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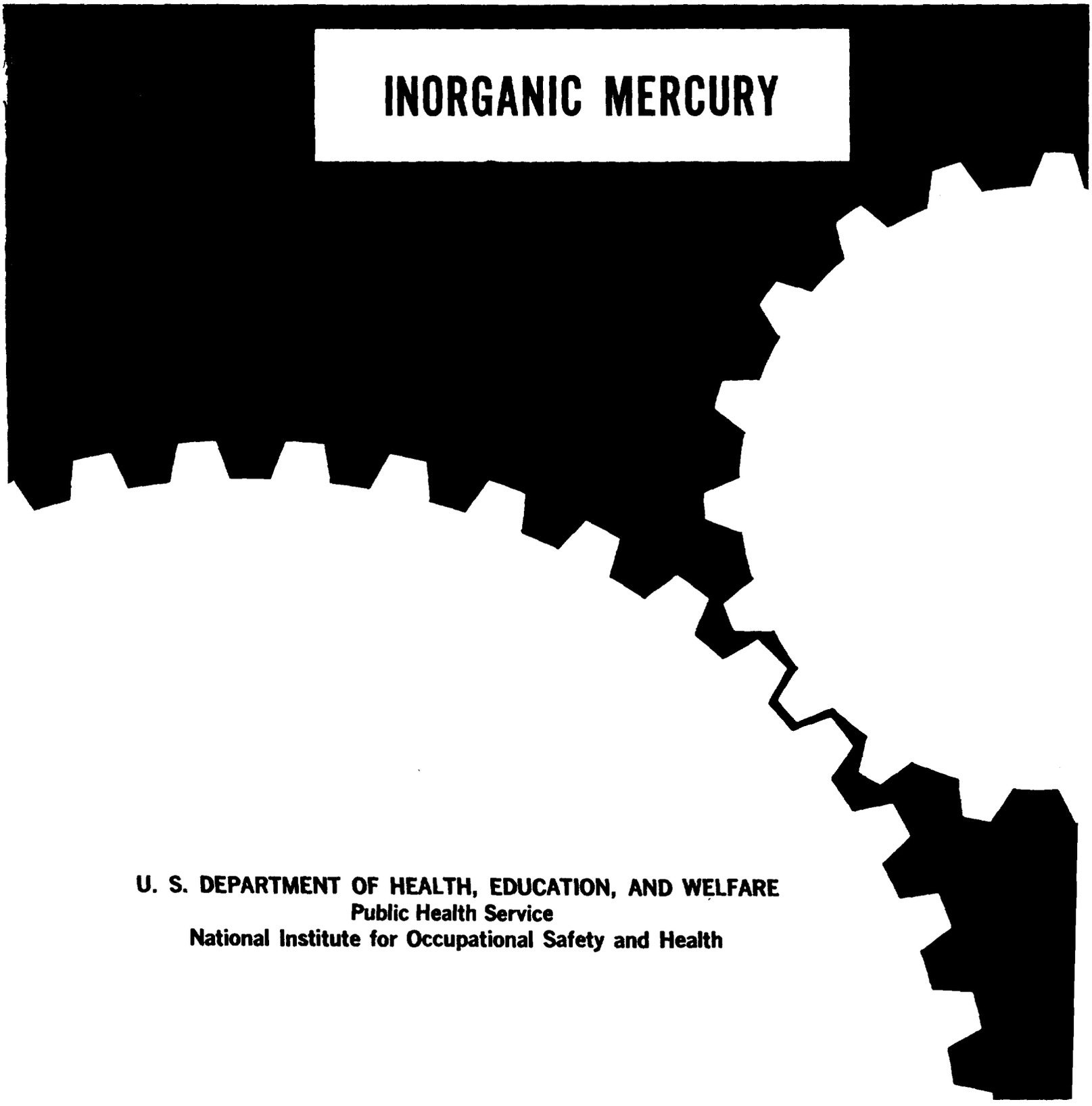
OCCUPATIONAL EXPOSURE TO



U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
National Institute for Occupational Safety and Health

criteria for a recommended standard . . . .

