED IN THE ELECTRONIC COMPONENT MANUFACTURING INDUSTRY[14]

	Occupational carcinogen	
Target organ/tissue	Confirmed	Suspected
Bone		Beryllium
Gastroenteric tract	Asbestos	
Hematopoietic tissue	Benzene	
Kidney		Chloroform[125]
Larynx	Asbestos Chromium (VI)	
Liver		Carbon tetrachloride Chloroform Perchloroethylene[125] 1,1,2-Trichloroethane[125] Trichloroethylene
Lung	Arsenic[35] Asbestos Chromium (VI) Nickel	Beryllium Cadmium Cobalt[48] Fiberglass[40]
Lymphatic tissue		Arsenic Benzene
Nasal cavity	Chromium (VI) Nickel	Epichlorohydrin
Prostate		Cadmium
Skin	Arsenic	Phenol[123] Cutting oils

TABLE 6-2. SUSPECTED CHEMICAL EFFECTS ON THE REPRODUCTIVE SYSTEM

Chemical	Chemical effect				Reference
	Mutagen	Teratogen	Fetotoxin	Male reproductive system toxin	
Acetic acid	X				150
Ammonia	X				150
Ammonium chloride	X				150
Arsenic		X	X		138, 140
Benzene			X		122
Cadmium		X	X		41, 140
Chloroform	X		X		49, 126
2-Ethoxyethanol		X			124
Formaldehyde	X				150
Hydrogen peroxide	X				150
Indium		X			41
Lead		X	X	X	138, 140, 134
Manganese				X	134
Methylene chloride	X				126
Molybdnenum			X		140
Nickel		X	X	X	138, 140, 134
Ozone	X				129
Perchloroethylene	X				126
Potassium chromate	X				135
Potassium dichormate	X				135
Selenium			X		140
Styrene	X				140
Toluene			X		122
Trichloroethylene	X				126

TABLE 6-3. EXPOSURE STANDARDS FOR MATERIALS ASSOCIATED WITH THE MANUFACTURE OF ELECTRONIC COMPONENTS

Material	OSHA PEL[a]	ACGIH TLV[b]	NIOSH recommended standard[c]
Acetic acid	10 p[d]	10 p	
Acetone	1,000 p	1,000 p	
Alumina		10 m[e]	
Aluminum—dust		10 m	
fume		5 m	
Aluminum acetate		2 m	
Ammonia	50 p	25 p	
Ammonium chloride—fume		10 m	
Aniline	S[f] 5 p	S 2 p	
Antimony—and cpds. as Sb	0.5 m	0.5 m	
Arsenic	0.5 m	0.2 m	
Arsenic trichloride		0.2 m	
Arsine	0.05 p	0.05 p	
Barium	0.5 m	0.5 m	
Barium carbonate	0.5 m	0.5 m	
Barium oxide	0.5 m	0.5 m	
Beryllium—and cpds. as Be	0.002 m	0.002 m	
Boron oxide	15 m	10 m	
Boron tribromide		1 p	
Boron trifluoride	C[g] 1 p	C 1 p	
2-Butoxyethanol	S 50 p	S 25 p	
n-Butyl acetate	150 p	150 p	
Cadmium—salts and dusts	0.2 m	0.05 m	0.04 m
fume	0.1 m	0.05 m	0.04 m
Calcium carbonate	15 m	10 m	
Calcium hydroxide		5 m	
Carbon dioxide	5,000 p	5,000 p	10,000 p
Carbon monoxide	50 p	50 p	35 p
Chlorobenzene	75 p	75 p	
Chloromethane	200 p		
Chloroform	50 p	10 p	C 2 p
Chromium—metal and soluble chromic and chromous salts, as Cr	0.5 m	0.5 m	
Chromium (VI)—water soluble cpds. as Cr (VI)	0.1 m	0.05 m	0.001 m
Copper—dusts and mists, as Cu	1 m	1 m	
fume	0.1 m	0.2 m	
Cobalt—metal fume and dust, as Co	0.1 m	0.1 m	
Cyanide	5 m	5 m	5 m
Diborane	0.1 p	0.1 p	
Dichromic acid	0.1 m	0.05 m	0.001 m
Dimethylformamide	S 10 p	S 10 p	
Epichlorohydrin	5 p	2 p	0.5 p
Ethanol	1,000 p	1,000 p	

TABLE 6-3. EXPOSURE STANDARDS FOR MATERIALS ASSOCIATED WITH THE MANUFACTURE OF ELECTRONIC COMPONENTS

Material	OSHA PEL[a]	ACGIH TLV[b]	NIOSH recommended standard[c]
Ethanolamine	3 p	3 p	
2-Ethoxyethyl acetate	S 100 p	S 50 p	
2-Ethoxyethanol	S 200 p	S 50 p	
Ethyl acetate	400 p	400 p	
Ethylene glycol		C 50 p	
Fiberglass	20 mp[h]	20 mp	
Fluoride	2.5 m	2.5 m	
Fluorocarbons	1,000 p	C 1,000 p	
Formaldehyde	3 p	C 2 p	C 0.8 p
Germane	0.2 p		
Glycerine		10 m	
n-Hexane	500 p	100 p	100 p
Hydrogen chloride	C 5 p	C 5 p	
Hydrogen cyanide	S 10 p	SC 10 p	C 5 p
Hydrogen fluoride	3 p	3 p	2.5 p
Hydrogen peroxide	1 p	1 p	
Indium		0.1 m	
Indium antimononide—as In		0.1 m	
Iodine	C 0.1 p	C 0.1 p	
Iron oxide—fume	10 m	5 m	
Isopropanol	400 p	S 400 p	400 p
Lead—inorganic dust and fume as Pb	0.05 m	0.15 m	
Magnesium oxide—fume	15 m	10 m	
Manganese	C 5 m	C 5 m	
Mercury	0.1 m	0.05 m	0.05 m
Methanol	200 p	S 200 p	200 p
2-Methoxyethyl acetate	S 25 p	S 25 p	
Methylene chloride	500 p	100 p	
Methyl ethyl ketone	200 p	200 p	
Methyl isobutyl ketone	100 p	50 p	
Mica	20 mp	20 mp	
Molybdnenum	15 m	10 m	
Nickel	1 m	0.1 m	0.015 m
Nickel carbonyl	0.001 p	0.05 p	0.001 p
Nitric acid	2 p	2 p	2 p
Nitric oxide	25 p	25 p	25 p
Nitrogen dioxide	C 5 p	3 p	C 1 p
Oil mist	5 m	5 m	
Ozone	0.1 p	0.1 p	
Paraffinic mineral oil	5 m	5 m	
Perchloroethylene	100 p	S 50 p	50 p
Petroleum distillates	500 p	400 p	90 p
Phenol	S 5 p	S 5 p	5 p
Phosgene	0.1 p	0.1 p	0.1 p

(continued)

TABLE 6-3. EXPOSURE STANDARDS FOR MATERIALS ASSOCIATED WITH THE MANUFACTURE OF ELECTRONIC COMPONENTS

Material	OSHA PEL[a]	ACGIH TLV[b]	NIOSH recommended standard[c]
Phosphoric acid	1 m	1 m	
Phosphoric—yellow, white	0.1 m	0.1 m	
Platinum—soluble salts as Pt	0.002 m	0.002 m	
Portland cement	50 mp	30 mp	
Potassium hydroxide		C 2 m	
Propanol—1,1,n,1,2	200 p	S 200 p	200 p
Rhodium	0.1 m	1 m	
Selenium	0.2 m	0.2 m	
Silane		5 p	
Silicon		10 m	
Silicon carbide	10 m	10 m	
Silver—metal	0.01 m	0.1 m	
Silver—sol. Cpds as Ag	0.01 m	0.01 m	
Sodium hydroxide	2 m	C 2 m	
Stibine	0.5 m	0.5 m	
Stoddard solvent	500 p	100 p	60 p
Sulfur dioxide	5 p	2 p	0.5 p
Sulfur hexafluoride	1,000 p	1,000 p	
Sulfuric acid—mist	1 m	1 m	
Tantalum	5 m	5 m	
Tellurium	0.1 m	0.1 m	
Thallium	0.1 m	S 0.1 m	
Tin	2 m	2 m	
Toluene	200 p	S 100 p	100 p
Toluene diisocyanate	0.02 p	C 0.005 p	0.005 p
Tributyl phosphate	5 m	2.5 m	
1,2,4-Trichlorobenzene		5 p	
1,1,1-Trichloroethane	S 10 p	S 10 p	
1,1,2-Trichloroethane	350 p	350 p	C 350 p
Trichloroethylene	100 p	50 p	100 p
Tungsten—solublef		1 m	
insoluble		5 m	
Xylene	100 p	100 p	S 100 p
Xthium	1 m	1 m	
Zinc chloride—fume	1 m	1 m	
Zirconium	5 m	5 m	
Zironium oxide—as Zr	5 m	5 m	

Asbestos: **OSHA**

2 fibers>5 μm/cc

ACGIH

Amosite	0.5 fiber>5 μm/cc
Chrysotile	2.0 fiber>5 μm/cc
Crocidolite	0.2 fiber>5 μm/cc
Other forms	2.0 fiber>5 μm/cc

(continued)

Footnote for Table 6-3 continued

Chrystalline silica (respirable).

OSHA AND ACGIH

Quartz: $\frac{10\ mg/m^3}{\%\ SiO_2 + 2}$

Cristabolite and tridymite: Use ½ quartz formula

NIOSH

50 mg/m^3 respirable free crystalline silica

[a] PEL—the Federal 8-hour time-weighted average permissible exposure limit as promulgated by the Federal OSHA.[213]

[b] TLV—8-hour time-weighted average threshold limit value as published by the ACGIH.[214]

[c] Recommended Standard—8-hour time-weighted average exposure as recommended by NIOSH.[187]

[d] p—parts of contaminant per million parts of air, by volume (ppm).

[e] m—milligrams of contaminant per cubic meter of standard air (mg/m^3).

[f] S—skin notation advises that the substance readily penetrates the intact skin.

[g] C—ceiling standard for which the contaminant concentration must not be exceeded for more than 15 minutes in any 8-hour period.

[h] mp—miliions of particles of contaminant per cubic foot of standard air.

6.3 PHYSICAL AGENTS

The physical agents can be divided into four broad categories: electromagnetic and particulate radiation, noise and vibration, temperature, and pressure.

6.3.1 Electromagnetic and Particulate Radiation

The electronic component manufacturing industry produces many components that generate electromagnetic radiation. Operating electronic tubes may generate electromagnetic radiation, and semiconductor devices may be used to process electromagnetic radiation. Electron tubes and semiconductors are usually tested before marketing, and workers may be exposed to electromagnetic and particulate radiation when they test these devices. Radiation is used in the fabrication of passive electronic components such as resistors and capacitors. Occasionally, radiation is inadvertantly generated during the manufacturing processes.

The literature indicates that testing and control laboratories in electronic component manufacturing facilities are the primary source of radiation exposures. The most common exposures are to X-ray, ultraviolet, infrared, microwave, and radio frequency radiation.[26 46] Proper design, operation, and maintenance are necessary to control these physical hazards.

6.3.1.1 Microwave and Radio Frequency Radiation—

A team of researchers examined the effects of low-level microwave exposure on arterial pressure in 885 electronics workers.[171] The study suggests that workers exposed to hundreds of microwatts of radiation per square centimeter had a significant incidence of elevated blood pressure; however, researchers state that high ambient air temperatures in the work area could have been a major contributor to the elevated blood pressure. The researchers state that exposure to microwave radiation at intensities below 10 microwatts per square centimeter was not associated with elevated blood pressure levels.