OCCUPATIONAL EXPOSURE TO INORGANIC MERCURY

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
National Institute for Occupational Safety and Health

1973

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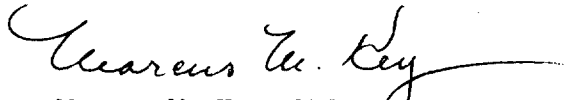
PREFACE

The Occupational Safety and Health Act of 1970 emphasizes the need for standards to protect the health and safety of workers exposed to an ever-increasing number of potential hazards at their workplace. To provide relevant data from which valid criteria and effective standards can be deduced, the National Institute for Occupational Safety and Health (NIOSH) has projected a formal system of research, with priorities determined on the basis of specified indices.

It is intended to present successive reports as research and epidemiologic studies are completed and sampling and analytical methods are developed. Criteria and standards will be reviewed periodically to ensure continuing protection of the worker.

I am pleased to acknowledge the contributions to this report on inorganic mercury by members of my staff, the valuable constructive comments by the Review Consultants on inorganic mercury, the ad hoc committee of the Society of Toxicology, and the ad hoc committee of the Industrial Medical Association, by Robert B. O'Connor, M.D., NIOSH consultant in occupational medicine, and Edwin C. Hyatt on respiratory protection. The NIOSH recommendations for standards are not necessarily a consensus of all the consultants and professional societies that reviewed this criteria document. Lists of the NIOSH Review Committee members and of the Review Consultants appear on the following pages.



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The Office of Research and Standards Development, National Institute for Occupational Safety and Health, had primary responsibility for development of the criteria and the recommended standard for inorganic mercury. Frank W. Mackison served as criteria manager and had NIOSH program responsibility for development of the document. Tabershaw-Cooper Associates, Inc., developed the basic information for consideration by NIOSH staff and consultants under contract HSM-099-71-46.

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CRITERIA DOCUMENT: RECOMMENDATIONS FOR AN OCCUPATIONAL EXPOSURE STANDARD FOR INORGANIC MERCURY

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I. RECOMMENDATIONS FOR AN INORGANIC MERCURY STANDARD

The National Institute for Occupational Safety and Health recommends that employee exposure to inorganic mercury in the workplace be controlled by adherence to the following sections. The standard is designed to protect the health and safety of workers for an 8-hour day, 40-hour week over a working lifetime. Compliance with the standard should prevent adverse effects of inorganic mercury on the health and safety of workers. The standard is measurable by techniques that are valid, reproducible, and available to industry and governmental agencies and is attainable with existing technology. The criteria and the standard recommended in this document will be reviewed and revised as necessary.

"Inorganic mercury" in this document includes elemental mercury, and all inorganic mercury compounds and organic mercury compounds other than ethyl and methyl mercury compounds.

"Exposure to inorganic mercury" is defined as exposure to a concentration of inorganic mercury greater than 40% of the recommended level in the workplace. Exposure at lower environmental concentrations will not require adherence to the following sections, except Section 7a.

Section 1 - Environmental (Workplace air)

(a) Concentration

Occupational exposure to mercury shall be controlled so that workers are not exposed to inorganic mercury at a concentration

greater than 0.05 mg Hg/cu m determined as a time-weighted average (TWA) exposure for an 8-hour workday.

(b) Sampling and Analysis

Procedures for collection of environmental samples shall be as provided in Appendix I, or by a method shown to be equivalent. Analysis of samples shall be as provided in Appendix II, or by any method shown to be equivalent in sensitivity, accuracy, and precision.

Section 2 - Medical

Comprehensive medical examinations (which should include complete urinalysis) shall be made available to all workers subject to "exposure to inorganic mercury" prior to employee placement and annually thereafter. These examinations should place emphasis on any symptoms or signs of unacceptable mercury absorption such as loss of weight, sleeplessness, tremors, personality change, or other evidence of central nervous system involvement.

Medical records shall be available to the medical representatives of the employer, of the Secretary of Labor, of the Secretary of Health, Education, and Welfare, and of the employee at his request. These records shall be kept for at least five years after the employee's last occupational exposure to inorganic mercury.

Section 3 - Labeling (Posting)

The following warning shall be posted to be readily visible at or near entrances or accessways to work areas where there is potential exposure to inorganic mercury.

WARNING!

MERCURY WORK AREA

Unauthorized Persons Not Permitted

The following warning shall be posted in readily visible locations in any work area where there is potential exposure to inorganic mercury.

WARNING!

MERCURY

High Concentrations

Are Hazardous to Health

Maintain Adequate Ventilation.

If environmental levels are at or greater than the recommended standard, add information to the warning describing the location of the respirators.

These warnings shall be printed in English and in the predominant primary language of non-English-speaking workers, if any.

Section 4 - Personal Protective Equipment and Work Clothing

Subsections (a) and (b) shall apply whenever a variance from the standard recommended in Section 1 is granted under provisions of the Occupational Safety and Health Act, or in the interim period during the application for a variance. When the limits of exposure to inorganic mercury prescribed in paragraph (a) of Section 1 cannot be met by limiting the concentration of mercury in the work environment,

an employer must utilize a program of respiratory protection to effect the required protection of every worker exposed.

(a) Respiratory Protection

Engineering controls shall be used wherever feasible to maintain inorganic mercury concentrations in the workplace air at or below the prescribed limits. Appropriate respirators, as prescribed in Table I-1, shall be provided and used when a variance has been granted to allow respirators as a means of control of routine operations and while the application is pending. Administrative controls can also be used to reduce exposure. Respirators shall also be provided and used for nonroutine operations (occasional brief exposures above the environmental standard and for emergencies); however, for these instances, a variance is not required but the requirements set forth below continue to apply. Respirators shall only be used pursuant to the following requirements:

(1) For the purpose of determining the class of respirator to be used, the employer shall measure the atmospheric concentration of inorganic mercury in the workplace when the initial application for variance is made and thereafter whenever process, worksite, climate or control changes occur which are likely to affect the mercury concentration. The employer shall ensure that no worker is exposed to inorganic mercury in excess of the standard because of improper respirator selection or fit.

Table I-1

Requirements for Respirator Usage

At Concentrations Above the Standard

Mg Hg/cu m	Respirator Type*
Less than 5.0	I, II, III
Greater than 5.0	II, III

*TYPE I - Full facepiece gas mask equipped with a high efficiency filter plus canister containing iodine-impregnated charcoal.

TYPE II - Type C (positive pressure) supplied air respirator.

TYPE III - (Positive pressure) self-contained breathing apparatus.

(2) Employees experiencing breathing difficulty while using respirators shall be evaluated by a physician to determine the ability of the worker to wear a respirator.

(3) A respiratory protective program meeting the general requirements outlined in section 3.5 of American National Standard for Respiratory Protection Z88.2-1969 shall be established and enforced by the employer.

(4) The employer shall provide respirators in accordance with Table I-1 and shall ensure that the employee uses the appropriate respirator.

(5) Respiratory protective devices described in Table I-1 shall be either those approved under 30 CFR 11, published March 25, 1972, or under the following regulations.

(A) Gas masks - - - 30 CFR 13 (Bureau of Mines Schedule 14 E)

(B) Self-contained breathing apparatus - - - 30 CFR 11 (Bureau of Mines Schedule 13 E)

(C) Supplied air respirator - - - 30 CFR 12 (Bureau of Mines Schedule 19 B)

(6) Usage of a respirator specified for use in higher concentrations of inorganic mercury is permitted in atmospheres of lower concentrations.

(b) Work Clothing

(1) Each employee subject to exposure to inorganic mercury shall be provided coveralls or similar full body work clothing, shoes

or shoe covers, and hat, which shall be worn during the working hours in areas where there is exposure to inorganic mercury. A daily change of clean work clothing shall be supplied by the employer.

(2) Adequate shower facilities provided with hot and cold or tempered water shall be available for use and used by workers.