Microwave and radio frequency (MW/RF) radiations are suspected of causing cataract formation in humans;[172 173] however, in one case, cataract formation in a radar technician was diagnosed to result from trauma not associated with radar.[174] The principal hazard from MW/RF radiation is a thermal effect on the tissues of the body where thermal sensitivity is poor (i.e., the viscera). Other affected organs are the eyes and the testicles. A decrease in fertility rates has been alleged to have resulted from MW/RF exposure.[175]

The biological effects produced in man by exposure to microwave radiation and the levels of exposure that can induce the effects are unclear. The long-term effects of microwave radiation are especially uncertain. Nonthermal and microthermal effects have received much inquiry without the production of much useful information. The literature search indicated that the nonthermal effects involve nearly all systems of the body, particularly the centralnervous, cardiovascular, and endocrine systems.[176] Nonthermal effects are not associated with a temperature rise, and microthermal effects are associated with minute temperature elvation in specific tissues that absorb microwave radiation.

A recent epidemiological study of 20,000 male radar technicians potentially exposed to microwave radiation during the Korean war did not reveal any adverse effects that were experienced by the men and could be attributed to microwave exposure. However, functions and behavioral changes and ill-defined conditions that have been reported as effects of microwave exposure could not be investigated in this study.[176] Another study of similarly exposed servicemen also failed to show a relationship between microwave exposure and cataract incidence.[177]

Another article selectively reviewed recent publications on the effects of radio frequency and microwave radiations on biological tissues.[178] The emphasis of this review was the low-level effects that might occur below the current exposure standard. This study revealed that 20 to 30 minute exposures of 0.03 to 2.5 mW/cm^2 (the U.S. standard is 10 mW/cm^2) have altered the permeability of the blood-brain barrier of rats to certain compounds. This altered permeability was apparent 4 hours after exposure. The author concludes that this efect may allow normally excluded substances to penetrate the brain. Therfore, infectious and toxic agents may enter the brain that would normally not pass through the blood-brain barrier. The implications of this very significant discovery should be further researched. The study also states that there is ample evidence that subtle behavioral and physiological changes occur in mammals exposed to low levels of microwave radiation. The author recommends that the U.S. standard be reduced to 1 mW/cm^2.[178]

In one semiconductor facility surveyed by NIOSH, radio frequency induction coils were employed as heating devices in vacuum furnaces in the thin rod production area for growing silicon ingots. This area had not been monitored for radio frequency energy levels.[37]

6.3.1.2 Particulate Radiation—

Beta radiation is used in the industry to make routine estimations of plated coating thickness,[26] and alpha radiation may be used to remove static charges. The specific nuclides and their energy levels used by the electronic components industry were not revealed in the literature review. These levels are known to and regulated by the NRC and respective state agencies.

It is likely that radionuclides of many different energy levels are used for different purposes. Beta radiation is easily shielded by only a few centimeters of plastic or aluminum; however, procedures should guard against ingestion of alpha or beta emitters. These materials are not very hazardous outside the body, but they can cause severe damage if they gain entrance to the body through ingestion or inhalation.

6.3.1.3 Infrared Radiation—

All hot bodies emit infrared radiation. This radiation has a wavelength that is invisible to the human eye; therefore, it does not produce an avoidance reaction similar to that caused by glare or brightness. One report discusses a worker who received eye damage and hand burns from a 500-watt quartz-halogen tungsten lamp used to install heat shrinkable soldering devices.[179] After three months of exposure, ocular symptoms included blurred vision, cortical lens opacities, and stripping of the pigmented epithelium. A viewing shield over the infrared tool greatly reduces the potential hazard from infrared radiation from this source.

6.3.1.4 Laser Radiation—

Lasers are used for various purposes in the electronic component manufacturing industry; types of lasers include visible wavelength, Q-switching, ultraviolet, infrared, gas, and repetitively-pulsed lasers. The retina of the eye is the tissue most readily damaged by visible lasers. Laser irradiation has produced iritis and cataracts in animals studies.[180] Biological damage from exposure to multiple-pulsed lasers can be 100 times as great as the damage produced by a single-pulse laser having the same total energy.[181] Another study states that the integrity of the pigment epithelium of the human eye is lost and retinal damage probably will result from a clinical ruby laser exposure of greater than 16 joules per square centimeter.[182] Additional information on laser wavelength, type, and power output is provided in reference 214.

6.3.1.5 Ultraviolet Radiation—

Ultraviolet radiation is used in some photoresist processes in the electronic components industry.[6] Ultraviolet exposure principally affects the skin and the cornea of the eye. Ultraviolet light is invisible to mammals; therefore, it can cause ocular damage before the exposed person is aware of the danger. After eye exposure, there is a latent period before symptoms become evident. This latent period varies from ½ to 24 hours, but it is typically 6 to 12 hours. After the latent period, the symptoms of conjunctivitis, lachrymation, photophobia, and blepharospasm accompanied by a paresthesiasis of "sand in the eyes" may occur. Unlike the skin, the eye does not develop a tolerance to ultraviolet exposure. However, ocular exposure to ultraviolet light very rarely results in permanent damage.[183] Additional information on ultra-violet radiation is provided in reference 214.

6.3.1.6 X-Radiation—

X-rays can cause chemical ionization in body tissues, and the resulting damage can be serious. Any electrical device operating at more than 16,000 volts should be regarded as a potential source of x-ray exposure.[170] The electron microscope operates at more than 16,000 volts, and it may be employed in the research and development aspects of the electronic components industry. These microscopes are used to evaluate thin-film memory elements, and electron microscopes may become an important tool in the field of high resolution information storage and retrieval systems. A survey of 45 electron microscopes revealed that 11 of these devices were emitting detectable amounts of x-radiation.[184] However, no radiation was detected at the operator's position, and exposure levels were not measured.

Television picture tubes are known to emit x-radiation, but one study revealed that picture tube testers received very minimal amounts of x-ray exposure.[185]

6.3.2 Noise and Vibration

Noise may not be a significant hazard in the manufacture of electronic components;[46] however, OSHA has issued several noise citations in the industry (see Appendix C). Ultrasound levels near ultrasonic cleaners and turning devices that are used in the semiconductor industry do not appear to create a hazardous working environment.[186]

6.3.3 Temperature and Pressure

Health problems from extreme temperatures were not mentioned in the surveyed literature. The only study discussing heat stress in the industry stated that exposures are minimal because high temperatures exist in only very small heating units.[46] No references concerning human exposure to abnormal atmospheric pressures in the electronics industry have been located.

6.3.4 Carcinogenicity, Mutagenicity, and Teratogenicity

Ionizing and certain nonionizing radiation can cause cancer, genetic mutations, and fetal abnormalities. These radiation-induced abnormalities are the subject of current research.

Microwave and radio frequency radiations have been implicated in a vast array of biological phenomena such as altered transmembrane potentials, increased membrane permeability, hyperthermia, hormonal imbalance, chromosomal anomalies, and mutagenesis. The relationships and mechanisms are not fully understood but these phenomena have been associated with carcinogenesis.[175]

Exposure to microwave radiation is alleged to have caused pancreatic cancer in radar repair workers, brain cancer in electronic workers, and leukemia in the Moscow embassy employees.[175] Much more research is needed in this area to confirm or refute these allegations.

In one study, rats were exposed throughout gestation to 35 mW/cm^2 microwave radiation at 6,000 MHz. The mean exposure period was 102.3 hours. All animals were killed on the 22nd day of gestation, and feti and mothers were examined for the following parameters: maternal weight gain, maternal blood elements, litter size, fetal weight, placental weight, resorption rate, and abnormality rate. These parameters did not indicate a significant difference between the experimental and control groups.[188]

Ultraviolet light causes skin cancer in mice, and it is suspected of causing skin cancer in man. Animal experiments clearly show that repeated exposure to ultraviolet light had a cumulative carcinogenic effect. Therefore, it is important to consider the ultraviolet light hazard in terms of repeated exposure rather than in terms of the magnitude of single exposures. The magnitude of the dose, wavelength, and the time lapse between exposures affect the rate of carcinogenesis.[189]

6.4 ERGONOMIC STRESSES

Eyestrain, psychogenic illnesses, and repetitive motion were among the ergonomic stresses cited in the literature. Discussion of these occupational illnesses reflects the extent of the information available in the published literature.

6.4.1 Stress-Related Health Incidents

Many chemicals in the workplace atmosphere can be detected by their odor before they reach hazardous concentrations. In one electronics plant 90 first-shift reported several nonspecific symptoms, including headache, dizziness, and lightheadedness, in response to an unusual odor in the work area. Thorough environmental testing did not reveal a toxicological basis for the illness outbreak.[192] A random sample of affected and nonaffected workers was surveyed to assess the influence of psychological, sociological, and work environment factors. Affected workers reported a significantly higher degree of physical discomfort resulting from temperature variations and poor lighting than did the nonaffected workers. The affected employees also reported greater psychological job stress, including increased workload and conflicts with supervisors.[192]

In another situation, the anxiety or fear associated with the unknown odor led to hyperventilation in a few workers and this catalyzed hyperventilation in more workers. The hyperventilation progressed to the point of respiratory alkalosis which caused the noted symptoms of numbness, dizziness, nausea, and heavy feelings in the arms and legs.[164]

NIOSH conducted a health hazard evaluation at a plant where many of the operations were similar to those in electronic components manufacture. This plant had 12 incidents of multiple acute illnesses during 9 months. The report on the evaluation concluded that in most of the cases no etiological agent could be identified although irritating or offensive airborne contaminants could have been involved as the precipitating agent. This report states that the incidents may represent a form of psychophysiologic responses to a stressful environment.[191]

Affected workers seemed to suffer from an unorganized work structure. Worker complaints included too many supervisors, conflicting orders from supervisors, and lack of personal authority to carry out job responsibilities. On personality tests measuring extraversion and hysteric tendencies, affected workers scored significantly higher than nonaffected employees.[192]

The semiconductor manufacturing industry has reported several instances in which symptoms experienced cannot be linked to a causative agent.[191] [192] One factor that has not been investigated in these incidents is the balance of small air ions. There is some evidence that an abnormal distribution of the positive and negative ions in the atmosphere may cause or exacerbate anxiety and frustration.[190] In the semiconductor industry, these small air ion imbalances could be caused by the extensive production area air cleaning devices. Some air cleaning devices, if they use fiberglass filters, have been known to release glass fibers into the workroom air and to contribute to the overall anxiety level due to skin and respiratory tract irritation.[16]

A recent national study of workers showed that 48 percent of the workers felt trapped in role conflicts, 45 percent felt overworked, and 35 percent felt a lack of clarity in the scope and responsibility of their jobs.[193] Another study reveals that steel mill employees who had more than the average number of accidents were absent more than other employees for reasons other than health problems. These nonhealth-related absences were caused by monetary, housing, child care, and marital problems.[193] The study suggests that mental health is important for job safety. Furthermore, one authority recommends that mental examinations be given with worker physical examinations because "the greatest amount of job dysfunction is caused not by physical illness, but by behavioral problems.[193] Preventive measures for reducing job-related stress are:

- The employee is well trained and well oriented,
- Responsibilities and job descriptions are well defined,
- The employee is given positive reinforcement,
- Interest is shown in the employee's task, and
- The employee is made to feel valuable to the company.[193]

Stress-related incidents in the electronic component manufacturing industry may be precipitated or exacerbated by worker dissatisfaction because of poor working conditions poor supervisory style, and interpersonal conflicts with coworkers.[194] Other contributing factors may be personal problems and poor psychological health.