(3) Work and street clothing shall not be stored in the same locker.

(4) Work clothing should be vacuumed before removal. Clothes shall not be cleaned by blowing or shaking.

Section 5 - Apprisal of Employees of Hazards from Inorganic Mercury

(a) Each employee exposed to inorganic mercury shall be apprised at the beginning of his employment or assignment to an inorganic mercury work area of hazards, relevant symptoms, appropriate emergency procedures, and proper conditions and precautions for safe use or exposure. He shall be instructed as to availability of such information including that prescribed in (b) below. Such information shall be kept on file and shall be accessible to the worker at each place of employment where inorganic mercury is used.

(b) Information as specified in Appendix III shall be recorded on U.S. Department of Labor Form OSHA-20, "Material Safety Data Sheet" (see Appendix III) or on a similar form approved by the Occupational Safety and Health Administration, U.S. Department of Labor.

Section 6 - Work Practices

(a) Emergency Procedures

(1) Procedures, including fire fighting procedures, shall be established and implemented to meet foreseeable emergency events.

(2) Respirators shall be available for wearing during emergencies. Self-contained respirators shall be available for employee use in the event of fire or other emergencies where equipment or operations cannot be abandoned because of an emergency.

(b) Exhaust Systems

Where a local exhaust ventilation system is used, it shall be designed and maintained to prevent the accumulation or recirculation of mercury vapor, dust, and fumes into the workroom.

(c) General Housekeeping

(1) Floors, work surfaces, and equipment shall be so constructed and maintained as not to have cracks, crevices, or other areas which may retain mercury.

(2) Spills and leaks of mercury shall be promptly cleaned up either mechanically or chemically, or by other appropriate means. No blowing or dry sweeping shall be permitted. When vacuum cleaners are used, they shall be equipped with mercury vapor absorbing filters to prevent dispersal of mercury vapors into the workplace air and shall be maintained so they will not disperse mercury-laden dust into the workplace.

(3) Waste mercury or materials contaminated with mercury shall be kept in vaporproof containers, under water, or in chemically treated solutions, pending removal for disposal or processing for reuse.

(d) General Procedures

(1) Containers of mercury shall be kept covered when it is not necessary to have them open for process operations.

(2) Open containers of mercury, to the greatest extent possible, shall have the surface of the mercury covered with an aqueous layer maintained at a temperature below its boiling point to prevent vaporization of the mercury.

Section 7 - Sanitation Practices

(a) Food preparation, dispensing (including vending machines), and eating shall be prohibited in mercury work areas.

(b) Smoking materials shall not be permitted in mercury work areas.

(c) Handwashing facilities, including hot and cold running water, soap, and towels, shall be made available adjacent to mercury work areas. Employees shall be instructed in the importance of thoroughly washing their hands before eating or smoking.

(d) Soiled clothing shall be stored in vaporproof containers pending removal for laundering.

(e) Laundering of work clothing shall be provided by the employer. Persons responsible for laundering mercury contaminated clothing shall be informed of the hazards involved.

Section 8 - Monitoring and Recordkeeping Requirements

Workroom areas where it has been determined, on the basis of an industrial hygiene survey or the judgment of a compliance officer, that environmental levels do not exceed 40% of the environmental standard shall not be considered to involve worker exposure to inorganic mercury. An additional survey shall be made if there is a change in process or engineering controls. Records of these surveys, including the basis for concluding that air levels are below 40% of the environmental standard, shall be kept.

Requirements set forth below apply to inorganic mercury exposures.

(a) Employers shall monitor environmental levels of inorganic mercury at least every 6 months. Breathing zone samples shall be collected to permit calculation of a time-weighted average exposure for every operation.

(b) When any time-weighted average exposure is at or above the environmental standard, immediate steps shall be taken to reduce environmental levels. Samples shall be taken every 30 days until the environmental level has been reduced below the standard.

(c) Records shall be maintained for all sampling schedules to include the sampling and analytical methods, type of respiratory

protection in use (if applicable), and the air concentrations of mercury in each work area. Records shall be maintained so that each employee shall be able to obtain information on his own environmental exposure.

II. INTRODUCTION

This report presents the criteria and the recommended standard based thereon which were prepared to meet the need for preventing occupational disease arising from exposure to inorganic mercury. The document fulfills the responsibility of the Secretary of Health, Education, and Welfare, under Section 20(a)(3) of the Occupational Safety and Health Act of 1970 to ". . . develop criteria dealing with toxic materials and harmful physical agents and substances which will describe . . . exposure levels at which no employee will suffer impaired health or functional capacities or diminished life expectancy as a result of his work experience."

The National Institute for Occupational Safety and Health, after a review of data and consultations with others, formalized a system for the development of criteria upon which standards can be established to protect the health of employees from exposure to hazardous chemical and physical agents. It should be pointed out that any recommended criteria for a standard should enable management and labor to develop better engineering controls resulting in more healthful work practices and should not be accepted as a final goal.

These criteria for a standard for inorganic mercury are part of a continuing series of criteria developed by NIOSH. The proposed standard applies only to the processing, manufacture, and use of

mercury as applicable under the Occupational Safety and Health Act of 1970.

The occupational safety and health aspects of mining and milling mercury ores are covered by provisions of the Federal Metal and Nonmetallic Mine Safety Act (30 U.S.C. 725 et seq.) under which the Bureau of Mines has responsibility.

The recommended standard is based on currently available information relating exposure to effect. The environmental limit is based on the prevention of effects on the central nervous system such as tremor, behavioral and personality changes, and nervousness, attributable to occupational exposure to mercury.

These criteria were developed to assure that the standard based thereon would 1) protect workers against the acute or chronic toxic effect of mercury; 2) is measurable by techniques that are valid, reproducible, and available to industry and governmental agencies; and 3) is attainable by existing technology.

III. BIOLOGIC EFFECTS OF EXPOSURE

Extent of Exposure

Nearly four million pounds of mercury are currently consumed annually in the United States, but the production and usage of mercury has fluctuated widely through the years. [1] (See Table XII-1 and Figure XII-1.) Although the general trend in its use has been downward since 1969, increased consumption has been noted for a limited number of uses as shown in Table XII-2. [1] The demand for mercury in the future is predicted to increase significantly through the year 2000 as shown in Table XII-3. [2] The proportions of mercury used by various industries are also shown in these tables.

Major uses for mercury are in electrical preparation of chlorine and caustic soda and in the manufacture of electrical apparatus. The properties of mercury, Table XII-4, [3] have made it particularly useful in a variety of industries and, at the same time, have made controlling exposure to it difficult. Among these are liquidity at ordinary temperatures, high density and surface tension, conductivity, and uniform thermal expansion.

A list of specific occupations or trades involving frequent exposure to mercury has been prepared by Gafafer [4] and is presented in Table XII-5. The variety of occupations listed in that table indicates why an exact measure of the extent of exposure to mercury is nonexistent. It should not be assumed that all persons in these

occupations are actually exposed to mercury; however, they are subject to exposure, and therefore, are subject to risk of mercury absorption. Estimations based upon a study of industries in Chicago indicate that a minimum of 150,000 individuals are routinely exposed to mercury. [5]

To the exposure which an individual receives by virtue of his occupation can be added that exposure which is contributed from nonoccupational sources. These sources of exposure to mercury are highly variable and include atmospheric sources. [6-8] The atmosphere contains small but measurable amounts of mercury from vaporization and dispersal into the atmosphere of mercury occurring naturally in the earth's surface. [9] Other sources of atmospheric mercury are from the burning of fossil fuels, such as oil and coal, and airborne discharges from mercury-using industries. [9] It has been estimated [10] that atmospheric concentrations in large industrial cities may approach a level of 1 microgram per cubic meter of air (1 μg Hg/cu m), although sufficient data to substantiate this estimate are not yet available. Also, varying amounts of mercury are found in food and water. [11,12] In addition, individuals may be exposed through dental and medical treatment. [13]