6.4.2 Eyestrain

Eyestrain seems to be an ergonomic problem encountered in the electronic components industry. Eyestrain should be studied in relation to worker health and well-being, and further research in this area will be a valuable aid to both industry and the worker. Eyestrain primarily occurs in the semiconductor industry where the use of microscopes is widespread,[46] but eyestrain also occurs in other areas of component manufacture when small articles must be visually inspected.[195]

Continual focusing on small objects causes eyestrain. When a small object is brought into focus, ocular muscles squeeze the eyeball and lens into the proper shape. When this focusing is prolonged, the muscles become fatigued and headaches, dizziness, and nausea may result. Too little light in the work area cannot cause eyestrain or damage the eyes, but adequate lighting is desirable because it increases the speed of visual perception. This increase will lessen the chance of accidents and increase productivity.[41]

A contributing factor that results in eyestrain in the semiconductor industry is the pre-existing vision deficiencies of many workers. Visual testing and screening before employment should be required, and workers with defective or inadequate eyeglasses or contact lenses should not perform tasks that require visual acuity.[196 197 198]

In another ergophthalmological study of 162 workers in the electronics industry, 43 percent of the eyeglasses evaluated were considered insufficient for the job being performed. In addition, 68 percent of the eyeglasses worn by workers had tinted lenses even though the majority of the persons wearing tinted lenses considered the working illumination inadequate.[199]

An in-depth study of visual strain experienced by microscope operators at an electronics plant stated that mild refractive errors did not appear to have a significant impact on the occurrence of visual strain.[200] The explanation for this observation is that workers with long-sightedness (hyperopia) and near-sightedness (myopia) correct these vision errors through adjustment of the microscope until a sharp image is obtained. However, if the refraction is not equal in both eyes, the adjustment of the microscope will not produce a crisp image in both eyes. Some microscopes have one ocular (eye-piece) that is independently adjustable. Microscopes of this type can be adjusted to allow a clear binocular image for operators with unequal refraction. However, workers with uncorrected astigmatic refractive errors cannot adjust the microscope to correct for their vision deficiencies. The worker with uncorrected astigmatism is forced to vary eye adjustment continuously between two different planes. Therefore, operators with astigmatic refractive errors probably experience the severest symptoms of visual strain in microscope work.[200]

Many of the devices manufactured by the electronic components industry are color coded for easy identification. Before a worker is assigned a task where color vision is important, he should be examined for color defective vision. Eight percent of all males are afflicted with anomalous color perception.[201]

Another factor which causes eyestrain is a lack of worker training on procedures that rest the ocular muscles. Resting the eyes completely can be accomplished by frequently gazing in the distance[198] to relieve muscle fatigue and its associated symptoms. When workers at one plant used proper vision corrective devices, rested their eyes correctly, used properly maintained microscopes, and changed their seating position frequently, eye fatigue complaints decreased dramatically and production did not deteriorate.[198]

6.4.3 Repetitive Motion

Tasks requiring repetitive movements are common in the electronic component manufacturing industry. Repetitive movements of any muscle group will eventually cause fatigue in that group and result in tension in other muscles during execution of the task. When using the upper limbs in a repetitive manner, muscles in the shoulders, neck, and back usually are tensed and become fatigued during the course of movement. Other muscle groups that are not directly involved in task performance may also become highly fatigued.

Two studies dealing with monotonous and repetitive work in a picture tube and resistor plant revealed that more than half the workers reported headaches, back pain, eye pain, and general fatigue by the end of the shift.[202 203] Eighty-seven percent of the workers questioned in the picture tube plant reported that they slept erratically. Another Russian study of 39 assembly conveyor belt workers demonstrated that monotonous and local muscular work is accompanied by at least one significant change in normal body metabolism. This study showed that monotonous tasks caused a phase shift in the normal diurnal excretion of 17-hydroxycorticoids, which are conversion products of adrenocortical hormones. The excretion of 17-hydroxycorticoids increases during intensive muscular activities and during periods of emotional excitation. For the normal person, the excretion of the 17-hydroxycorticoids is highest during the waking and working hours; for persons doing monotonous work, the maximum excretion levels occurred at night. The medical significance of this shift in 17-hydroxycorticoid excretion levels is unknown. The study states that this shift in excretion levels is evidence of lowering of the "working tone" below the optimum level.[204]

Repetitive tasks can cause tenosynovitis, which is an inflammation of the overworked tendon sheath. If certain repetitive movements occur over a period of time, carpal tunnel syndrome can result. The symptoms of pain and burning or a tingling paresthesia in the fingers, hands, and forearm are a result of compression of the medial nerve in the carpal tunnel.[14]

Repetitive motion has also been implicated as a cause of poor worker productivity and morale. The monotony and boredom that often accompany repetitive tasks invariably exacerbate worker fatigue and loss of productivity. Monotonous tasks can cause inhibition of certain physiological functions. Changes in blood pressure and heart rate also reportedly result from repetitive monotonous work. The best methods to control this type of occupational stress include more automation, frequent rest periods, and tools and work stations that are properly designed from an ergonomic standpoint.[195]

6.4.4 Lower Back Pain

Lower back pain is a very significant problem in all segments of industry. One of the most confounding aspects of this disorder is that individuals vary greatly in their ability to tolerate mechanical loads on the musculoskeletal system. A study suggests that isometric back strength tests can be used as a valuable predictor of those persons most likely to suffer lower back pain from lifting.[205] If this test was used in preplacement physical examinations, employees with easily damaged backs might be identified and placed in jobs where lifting and bending tasks are minimal. The economic value of such testing and placement to industry might be very significant.

Other methods that are effective in the reduction of the number of lower back injuries include training and design of work stations and workloads. A report stated that the majority of back pathologies can be regarded as cumulative injuries.[206] Therefore, if high stress loads are avoided, or at least reduced in frequency, the risk of back injury would probably be lessened considerably. Reduction of high stress loads can be accomplished by training in proper lift techniques, providing mechanical assistance for load bearing, and instigating proper design and operation of work stations.

Some evidence indicates that after the age of 45, the load tolerance of the average human back rapidly decreases. This decrease may be as much as 50 percent of mature adult capacity by the age of 55.[206]

6.4.5 Video Display Terminals

Much concern has been expressed in recent years concerning possible hazardous levels of radiation emitted by video display terminals. However, studies indicate that the video display terminals present no radiation hazard.[207] [208] [209] Workers using video display terminals have complained of symptoms which include headaches, blurred vision, dizziness, and fatigue. These symptoms suggest that the video display terminal presents significant ergonomic stresses to the worker. Several articles have offered suggestions for reducing the amount of ergonomic stress involved with video display terminal work.[210] [211] [212] These suggestions include:

- Regular rest periods,
- Detached and adjustable keyboards,
- Room lighting, machine, and operator positions that are adjusted to avoid glare,
- Chairs that can be adjusted by the individual worker,
- Avoidance of short persistence phosphors to control flicker; refresh rates of less than 50 Hz are unacceptable, and
- A terminal that displays illuminated characters on a dark background.

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SECTION 7

DISCUSSION AND RECOMMENDATIONS

7.1 INTRODUCTION

Electronic components manufacturing is one of the most rapidly expanding and innovative segments of American industry. Development of new technologies, increasing employment, and the use of a wide variety of novel materials have been associated with this growth.

The hazard assessment is directed at providing workers, industry, and government with basic information concerning potential health hazards in the electronic component manufacturing industry and is intended to aid in establishing priorities for further research. Industries that are included in the hazard assessment are involved with the manufacture of items identified under Standard Industrial Classifications 3671 through 3676.

A broad approach to an industrial occupational health assessment could include (1) the identification of potentially toxic or hazardous agents in the workplace, (2) a literature search of the agents' harmful effects, and (3) determination of the extent of worker exposure. If additional information is needed, the study could include (4) experimental toxicological studies, (5) morbidity or mortality studies on exposed workers, and (6) the appropriate steps for controlling exposure, as necessary. An indepth evaluation of the existing information on potential health hazards in the electronic components industry is necessary to obtain the most productive use of NIOSH resources. Therefore, this preliminary study is directed only at the first two objectives presented above.

A large variety of electronic components are currently manufactured; therefore, the study was limited to those components that are manufactured in large numbers, are likely to continue to be used, and are likely to present some health risks to plant employees. The research includes the manufacture of semiconductors, capacitors, resistors, and electron tubes (including cathode ray, receiving, and transmitting tubes). A further selection process breakdown within these product lines was based on product volume and demand.

Technological and health effects information was obtained from published, unpublished, foreign, and domestic data bases. Computerized files and manual data bases were used. Reports from the U.S. Occupational Safety and Health Administration, NIOSH (Health Hazard Evaluations, National Occupational Hazard Survey, and Health Interview Survey), insurance carriers, trade associations, labor unions, and state and foreign health agencies were collected and reviewed. An overview of the results of the Project on Health and Safety in Electronics (PHASE) data and NIOSH Health Interview Study are contained in Appendices D and E, respectively.

Walk-through industrial hygiene surveys of 15 carefully selected facilities were included in the study. Surveys were performed in eight semiconductor facilities, three electron tube facilities, two electronic capacitor facilities, and two electronic resistor plants.

Information obtained from these surveys includes an overview of the medical, hygiene, and safety programs implemented; administrative practices; engineering controls; educational programs; sick-leave policy; illness and injury data; materials used; maintenance procedures; and personnel record systems. Company management was asked to provide suggestions on how to provide a safer workplace. The 15 surveys were not intended to provide a representative profile of the industry because an insufficient number of surveys were performed. However, the surveys provide examples of the representatives plant's approaches to the above considerations. The survey team usually visited larger facilities that represent a greater spectrum of operations and approaches toward health and safety. The survey team provided recommendations on good practices to facilities where unsafe or unhealthful situations were observed. The surveys help to broaden and verify the sometimes incomplete material and process information which is in the open literature.

This section presents an overview of the findings of the hazard assessment and recommendations for further research. Discussion and recommendations are presented in four sections: toxicology, general occupational safety and health principles, process and engineering controls, and morbidity data. The recommendations presented are basically a distillation of the opinions of all survey participants.

7.2 TOXICOLOGY

The electronic component manufacturing industry uses a wide variety of process materials. These materials may be used in combinations as complex formulations or they may be related through sequential job tasks. Often, information that describes the relationship between the processes and potential worker hazards is not available. Representative data on worker exposure to many chemical and physical agents are not available for many of the industry's processes.

This study attempted to collect representative toxicological data for the common process chemicals used to manufacture electronic components. This approach invariably resulted in an incomplete toxicological review of all process chemicals. Complete information about reproductive hazards, catastrophic potential, and long-term chronic effects of process chemicals could not be thoroughly researched or documented within the limits of this study. In addition, the published and unpublished data base is limited in terms of health effects information relevant to the electronic component manufacturing industry.

Suggestions on further research to broaden the industry health and safety data base are given below.

- Many proprietary solutions and mixtures are used in the electronic component manufacturing industry. Further efforts should be made to identify the chemical composition, toxicological information, handling procedures, and disposal practices for these trade-name substances. Chemical manufacturers and suppliers are a logical source of this information.
- More information is needed on the effects of long- and short-term, low-level exposure to chemical agents, i.e., derivatives of silane, boron, and fluorides, and physical agents, i.e., ultraviolet, microwave, and radio frequency radiation. The psychogenic, carcinogenic, mutagenic, teratogenic, reproductive, and other disabling effects of these exposures should be determined.
- Research should focus on the synergistic effects of process chemicals. Very little investigation concerns potential synergistic effects among the chemicals used to fabricate electronic components, or the potential byproducts in the production area. An extensive study should be conducted on this issue, preferably to determine if the combined exposure to two process chemicals, singularly at concentrations too low to induce an ill effect in workers, could account for the occupation illness in the industry.
- The III-V semiconductor materials (e.g., gallium arsenide, gallium phosphide, gallium arsenic phosphide, and indium antimonide) should be toxicologically evaluated. These evaluations should focus on pulmonary pathogenesis, as suggested by recent Russian articles.
- Exposure levels and health effects should be determined for cathode ray tube phosphors such as aluminum cobalt, cadmium sulfide, zinc cadmium sulfide, zinc sulfide, and yttrium oxide.
- The human carcinogenic potential of these four electronic component process materials—beryllium, selenium, cadmium, arsenic—should be investigated. Agent-specific studies should include experimental toxicological assessments.
- Agents that are capable of causing respiratory and dermal sensitization of individuals are used to manufacture electronic components. Safer substitutes or improved controls (i.e., isolating the worker from the sensitizing agent) should be developed. Efforts should also be made to identify safer, less toxic process chemicals. Feasible substitutes for toxic chemicals (e.g., trichloroethylene, and boric acid) presently in use should be found if not already done. In addition, a noncorrosive electrically nonconductive soldering flux that can be substituted for colophony is needed.
- Epoxy resins are used throughout the electronic component manufacturing industry. Hundreds of epoxy materials are available to the industry, and some of these materials have been toxicologically evaluated. Whenever possible, substitutions should be made for the materials that have not been evaluated from a health effects viewpoint. Skin and respiratory irritation and allergic potential should be considered in the evaluation in addition to carcinogenicity, mutagenicity, and teratogenicity.

7.3 GENERAL OCCUPATIONAL SAFETY AND HEALTH PRINCIPLES

The walk-through survey reports contained in Appendix F indicate that a few facilities have instituted excellent health and safety programs, a number of facilities are in the midst of developing excellent programs, and a few facilities have only developed minimum programs. Since a wide range of programs is described in Appendix F, the best approach is to select those program areas that are best suited to a particular operation.

Elements of a good safety and health program could include the following:

- Access to an industrial hygienist certified by the American Board of Industrial Hygiene (ABIH), a registered nurse certified by the American Board of Occupational Health (ABOH), a safety engineer certified by the Board of Certified Safety Professionals (CSP) and a physician who is either trained in occupational medicine or certified by the American Occupational Medical Association (AOMA).
- A medical surveillance program that can detect worker exposure to process chemicals through periodical medical tests specific to a particular job task or category.
- Preemployment and annual medical examinations with special examinations that are specific to particular on-the-job exposures (i.e., arsenic and eye problems).
- Routine industrial hygiene sampling, including area and personnel air sampling, to determine the level of contaminants in the production areas and potentially alert the industrial hygienist and process engineer of abnormal operation conditions. Wipe samples should also be taken where appropriate.
- A safety committee to aid in the communication of health and safety data between management and the production workers.
- The establishment of training programs for medical emergencies (emergency medical technician training, cardiopulmonary resuscitation, and first aid), equipment operation (training prior to entering the production area and on-the-job training by the area supervisor or staff), health and safety (chemical handling and disposal and the use of protective equipment), and operational emergencies (evacuation procedures and hazard reporting).
- Written standard operating procedures for all process and maintenance operations should be prepared and made available to the production workers. The procedures should cite all safety precautions and equipment for each operation.

As a result of the 15 walk-through surveys, additional elements of a comprehensive safety and health program were encountered including:

- Protective clothing as required on certain jobs should be available. If protective clothing (laboratory coats and caps) is laundered, the company should provide the service (either in-house or through an outside contractor) to prevent potential contamination of an employee's home environment.
- Complete records should be kept on all maintenance operations including the action taken and the date.
- As a general rule, a company should initiate engineering rather than administrative controls (i.e., job rotation, transfers, and reduced worktime) to provide a solution to a worker's exposure to a hazardous chemical or physical agent. The implementation of engineering controls to prevent worker exposure to a particular chemical is preferred over the administrative controls used at several of the facilities surveyed.
- Electrocution is a cause of work-related deaths in the electronic components industry. The use of high-power process equipment, such as ion implanters, may result in additional deaths if the operational and maintenance procedures do not include adequate precautions to avoid shortcuts, and the equipment does not have extensive electrical interlocks.
- Employees should be notified verbally and in written form of the results of the safety committee meetings and industrial hygiene sampling in the plant. More open communication will provide a better informed employee.
- The potential health and safety hazards of process equipment and/or process materials should be determined prior to their incorporation into the production operations. One surveyed plant required that each new piece of process equipment receive a safety permit before being brought out on the production floor. The permit was verified by the production engineer, industrial engineer, maintenance department, department supervisor, and safety engineer.
- The plants should use ad hoc committees that can define and explore ways to reduce worker exposure to chemical and physical agents in each production area. The committees can report to the plant's safety committee.

- A plant should have an emergency team that can respond to medical emergencies, chemical spills, and operational emergencies (fire, power failure, and earthquakes). The members should be specifically trained and supplied with the proper equipment (including a self-contained breathing apparatus) to respond to any emergency.
- The surveyed facilities that require the use of respirators by their operational and maintenance personnel usually did not have a respirator selection, fit, or maintenance program. Without these programs, the effectiveness of a respirator is greatly reduced.
- Efforts should be taken to exclude the maintenance and janitorial staff from the production areas during operational hours. If this type of assignment is unavoidable, the plant should consider enlisting the janitorial and maintenance personnel in a medical surveillance and chemical training program. Also, personnel air sampling should be conducted to determine the degree of process chemical exposure to these plant personnel.

Based on the walk-through surveys, several practices were found to be especially effective in improving health and safety practices. These include:

- Several facilities equipped the process equipment in their production areas with hydrogen detectors, arsine/phosphine continuous monitors, and infrared spectrometers. An audible or visible alarm alerts area personnel of an equipment malfunction. These types of detector systems are highly recommended when toxic or flammable gases are used.
- One surveyed company installed a closed-circuit television monitoring system to allow a process operation to be viewed from an area where the operator would be safe from potential exposure to hazardous agents. This type of control is recommended where a hazardous exposure might occur if the process equipment malfunctions.
- A few surveyed facilities installed Dwyer or indicating manometers in their exhausted enclosures (this is a requirement in California). Other plants used magnehelic gauges. These types of indicators provide the operator and maintenance personnel with a simple method to verify exhaust system operation.
- One surveyed facility recommends a preventive maintenance program with scheduled down time for all process equipment. By avoiding equipment failure, the company can decrease worker injuries.
- One surveyed facility has a computerized chemical inventory to allow the plant's safety manager to review all chemical purchase orders. Protective equipment orders made by staff and process equipment purchases also are reviewed in terms of operator safety and health.
- One surveyed facility has computerized safety material data sheets for approximately 2,800 to 3,000 chemicals. The sheets are available for review by the production workers.
- Several surveyed facilities performed safety audits of the production areas at least monthly. The audits were usually performed by the safety committee, area supervisor, and/or plant safety manager. Safety violations were noted and corrected by the area personnel.
- One surveyed facility encourages worker input on safety and health matters in the production areas. The plant has (1) a program by which an employee can ask a written question concerning plant operations and receive a prompt reply from management, and (2) a hot line for the operators to report odors, safety violations, or problems to the safety office. The plant management uses a written memorandum format to describe safety hazard(s) observed by the production worker and to indicate procedures implemented to control unsafe process operations. The plant also has a safety alert program which uses a written memorandum to inform the staff of a safety fatality, equipment problem, or unsafe condition. Depending on the severity of the alert, the situation is corrected in a given time frame—24 hours to 1 month. In addition, accident reports are prepared for all work-related injuries or illnesses and reviewed by the safety office.
- For additional safety in the piping of hazardous gas, the management at one plant recommended use of a double line, i.e., a conduit pipe that is purged with nitrogen and discharges to a vented cabinet. The cabinet should also be equipped with a sensor alarm system to detect gas leaks.
- Employees should receive a copy of the plant's safety procedures and all relevant operating materials pertinent to performance of the assigned job task. This material should include safety data sheets and written operating and maintenance procedures for the production area.

- A committee of occupational safety and health experts has been formed to consult the staff of electronic component manufacturing facilities (especially small companies) on solving specific exposure problems or developing programs. The service is provided through one of the industry associations (American Electronics Association, Electronics Industry Association, Semiconductor Industry Association, Semiconductor Equipment and Materials Institute, or American Industrial Hygiene Association) or by an independent group of safety and health leaders in the field, such as a Committee on Occupational Safety and Health (COSH groups).

Recommendations for future research in general safety and health issues pertinent to the electronic component manufacturing industry are discussed below. The majority of the topics have been discussed with the survey participants.

- A nationwide health and safety information network is needed by the industry. Information is available but a distribution network is not. The industry safety associations could provide this service. However, safety organizations are presently bypassing smaller companies. The survey participants from the smaller firms indicated that they usually acquire safety and health information including ventilation design and operating parameters from companies with similar operations. Overall, the surveyed plants indicated that most safety and health information is self-generated with little sharing or communication occurring across the industry.
- A computer program similar to the IBM-Echo program should be developed by NIOSH or OSHA for use by the industry. The program could provide an instantaneous readout correlating worker health and industrial and hygiene survey data. The program could be used at the plant and corporate levels and provide smaller companies (100 employees or less), which have limited resources and staff, with a valuable tool for evaluating their occupational environment(s).
- A number of survey participants recommended the inclusion of worker interviews as a source of health and safety information for the hazard assessment. NIOSH evaluated these requests and decided that worker interviews were beyond the scope of the RTI hazard assessment. NIOSH should determine if follow-up studies should be performed and designed to include more extensive worker input.
- Safety incentive programs instituted at one manufacturing facility appeared to reduce worker injury/illness rates. The effect of such programs should be studied and applied to other manufacturing operations, if they are deemed applicable.
- The effect(s) of nonstandard workweeks on worker body burden as researched by NIOSH should be continued. Contaminants with longer human biological half-lives should be emphasized. Extended work periods are common in the electronic components industry, and most standards are designed for a 40-hour workweek.
- Further research should be conducted to develop work schedules that reduce the number of hours spent per day at visually tedious tasks. Such tasks are viewed as inherently stressful, and rotation of workers to other tasks should be encouraged on an interday basis. The increase in efficiency and productivity and the reduction in labor turnover rates and absenteeism in visually demanding tasks will probably offset the expenses incurred in the implementation and maintenance of such a program.

7.4 PROCESS AND ENGINEERING CONTROLS

A variety of process equipment is employed in the manufacture of semiconductors, electron tubes, capacitors, and resistors. Some surveyed plants installed engineering controls on all process equipment, other plants installed the minimum needed for a specific process yield. The majority of the surveyed plants used engineering controls, primarily local and general ventilation, to minimize worker exposure to hazardous agents. Standardized specifications for process engineering controls are not available for all fabrication equipment. This type of information is an expressed industry need.

Several recommendations for future research to provide the industry with a more comprehensive data base on process and engineering controls are described below.

- Research should be continued to determine if a potential occupational hazard exists from the operation of automated, dry processing equipment. This new type of process equipment usually requires high concentrations of dopant gas, i.e., arsine, phosphine, and hydrogen, which may pose a catastrophic effect to the worker in case of an equipment malfunction or accident.

- NIOSH should conduct research concerning the interaction and emission of byproducts from electronic component manufacturing equipment, e.g., ion implantation. Within a fabrication area, numerous operations such as acid etching, solvent cleaning, diffusion and deposition reactions, epitaxial growth, oxidation, photomasking, and metallization occur simultaneously. Depending on the area operations and lay-out, secondary reactions may also occur. Extensive research on such reactions and their proposed origins is needed to better understand the occupational health environment of a fabrication area. Specific examples of materials which are used or generated in small amounts in the industry and require future research to determine if they are reaction byproducts are formaldehyde resulting from solder and flux usage, hydrogen chloride from phosphorus oxychloride deposition, sulfur dioxide from etching operations, nitrogen oxides from etching operations, carbonyl fluoride from plasma etching, phosgene from clean station, and aluminum chloride from plasma etching.
- The industrial ventilation equipment installed on the surveyed process equipment ranged from natural ventilation to laminar flow work stations (Class 100 areas—100 particles per cubic foot of air). Recommended performance standards for each specific fabrication operation should be promulgated throughout the industry. The performance standard should specify ventilation control parameters (capture velocities, percent of make-up air, and laminar air velocity rate) and maintenance procedures including required test equipment (velometer, annometer, manometer, magnehelic gauges), and schedules (routine measurements for each piece of equipment).
- Ultrasound exposure levels and their health effects should be studied. A few of the surveyed plants used ultrasonic process equipment. Some plants have conducted sampling but not enough data are available for a full evaluation.
- Production workers use a wide variety of protective equipment in the surveyed plants. Some plants require only gloves, while other plants require full garb including bunny suits, hats, and shoe covers. In some cases, the clothing was primarily assigned to protect the product. In other cases, gloves, glasses, aprons, armguards, etc. were provided primarily for worker protection; however, the worker also benefits from the practice. Recommended performance standards should be widely disseminated throughout the industry that specify the type of worker protection equipment required by process operation including chemical handling, dispensing, and disposal. Also, testing and evaluation should be continued for personal protective clothing in specific electronic component process operations—specific acid etch operations, solvent cleaning, and photomasking. These test results should be distributed throughout the industry so that protective clothing is only distributed specifically for use in operations where it was effective.
- A wide variety of chemical dispensing and disposal practices was observed during the walk-through surveys. Approaches range from (1) having the production workers collect acids or solvents in 1-gallon transport cans and manually transport these cans to the process areas and wastes back to the chemical storage area to (2) having solvents, acids, and gases piped directly into the process areas with separate drains and exhaust ports for disposal. Chemical exposure from method (1) could be eliminated or at least reduced if proper engineering controls were introduced. Guidelines on such control (process and protective equipment) should be prepared.
- Human engineering research should be continued into the design of the electronic component manufacturing facility to minimize ergonomic stress among production workers, especially if a large amount of manual or eye work is required by the process operation. Ergonomic considerations should also be a special concern where repetitive operations are performed.

7.5 MORBIDITY DATA

The electronic component manufacturing industry uses a large number of process chemicals, up to several hundred types of chemicals in the larger facilities. For the semiconductor industry, chemical burns from commonly used acids and alkalies represent 16 to 19 percent of all injuries as compared to strains (28 to 30%) and contusions (25 to 27%).

Labor and industry representatives have

expressed concern that little reliable morbidity data are available on employees in the electronic component industry. Existing illness and injury data are limited because of inconsistencies in reporting, the small number of individuals involved, and the combining of various specific causes into large groups.

Appendix B outlines the United States and California injury and illness data for the electronic component manufacturing industry. During the walk-through surveys, the plant's injury and illness data was reviewed. A close examination of the industry morbidity data is required to determine the number and type of illnesses or injuries experienced by the workers in the electronic components manufacturing industry, the possible relation between these illness/injury cases to any specific job category or type, and the type of control required for the occupational environment of the production facilities to reduce the number of injury and illness cases in the industry.

Additional work is needed to define the demographic characteristics of the electronic component manufacturing industry workforce. These data would be invaluable in an industry morbidity study. Table 7-1 lists the number of women working in the electronic component manufacturing industry in 1980 and May 1981. In the plants surveyed, 41 to 81.6 percent of the workforce were production workers, and 34 to 89 percent of the production workers were women. Since a large percentage of the electronic component industry workers are women, epidemiological studies concerning teratogenesis and mutagenesis hazards would be appropriate.

The workforce in different parts of the United States has a large ethnic minority base. At the facilities surveyed, minorities (Black, Hispanic, Asian, Indian, and South Pacific Islanders) comprised from 8.7 to 65 percent of the plant's workforce. Hispanics, Asians, and South Pacific Islanders comprised the majority of the workforce in the California plants surveyed. Blacks comprised the majority of the workforce in the southern plants surveyed. The workforce in the plants located in the Mideast and New England were predominantly Caucasian. Research should be conducted to determine if any minority group in an electronic component manufacturing facility is specifically sensitive to a physical or chemical agent in the process.

Besides specific illnesses, there were several undiagnosed and unreferenced cases of illness among electronics workers reported to the RTI and NIOSH survey teams during the walk-through industrial hygiene surveys. The existence and causes of these illnesses should be reviewed. Presently, illnesses that do not have a detectable causitive agent are sometimes referred to as psychogenic. The role of monotonous and repetitive work and its relationship to mass psychogenic illness should be studied. Work practices to alleviate boredom and fatigue should be developed.

7.6 SUMMARY

This report fulfilled a need to collect, analyze, and compile health effects information relevant to the electronic component manufacturing industry. The results of this research are to be used by management, labor, and govern-

TABLE 7-1. WOMEN EMPLOYEES IN THE ELECTRONIC COMPONENT MANUFACTURING INDUSTRY

Electronic component	SIC code	Number of women employees (x 1,000) 1980	Number of women employees (x 1,000) 1981[a]	Percent of total workforce 1980	Percent of total workforce 1981[a]
Electron tubes	3671-3673	16.1	16.5	37.8	37.7
Semiconductors	3674	107.5	109.4	47.4	46.4
Capacitors, resistors, coils, and connectors	3675-3678	49.9	47.7	67.5	65.1

[a]Source: May 1981, Bureau of Labor Statistics data.

ment to (1) better identify potential health hazards in the industry, and (2) take further steps toward evaluating the severity of health and safety hazards and controlling these hazards when necessary. Research needs to be initiated where specific hazard information is lacking. Through a concerted effort between industry, labor, and government, the health and safety of the worker in the electronic component manufacturing industry can be more fully evaluated and protected.

7.6.1 Electron Tubes

Worker health and safety in the receiving, cathode ray, and industrial electron tube manufacturing industry was assessed by conducting walk-through industrial hygiene surveys of 3 manufacturing facilities and reviewing the pertinent published and unpublished literature. At the plants surveyed, both the receiving and transmitting tubes were hand-assembled in a job-shop environment. Tubes were made to order with very little process automation, thus increasing the probability of process material/worker interaction during the bench assembly operations. The cathode ray tube manufacturing facility, on the other hand, was highly automated with minimal worker contact with the process materials and the tube component parts.

The receiving and transmitting tube manufacturing industry uses older technology which has been tried and proven. As a result, operations that have resulted in worker injury or illness have been recognized and controlled, in most cases, to reduce worker exposure to hazardous agents and ergonomic stresses. The industry is declining, resulting in fewer workers in the future, little expansion, and a small probability that either new material applications or engineering controls will be developed for the existing facilities. There is little prospect for additional industry growth in the United States.

The cathode ray tube manufacturing industry may expand in the future but probably not in the United States. The few plants that are located in the United States use automated, assembly line production. Engineering controls are installed to produce a high quality product and protect the worker. Since little domestic expansion is slated for the industry, existing operations will probably continue to operate with present-day engineering controls until the product lines are discontinued.

Overall, the electron tube industry has a small workforce employed at a few manufacturing facilities in the United States. The chemicals in use are well-documented. Worker exposure to process chemicals have been minimized in most cases through the use of engineering controls. The process materials, operations, and controls of the electron tube manufacturing industry are not likely to change in the near-term. The main problems facing the workforce are the vitality of the industry and its complacency with process materials, operations, and controls. Efforts should be concentrated on educating the worker on the chemical hazards in their work areas and controlling the use of process chemicals, especially the solvents and metals used in tube fabrication.

7.6.2 Semiconductors

The majority of the effort in performing the hazard assessment was centered on the semiconductor industry. The semiconductor industry has a greater growth potential, a larger worker force, and as great, if not greater, safety and health concerns than either the electron tube, capacitor, or resistor manufacturing industries.

The industry incorporates a wide variety of engineering controls to protect the worker from potential occupational health hazards and to protect the product from contamination. However, as new process chemicals and new applications for existing chemicals are introduced, new engineering controls will have to be developed and implemented to protect the worker from hazardous physical and chemical agents. For example, several facilities designed special handling procedures and vented enclosures for the high concentration dopant and passivation gases presently in use. Other facilities are planning to implement dry processing operations to replace the standard process operations. Engineering controls will have to be designed, fabricated, and tested for these new state-of-the-art applications.

The semiconductor industry is a growing industry, More process operations will be automated in the future. The automation will reduce the number of operators in the work area and subsequently reduce potential worker exposure to chemical and physical agents. New facilities will likely be constructed instituting state-of-the-art process operations to ensure a high product yield and, at the same time, worker safety.

In the overview of the industry, the study did concentrate its review on facilities approaching or developing state-of-the-art technology. Consideration should also be given to the occupational environment in the smaller job shops. The larger facilities usually have fairly complete safety and health programs. The smaller job shops, for the most part, do not. As a result, the occupational environment at the smaller facilities may be more hazardous to the worker than at the larger plants.

Other areas needing greater clarification are the synergistic effect of process chemicals on the workforce, and the toxicity of the process chemicals. Presently, engineering controls protect the worker from exposure to hazardous chemicals in many process operations. But until all process chemicals can be examined from a toxicological and synergistic point of view, the exact effeciency of industry engineering controls is hard to evaluate.

The industry is growing as is the workforce in the United States. The process operations are changing along with the process chemicals. At the facilities surveyed, most physical and chemical hazards along with ergonomic stresses were controlled to reduce worker exposure. However, efforts to understand the interaction between process operators and chemicals need to continue and develop along with the technology. The worker's health can be and is in most cases protected with today's technology.

7.6.3 Capacitors and Resistors

Worker health and safety was assessed at four facilities manufacturing a wide resistors and capacitors. Even though there are numerous facilities manufacturing variety of capacitors and resistors in the United States, the surveyed process operations were assumed to be representative of each industry as a whole. The facilities surveyed were using dated technology, incorporating a range of hand operated to automated process operations.

In both the capacitor and resistor plants, the operator worked closely with the process materials. The process materials and operations were well established. Worker exposure to the process materials had been well characterized over the years. Operations that had resulted in worker injury or illness along with recognized physical and chemical occupational hazards and ergonomics stresses, have been recognized and controlled to a great extent.

Overall, the capacitor and resistor manufacturing industries are mature and becoming outdated in the United States. The integrated circuit industry will dwarf the future growth of both the capacitor and resistor industries. Present plants must consider moving operations to foreign countries or automation to increase plant production to retain their market.

7.7 REFERENCES

1. Lassiter, Donald V., Occupational Safety and Health in the Semiconductor Industry—A Statistical Analysis and Comparison with Other Manufacturing Sectors. Sponsored by the Semiconductor Industry Association, August 1981.

APPENDIX A

STANDARD INDUSTRIAL CLASSIFICATION

CODES 3671 to 3676

APPENDIX A

STANDARD INDUSTRIAL CLASSIFICATION

Codes 3671 to 3676

This appendix describes the industry codes 3671 to 3676 as listed in the Standard Industrial Classification Manual published by the Office of Management and Budget in 1972 and revised in 1977.

Code Number

3671 *Radio and Television Receiving Type Electron Tubes, Except Cathode Ray*

Establishments primarily engaged in manufacturing radio and television receiving type electron tubes, except cathode ray tubes. Establishments primarily engaged in manufacturing televison receiving type cathode ray tubes are classified in Industry 3672; transmitting tubes in Industry 3673; and X-ray tubes in Industry 3693.

Electron tubes, radio and television receiving: except cathode ray tubes

3672 *Cathode Ray Television Picture Tubes*

Establishments primarily engaged in manufacturing television receiving type cathode ray tubes. Establishments primarily engaged in manufacturing other radio and television receiving type electron tubes are classified in Industry 3671; and transmitting tubes in Industry 3673.

Cathode ray television receiving type tubes
Picture tube reprocessing
Television receiving type tubes, cathode ray

3673 *Transmitting, Industrial, and Special Purpose Electron Tubes*

Establishments primarily engaged in manufacturing transmitting, industrial, and special purpose electron tubes. Establishments primarily engaged in manufacturing radio and television receiving tubes are classified in Industry 3671; television receiving type cathode ray tubes in Industry 3672; and X-ray tubes in Industry 3693.

Cathode ray tubes, except television receiving type
Electron beam (beta ray) generator tubes
Electron tubes (transmitting, industrial, and special purpose)
Gas and vapor tubes
Geiger Mueller tubes
Industrial electron tubes
Klystron tubes
Light sensing and emitting tubes
Magnetrons
Transmitting electron tubes
Traveling wave tubes
Tubes for operating above the X-ray spectrum (with shorter wavelength)
Vacuum capacitors, relays, and switches

3674 *Semiconductors and Related Devices*

Establishments primarily engaged in manufacturing semiconductor and related solid state devices, such as semiconductor diodes and stacks, including rectifiers, integrated microcircuits (semiconductor networks), transistors, solar cells, and light sensing and emitting semiconductor (solid state) devices.

Computer logic modules
Controlled rectifiers, solid state
Diodes, solid state (germanium, silicon, etc.)
Electronic devices, solid state
Fuel cells, solid state
Gunn effect devices
Hall effect devices
Hybrid integrated circuits
Infrared sensors, solid state
Light emitting diodes
Light sensitive devices, solid state
Magnetic bubble memory device
Magnetohydrodynamic (MHD) devices
Memories, solid state
Metal oxide silicon (MOS) devices
Microcircuits, integrated (semiconductor)
Modules, solid state
Molecular devices, solid state
Monolithic integrated circuits, solid state
Nuclear detectors, solid state
Parametric diodes
Photoelectric cells, solid state (electronic eye)
Photovoltaic devices, solid state
Rectifiers, solid state
Semiconductor circuit networks (solid state integrated circuits)
Semiconductors (transistors, diodes, etc.)
Solid state electronic devices
Strain gages, solid state
Stud bases or mounts for semiconductor devices
Switches, silicon control
Thermionic devices, solid state
Thermoelectric devices, solid state
Thin film circuits
Transistors
Tunnel diodes
Ultraviolet sensors, solid state
Variable capacitance diodes
Zener diodes

3675 *Electronic Capacitors*

Establishments primarily engaged in manufacturing electronic capacitors

Capacitors, electronic (fixed and variable)
Condensers for electronic end products

3676 *Resistors for Electronic Applications*

Establishments primarily engaged in manufacturing resistors for electronic end products. Establishments primarily engaged in manufacturing resistors for telephone and telegraph apparatus are classified in Industry 3661.

Resistors for electronic end products
Thermistors, except temperature sensors
Varistors

APPENDIX B

Department of Labor Industry

Injury and Illness Data

APPENDIX B

DEPARTMENT OF LABOR INDUSTRY INJURY AND ILLNESS DATA

Injuries and Illnesses

Approximately 1 out of every 11 private sector American workers was injured or experienced illness as a result of exposure to occupational hazards during 1978. The U.S. Department of Labor, Bureau of Labor Statistics defines occupational injuries and illnesses in the following manner:[1]

> Occupational injuries are caused by work accidents or from exposure involving a single incident in the work environment. These injuries are recorded if they result in death, worktime lost, medical treatment other than minor first aid, loss of consciousness, restriction of work or motion, transfer to another job, or termination of employment.
>
> Occupational illnesses include any abnormal condition or disorder, other than one resulting from an occupational injury, caused by exposure to environmental factors associated with employment. The incidence of occupational illnesses measured by the annual survey refers to the number of new illness cases occurring during a year and does not measure continuing conditions of illness reported in previous surveys. Illnesses are recorded only in the year in which they are diagnosed and recognized as work related.

The private sector data in this appendix represent the work experience of 71.5 million workers in approximately 5 million establishments. Self-employed individuals, farms with fewer than 11 employees, Federal, State and local governments are not included in the data.

Injuries are usually easy to identify and define; therefore, few measurement problems are associated with the reporting of occupational injuries. However, the recording and reporting of occupational illnesses often presents a problem because employers and physicians are often unable to discern the relation between some illnesses and the work environment. Therefore, the occupational illness data presented in this appendix represent only the proportion of occupational illnesses that are recognized. These data on occupational illness are not considered by BLS to be statistically valid but are included in this report as the only source of information on occupational illness. These data are meant to provide an estimate of the proportion of occupational illness. Of the 5.8 million occupational illnesses and injuries reported in the most recent data available (1978), approximately 2.5 percent were classified as illnesses and 97.5 percent are classified as injuries. Approximately 2.2 percent of the total worktime lost resulted from illnesses and 97.8 percent resulted from injuries. Skin diseases and disorders continued to account for approximately half of all occupational illnesses.

In the electronic components and accessories category (SIC 367), 35,043 occupational injury and illness cases were reported in 1978; 3,186 (9 percent) of these were occupational illness cases. The only category of the electronic components and accessories manufacturing industry for which data are available is SIC 3674 (semiconductors). There were 10,694 reported injuries and illnesses in the industry nationwide in 1978, and 1,504 (15 percent) of these were classified as occupational illnesses.[1]

United States Injury and Illness Data

Both frequency and severity should be considered when injury and illness rates are reviewed. In this section, frequency is defined as the number of injury or illness cases per 100 full-time workers per year. Severity is defined in terms of the number of lost workdays that result from injury or illness per 100 full-time workers per year. Separate consideration of either the frequency or severity of injuries or illnesses does not provide a good indication of the degree of hazard associated with an occupation. When severity and frequency rates are multiplied, the product is a much more meaningful indicator of the degree of hazard. In this appendix, the square root of the product of the severity and frequency will be called the disabling injury index. This index is suggested by the National Safety Council for use where a

TABLE B-1. U.S. OCCUPATIONAL INJURY AND ILLNESS DATA,[1] 1978

Industry	SIC code	Frequency[a]	Severity[b]	Disabling injury index[c]
Private sector[d]		9.4	63.5	24.4
Manufacturing		13.2	84.9	33.5
Electronic components and accessories	367	7.7	34.1	16.2
Electron tubes (receiving)	3671	3.9	24.0	9.7
Cathode ray television picture tubes	3672	10.7	94.9	31.9
Electron tubes (transmitting)	3673	7.4	38.1	16.8
Semiconductors and related devices	3674	6.4	28.8	13.6
Electronic capacitors	3675	5.9	24.7	12.1
Electronic resistors	3676	9.0	41.7	19.4

[a] The frequency is expressed as the number of cases of occupational illness per 100 full-time workers per year.

[b] The severity is expressed as the number of lost workdays caused by occupational illness per 100 full-time workers per year.

[c] The disabling injury index is the square root of the product of the severity and frequency.

[d] All industry excluding Federal, State, and local government.

TABLE B-2. OCCUPATIONAL ILLNESS DATA FOR THE CALIFORNIA SEMICONDUCTOR INDUSTRY[2 3 4 5 6 7]

Year	Frequency[a]	Severity[b]	Disabling injury index[c]
1973	1.8	2.4	2.1
1974	1.4	3.3	2.2
1975	1.4	4.4	2.5
1976	1.3	6.2	2.8
1977	1.3	3.3	2.1
1978	1.3	2.1	1.7

[a] The frequency is expressed as the number of cases of occupational illness per 100 full-time workers per year.

[b] The severity is expressed as the number of lost workdays caused by occupational illness per 100 full-time workers per year.

[c] The disabling injury index is the square root of the product of the severity and frequency.

TABLE B-3. OCCUPATIONAL INJURY DATA FOR THE CALIFORNIA SEMICONDUCTOR INDUSTRY[2 3 4 5 6 7]

Year	Frequency[a]	Severity[b]	Disabling injury index[c]
1973	8.6	20.5	13.3
1974	6.5	25.3	12.8
1975	4.9	32.9	12.7
1976	5.6	38.2	14.6
1977	6.3	36.1	15.1
1978	7.8	30.2	15.4

[a] The frequency is expressed as the number of cases of occupational illness per 100 full-time workers per year.

[b] The severity is expressed as the number of lost workdays caused by occupational illness per 100 full-time workers per year.

[c] The disabling injury index is the square root of the product of the severity and frequency.

single numerical indicator of injury or illness rates is desired.[8]

In 1978, the overall U.S. disabling injury index, including injuries and illnesses, for private sector industries was 24.4. This index for the manufacturing industry is 33.5. Electronic component fabrication is listed under manufacturing. Other prominent industry divisions include construction, with an index of 41.8, and mining, with an index of 40.6.

Electronic components and accessories (SIC 367) had an overall disabling injury index of 16.2 for 1978. Some subdivisions of the electronic components and accessories manufacturing industry and their respective indices can be found in Table B-1.

Summary

The overall injury and illness data presented in Table B-1 indicate that all segments of the electronic components and accessories industry, except cathode ray television picture tubes, have low indices as compared to the private sector and the manufacturing industry. Data from the semiconductor industry in California shows a trend toward a lower illness index in the last 2 years reported (1977 and 1978), but the injury index has shown a slight upward trend. Tables B-2 and B-3 present the California data for the semiconductor industry from 1973 through 1978.

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APPENDIX C

COMPLIANCE INSPECTIONS OF ELECTRONIC COMPONENT MANUFACTURING FACILITIES

APPENDIX C

COMPLIANCE INSPECTIONS OF ELECTRONIC COMPONENT MANUFACTURING FACILITIES

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) made formal requests of the Occupational Safety and Health Administration (OSHA) regional offices to forward copies of all compliance inspection reports concerning the electronic components industry. As a result of these requests, the Research Triangle Institute (RTI) received 65 such reports. The reports were reviewed, and the information is summarized in Table C-1. In nearly all cases, the reports did not identify the specific industrial process that was associated with the exposures evaluated or the specific levels of exposure measured. However, 51 of these compliance inspections were initiated because of worker complaints; therefore, they serve as a valuable source of worker input. In addition, the exposures that were found to be in violation of Federal standards, as evidenced by the issuance of citations, were identified. These citations should give some insight into the more prevalent exposure problems in the industry.

TABLE C-1. OSHA INSPECTIONS IN THE ELECTRONIC COMPONENTS MANUFACTURING INDUSTRY

Plant classification (SIC code)	Number of employees	Hazards evaluated
3674	3,500	Noise,[a] nickel, cadmium
3674	28	Noise, epoxies, acetone, xylene
3674	2,300	Formaldehyde, xylene, 1,1,2-trichloroethane, 1,1,2-trifluoroethane, stoddard solvent, methyl cellosolve acetate
3674	1,850	Facility safety design,[a] chemical storage,[a] chemical handling,[a] electrical code,[a] sulfuric acid, nitric acid, acetic acid, hydrochloric acid, hydrofluoric acid
3674	27	Chromic acid,[a] toluene diisocyanate, cadmium, fluoride, xylene, sodium hydroxide, recordkeeping,[a] epoxies, lead, tin
3674	491	Fire extinguishers,[a] flammable liquid handling,[a] asbestos,[a] methyl ethyl ketone, acetone, isopropyl alcohol, perchloroethylene, xylene
3674	2,200	Posting of regulations,[a] film badges,[a] electrical codes,[a] facility safety design,[a] flammable liquid handling,[a] emergency equipment,[a] ladders,[a] arsenic
3674	1,500	Noise, alcohols, emergency equipment[a]
3674	422	Chromium[a]
3674	600	Noise,[a] iron oxide, copper, cyanides, hydrochloric acid, hydrofluoric acid, chromium, nickel, zinc chloride, illumination
3674	107	Lead, trichloroethylene, silica, methyl isobutyl ketone, noise, emergency equipment,[a] personal protective equipment[a]
3674	1,600	Machine guards, flammable liquid handling,[a] noise
3674	375	Hydrochloric acid, hydrofluoric acid, hydrogen peroxide
3674	350	Lead, trichloroethylene, toluene, silica, methyl chloroform, silver, acids
3674	375	Trichloroethylene, ethyl acetate, isopropyl alcohol, carbon monoxide, noise
3674	198	Trichloroethylene, xylene, ammonia, ethyl cellosolve
3674	1,100	Isopropanol, freon, methylene chloride
3674	325	X-rays, boron trifluoride
3674	200	Lead, isopropanol, abietic acid
3674	640	Nitric acid

See footnotes at end of table. (continued)

TABLE C-1. OSHA INSPECTIONS IN THE ELECTRONIC COMPONENTS MANUFACTURING INDUSTRY (continued)

Plant classification (SIC code)	Number of employees	Hazards evaluated
3674	640	Nitric acid, nitrogen dioxide
3674	565	Fiberglass, ethanol, isopropanol, ozone, fluoride, oil smoke, ferric chloride, copper, lead, iron oxide, noise
3674	500	Lead,[a] zirconium, asbestos, cadmium, rhodium, copper, tin, sulfuric acid, silica, trichloroethylene, xylene,[a] 1,1,1-trichloroethane,[a] nitric acid, hydrogen chloride, hydrogen cyanide, formaldehyde, noise[a]
3674	900	1,1,1-Trichloroethane, trichloroethylene, methylene chloride, ammonia, sulfuric acid, noise
3674	45	Barium, silver, lead, trichloroethylene, 1,1,1-trichloroethane
3674	1,600	Beryllium
3674	25	Chromic acid, nitric acid, X-rays, noise
3674	75	Trichloroethylene, noise[a]
3674	1,400	Silica, antimony, diborane[a]
3674	1,123	Diborane
3674	1,050	Lead, silica
3674	500	Lead, tin, carbon monoxide, zinc chloride, phosgene, hydrogen chloride, colophony, insect bites
3674	320	Ferric chloride, isopropanol, iodine, trichloroethylene, methyl chloroform
3674	1,850	Chloroform[a]
3674	45	Carbon monoxide, acetone, nitric acid, trichloroethylene
3674	211	Noise, carbon monoxide
3674	N/A	Gallium, arsenic
3674	30	Chlorobenzene, acetone
3674	320	Trichloroethylene
3674	850	Caustic materials handling (sodium hydroxide),[a] compressed gas storage[a]
3674	880	Phenol, xylene, n-butyl acetate, arsine, electrical codes,[a] emergency facilities,[a] compressed gas storage[a]

See footnotes at end of table.

(continued)

TABLE C-1. OSHA INSPECTIONS IN THE ELECTRONIC COMPONENTS MANUFACTURING INDUSTRY (continued)

Plant classification (SIC code)	Number of employees	Hazards evaluated
3674	705	Machine guards,[a] fire extinguishers,[a] facility design,[a] compressed gas storage,[a] flammable liquid handling,[a] radiation monitoring,[a] electrical codes,[a] compressed air guns[a]
3674	705	Tin, methanol, noise[a]
3674	1,100	Hexamethyldichlorosilane, hydrogen fluoride, xylene, sulfuric acid, hydrogen peroxide, n-butyl acetate, acetone
3672	1,300	Welding flash,[a] toilet facilities, break rooms, electrical codes,[a] welding fumes,[a] compressed gas handling[a]
3672	2,800	Floor drains,[a] load capacity signs,[a] handrails,[a] emergency exits,[a] radiation warning signs,[a] flammable liquid handling,[a] blocked aisles,[a] protective clothing—welders,[a] protective clothing—acids,[a] safety glasses,[a] respirator program,[a] eye washes,[a] storage practices,[a] machine guards,[a] compressed gas handling,[a] electrical codes[a]
3672	1,700	Cadmium, zinc, fluorides, selenium, copper, chromium, methyl methacrylate, maleic anhydride, yttrium
3672	2,900	Lead
3672	N/A	Respirator program,[a] hydrochloric acid
3673	764	Lead,[a] arsenic,[a] noise,[a] medical training,[a] medical monitoring,[a] emergency equipment[a]
3673	1,500	Perchloroethylene, sulfuric acid, hydrochloric acid, nitric acid, cyanides and acids stored together,[a] eyewashes,[a] compressed air guns
3673	656	Trichloroethylene, acetone, methylene chloride, chloroform[a]
3671	700	Machine guards,[a] blocked aisles,[a] electrical codes,[a]compressed gas storage,[a] compressed air guns[a]
3675	100	Lead,[a] tin, zinc
3675	50	Methyl isobutyl ketone, butyl cellosolve, cyclohexanone, platinum, trichloroethylene, perchloroethylene, acetic acid, acetone, phthalic anhydride, respirator program
3675	918	Lead,[a] butyl acetate, trichloroethylene, methyl ethyl ketone

See footnotes at end of table.

(continued)

TABLE C-1. OSHA INSPECTIONS IN THE ELECTRONIC COMPONENTS MANUFACTURING INDUSTRY (continued)

Plant classification (SIC code)	Number of employees	Hazards evaluated
3675	400	Epoxy resins, tantalum, sulfuric acid, manganese, heat stress, noise, butyl acetate
3675	120	Trichloroethylene, lead, tin, zinc
3675	663	Dimethylformamide[a]
3675	495	Dichlorobenzidine, toluene, trichloroethylene,[a] silver, lead, tin, benzene

N/A=not available.

[a] Citation issued.

APPENDIX D

PROJECT ON HEALTH AND SAFETY IN ELECTRONICS (PHASE) DATA

APPENDIX D

PROJECT ON HEALTH AND SAFETY IN ELECTRONIC (PHASE) DATA

During the course of the NIOSH study on the Electronic Component Manufacturing Industry, certain labor unions and worker oriented organizations commented on the lack of direct worker input into the study. As a result of these comments, the Project on Health and Safety in Electronics (PHASE) was funded to prepare a summary of the telephone inquiries they had received on occupational illnesses and injuries from workers in the electronic component manufacturing industry. These data are not meant to be a scientific study of injury and illness rates but rather a summary of inquiries which is indicative of occupational concerns of workers in the industry.

The PHASE report is contained in this appendix in its entirety. The reader should be cautioned about drawing conclusions from these incomplete data.

A SUMMARY REPORT ON THE ELECTRONICS HAZARD HOTLINE

Based On The First 700 Calls Received

PROJECT ON HEALTH AND SAFETY
IN ELECTRONICS
PHASE

A Summary Report on the Electronics Hazard Hotline 6/81

In April 1979, the Project on Health and Safety in Electronics established the Electronics Hazard Hotline. PHASE is an independent non-profit education project working under the auspices of the Santa Clara Center for Occupational Safety and Health. Support for the project is provided by a grant from the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor.

The Hotline was designed to serve the electronics workers of Santa Clara County, known as "Silicon Valley," center of the multi-billion dollar, world-wide electronics industry. The electronics workforce represents more than a quarter of the working population in the County and is composed primarily of women (75% of production workers) and largely of ethnic minorities (40% of production workers). The workforce is almost completely unorganized and is geographically diffuse, spreading from San Jose to Mid-Peninsula. These factors make it very difficult to provide occupational health and safety services for electronics workers.

The Hotline was initiated as an independent and confidential source of technical information about substances used on the job, assistance in identifying potential hazards medical and legal referrals, and help in solving health and safety problems. Until the Hotline was started, no such services were available in the Santa Clara Valley. Because of the industry's "clean and light" image, little research had been done to determine the potential hazards in electronics work, and even less had been communicated to those who need the information most: the workers on the line. The Hotline has provided insight into workers' major health and safety concerns and guidance in planning future PHASE activities to meet their needs.

The following information reflects the Hotline's nature as primarily a hazard information service. The Hotline concept, whereby people call in for information, is based on self-selection. The number of calls reflects the effectiveness of outreach techniques employed by PHASE. Consequently, the Hotline does not generate a body of scientifically controlled experimental results. Our methodology has been oriented primarily around fulfilling client needs. No definitive scientific conclusions can be drawn from such an informal sample. Rather, directions for future research are indicated.

We would also like to point out that these data are *no replacement* for direct worker input into any NIOSH study of the electronics industry. No study can be considered accurate or comprehensive without such input.

Certainly the existence of a severe health and safety problem is evidenced by merely the volume of calls we have received.

This report summarizes relevant data from 527 of the 700 calls received over the first 18 months of the Hotline's operation. This represents a total of 1519 health and safety complaints. These are the calls from workers and professionals within the electronics industry. (See Table 1 for breakdown.) The remaining 173 calls were from other industries and others requesting general information, and are not included in this report. On NIOSH request we have included in this report only those calls from electronic production workers, management, engineers and other professionals. Callers in these categories correspond to SIC codes 3671-3676. We wish to emphasize that when figures for electronics workers alone are examined, the rate of health and safety complaints is higher in all categories across the board. Therefore, looking at the sample selected in this report gives a somewhat reduced impression of complaints reported by workers alone.

For the last 291 calls, our survey form was updated and refined, requesting the following information from each caller:

- Caller category: electronics worker; electronics management; electronics engineer; allied electronics
- Information only vs. action/referral
- How heard about Hotline
- Sex
- Workplace
- Workplace size
- Job title
- How long at this job
- How long in electronics
- Shift: day, swing, night
- Substance: plastics; acids/bases; solvents; gases; metals; fibers; brand names; other substances

- Condition: radiation; protective equipment; chemical storage/handling; ventilation; stressors/ergonomics; accidents; malfunctioning machinery; lighting; other
- Medical problem: general complaint; ears, nose, and throat; respiratory; cardiovascular organs; gastrointestinal; reproductive system; nervous system; skin; blood; cancer; eyes; allergy/sensitization; other
- Process: component or radiation equipment manufacture; semiconductor fabrication; printed circuit board manufacture; final product manufacture; chemical supplier/handler
- Do coworkers share problem/concern
- Do you have a union
- Have you contacted any other agency about this
- Need medical or legal referral

While most of this information was in the initial 236 calls requested; there were notable exceptions; i.e., "length in electronics" and "length at job." Consequently, those categories reflect the last 291 callers only (see tables 8 and 9). Also, in the process of collapsing the two data files, we were necessarily left with a few large "other" categories of caller complaints (see attached tables 2 - 5). These categories will be described below.

Who Used the Hotline?

The majority of callers (79%) were electronics production workers, including assemblers, fab operators and technicians. Another thirteen percent (13%) of calls were from electronics engineers and higher level management. The remaining eight percent (8%) of calls were from workers in allied electronics occupations.

The broad array of electronics companies from which workers called indicates that health and safety concerns are not concentrated in a handful of plants or in plants of any specific size. In fact, out of 386 electronics workers who were willing to reveal their workplace, 183 different companies were cited. Of these, companies ranged in size from small to very large. Most were from medium-sized plants with 101-500 employees (20%) and very large plants with 2,000 employees (50%).

It is interesting to note that more than a quarter of the electronics workers who called chose not to give the name of their company. While the majority of workers revealed their workplaces after being assured of the strict confidentiality of the service, this significant minority did not, most commonly citing fear of job loss or some other form of retaliation as their reason. Some callers have reported that their employers discouraged them from calling the Hotline. On the other hand, there were reports of employers who were supportive of their employees' rights to information and assistance and who allowed the Hotline number to be posted on company bulletin boards.

Only five percent (5%) of all callers reported that they belonged to a union. This is consistent with the fact that virtually the entire electronics workforce is unorganized, and therefore among the traditionally underserved in terms of occupational health and safety services. Women, another traditionally underserved group, remained under-represented among Hotline callers; while approximately seventy-five percent (75%) of electronics production workers are women, more than half (51%) of workers who called were men.

What Did People Call About?

*The largest single category of complaints, forty-one percent (41%), were concerning exposure to one or more *chemical substances* (see table 2):

- ***SOLVENTS*** were the most common concern in this category. This included calls about the MEK (methyl ethyl ketone), freons, xylene and numerous other solvents, including TCE (trichloroethylene), a suspect carcinogen and the subject of much controversy. Forty-two percent (42%) of all substance complaints and eighteen percent (18%) of overall complaints were regarding solvents.
- ***ACIDS*** were the second most common concern constituting fifteen percent (15%) of all substance complaints and six percent (6%) of overall complaints. Requests for information on acids included hydrochloric, hydrofluoric, and phosphoric acid.
- ***METALS,*** such as tin-lead solder and arsenic, were the next largest category—fourteen percent (14%) of substances and six percent (6%) of all complaints.
- Other substances receiving a large number of complaints were gases, such as phosphine and arsine; asbestos and fiberglass; epoxy resins and others.

*The next largest category of complaints were *medical problems* (see table 4), representing twenty-seven percent (27%) of all complaints. These included large numbers of inquiries about respiratory, reproductive, gastrointestinal, ENT, nervous system and skin problems.

*The third largest category was *specific work processes* (see table 5), representing sixteen percent (16%) of all complaints. Included were:

- ***WAFER FABRICATION*** (17% of all process complaints, 3% of overall complaints)
- ***SOLDERING*** (13% of all process complaints, 2% of overall complaints)

*The last major category was workplace conditions (see table 3), accounting for fifteen percent (15%) of all complaints. This broad category covered a variety of concerns including stress, radiation, lack of protective equipment and process leakage. The largest single complaint regarded ventilation, constituting eight percent (8%) of overall complaints and fifty-one (51%) of condition complaints.

Due to the nature of these data, statistical tests must be applied only as an indicator of possible problem areas. However, we did perform the basic Pearson Correlation test which verified some "common sense" interpretations of our figures (See table 10). A relationship between inadequate ventilation and solvents, and a variety of medical problems is indicated in the last 291 calls.

Medical problems cited by callers tended to be of an acute or immediate short-term nature. Potential patterns of chronic, long-term diseases, such as cancer, are not easily uncovered through a Hotline approach and may take longer to identify as being work-related. These potential long-term health effects of the work environment are, however, of serious concern to many callers.

*Finally, a substantial number of callers contacted the Hotline seeking general information concerning potential hazard in the electronics industry. These callers demonstrate the desire among workers for preventive education, which would allow them to identify and prevent hazards *before* a problem develops.

How Were Calls Answered?

The majority of Hotline calls were for technical information, some of which required research into the contents of brand name products or the results of recent scientific studies. PHASE answered all requests from electronics workers by researching, compiling and mailing the appropriate information. To respond to these requests, our technical staff used standard industrial hygiene and occupational health references, the series of PHASE factsheets (available in English and Spanish), as well as materials from other health and safety groups across the country.

In addition, nearly thirty percent (30%) of electronics workers who called were seeking assistance beyond technical information. This included medical and legal referrals; advise on how to obtain help from government agencies, such as OSHA and NIOSH; or help in exploring other approaches to solve problems with co-workers and mangement. The most common request was for a medical referral, indicating the pressing need for accessible occupational medical services in the Santa Clara Valley.

Along electronics management callers, most received technical information and referrals to Cal/OSHA Consultation.

The PHASE staff believes that the volume and content of the calls received on the Electronics Hazard Hotline reflect a broad concern regarding job health and safety among electronics workers. We anticipate that the volume of calls will continue to rise as more electronics workers become aware of the confidential, bilingual services offered through the Hotline, which serves as a unique occupational health and safety resource in "Silicon Valley".

TABLE D-1. CALLER CLASSIFICATION FREQUENCIES

Classification	Overall Incidence	Incidence Male	Incidence Female
Electronics Worker	416	212	204
Electronics Manager	45	37	8
Electronics Engineer	24	22	2
Electronics—Allied	42	32	10
TOTALS	**527**	**303** (57%)	**224** (43%)

TABLE D-2. SUBSTANCE COMPLAINTS

Substance	Overall Incidence	Incidence Male	Incidence Female
Acid/Base	97	43	54
Solvents (gen)	267	144	123
Gases	36	18	18
Metals (gen)	88	46	42
Other	142	86	56
TOTALS	**630**	**330** (52%)	**300** (48%)

TABLE D-3. CONDITION COMPLAINTS

Condition	Overall Incidence	Incidence Male	Incidence Female
Ventilation	118	62	56
Stress	5	0	5
Radiation	23	14	9
Protective Equipment	21	13	8
Office Hazard	5	0	5
CRT/VDT	4	3	1
Other	56	28	28
TOTAL	**232**	**120** (52%)	**112** (48%)

TABLE D-4. MEDICAL COMPLAINTS

Medical Problem	Overall Incidence	Incidence Male	Incidence Female
Cancer	0	0	0
Nausea	36	16	20
Reproductive	31	3	28
Respiratory	37	15	22
Other	307	128	179
TOTAL	**411**	**162** (39%)	**229** (61%)

TABLE D-5: PROCESS COMPLAINTS

Process	Overall Incidence	Incidence Male	Incidence Female
Soldering	32	17	15
Wafer Fabrication	43	16	27
Crystal Fabrication	6	4	2
General Info. Request	71	42	29
Other	94	51	43
TOTALS	**246**	**130** (53%)	**116** (47%)

TABLE D-6: SIZE OF WORKPLACE

No. of Workers	Overall Incidence	Incidence Male	Incidence Female
No answer	273	178	82
1-10	4	4	0
11-60	26	16	10
61-100	7	2	5
101-500	52	27	25
501-1,000	27	11	16
1,000-2,000	8	5	3
2,000+	130	51	79

TABLE D-7. WORK SHIFT

Shift	Overall Incidence	Incidence Male	Incidence Female
No answer	312	186	126
Day	165	87	78
Swing	38	14	24
Night	12	7	5

TABLE D-8. HOW LONG AT JOB (LAST 291 CALLS ONLY)*

Length	Overall Incidence	Incidence Male	Incidence Female
No answer	157	103	54
0—6 mos.	38	15	23
7 mos.—1 yr.	21	6	15
1—2 yrs.	35	16	19
2—3 yrs.	11	5	6
3—4 yrs.	12	7	5
4—5 yrs.	5	1	4
5—6 yrs.	2	1	1
6—7 yrs.	1	0	1
Over 7 yrs.	7	3	4

TABLE D-9. HOW LONG IN ELECTRONICS (LAST 291 CALLS ONLY)*

Length	Overall Incidence	Incidence Male	Incidence Female
No answer	206	128	78
0—6 mos.	3	2	1
7 mos.—1 yr.	8	4	4
1—2 yrs.	14	6	8
2—3 yrs.	11	6	5
3—4 yrs.	7	1	6
4—5 yrs.	4	2	2
5—6 yrs.	4	1	3
6—7 yrs.	5	0	5
Over 7 yrs.	29	10	19

TABLE D-10. PEARSON PRODUCT MOMENT CORRELATIONS (LAST 291 CALLS ONLY)

		Solvent Complaint	Ventilation Complaint
Ear, Nose & Throat Complaint	Male		
	Female		r= .2271 (132 cases) p= .004
Respiratory Complaint	Male		r= .2299 (159 cases) p= .002
	Female		
Nervous System Complaint	Male		r= .3659 (159 cases) p= .000
	Female	r= .2046 (132 cases) p= .009	

APPENDIX E

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH INTERVIEW STUDY

The National Institute for Occupational Safety and Health (NIOSH) found that an analysis of the Health Interview Survey, conducted between 1971 and 1974 by the National Center for Health Statistics, can provide a rough estimate of the morbidity experience of a large representative sample of the U.S. population with respect to employment. The proportion of observed to expected morbidity rates was directly adjusted for age, race, and sex using the 1970 U.S. Census population as the standard. A broad industry morbidity profile which included workers in SICs 361, 362, 364, 367, and 369 (classified as manufacturing of electrical machinery, equipment, and supplies) was produced from this data base. Persons in this classification were among the two highest users of medical care services. A more detailed analysis of occupations within this category and their relation to specific diseases indicated slightly elevated incidence of diseases of the respiratory system for white male and female assemblers, packers, and wrappers and for white female checkers, examiners, inspectors, graders, or sorters as a group. No excess was noted for persons employed as machine operators.

An additional excess morbidity rate was observed for endocrine, nutritional, metabolic, and blood type disorders in white females employed as assemblers or packers. The number of cases found in other groups was too insignificant for a morbidity evaluation. The profile indicated that white female assemblers or packers have elevated disease of the musculoskeletal systems, possibly because of ergonomic stress. The sampling contained persons afflicted with diseases of the digestive tract, skin and subcutaneous tissues, and neoplasms and persons employed as solderers or quality control examiners; however, there were not enough individuals in each category to allow any evaluations.

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