Because of the wide variability in the exposure individuals may receive, a "normal" level of mercury in the body is difficult to establish with certainty. To complicate factors further, many of the investigations reporting on "normal" levels of mercury in "nonexposed" individuals fail to give adequate consideration to the population

sampled, to all possible sources of exposure, to the sampling and analytical methods employed; thus, the data do not permit definite evaluation and comparison. [13]

Early Historical Reports

Archeologists have found that cinnabar (HgS), a sulfide ore, was used as a pigment by ancient Egypt and Babylon according to the history of mercury written by Goldwater. [14] The Greek physician Dioscorides recorded the use of mercury as a topical medicine but noted that the element was dangerous if swallowed. [15] Mercurials were used during the Middle Ages in the treatment of syphilis, and the concomitant gastrointestinal, urinary, nervous, and mental disorders were well known. [16] According to Almkvist, [17] it was not until the end of the 18th century that the symptom complex known as erethism, a peculiar form of emotional instability, was recognized as a specific effect of mercury intoxication.

Goldwater, [14] attributes a description of the earliest cases of occupational mercury poisoning to Jean Fernel in De lue venerea published in 1579. Significant contributions to the literature on occupational mercurialism were made by Agricola and Paracelsus in the 16th century. [14] The description of occupational mercury poisoning by these writers was similar to those of Ramazzini in the late 18th, by Kussmaul in the 19th, and Thompson in the 20th centuries. [14] The major symptoms which they recognized, erethism, tremor, and

gingivitis, are still the predominant ones associated with inorganic mercury poisoning.

The fur and felt hat industries were formerly the primary source of occupational mercury poisoning, and studies of the working conditions in these industries revealed a high incidence of mercury intoxication. [18-21]

The last major studies in these fur-felt industries were by Neal et al in 1937 [18] and 1941. [19] Shortly after they were published, a substitute for the mercuric nitrate used in carroting the fur was introduced in the felt industry, thus eliminating exposures to mercury. [22]

Effects on Humans

Mercury and compounds of mercury may be absorbed through the skin, the gastrointestinal tract, and the lungs. [16] The principal source of occupational mercury poisoning is mercury vapor, with exposure to mercury compounds occurring less frequently. [16] The discussion of mercury in this document will be limited to mercury vapor, inorganic mercury compounds, and organic compounds other than the short chain alkyl mercurials. Because alkyl mercurials (ethyl and methyl mercury compounds) are known to have a significantly greater toxic effect than other forms of mercury, [23,24] a separate criteria document, specific to alkyl mercury, is under consideration. Therefore, discussion of alkyl mercury compounds in this document will

be limited to occasional comparison with effects of other forms of mercury.

The adverse effects of mercury absorption have been investigated or reviewed by many researchers and are well documented. [16,21,23-32]

The appearance of gingivitis and stomatitis accompanied by excess salivation or a metallic taste, erethism, and tremor are identified by Bidstrup [16] as the classical signs of poisoning by mercury vapor and inorganic forms of mercury. Exposure to high levels of mercury vapor affects the respiratory system and is manifested by pneumonitis, bronchitis, chest pains, dyspnea or coughing. These symptoms may be accompanied by the classical symptoms mentioned above. Ingestion of some inorganic compounds, eg, mercuric chloride, causes irritation and corrosion of the body tissues contacted. [16,32,33] If high concentrations of the mercury reach the small intestine, severe abdominal pain and bloody diarrhea will result, with the likelihood of sudden death due to shock and circulatory collapse. [33,34].

The onset of symptoms of mercury toxicity from chronic exposure is insidious, [16,35] and with the exception of tremor, may be ignored by the individual or attributed to other causes. This is particularly true with erethism, which is characterized by irritability, outbursts of temper, excitability, shyness, resentment of criticism, headache, fatigue, and indecision. [16,32] Erethism is the most difficult manifestation of chronic mercury toxicity to evaluate, particularly

when tremor is absent and these symptoms may be attributed to anxiety or neurasthenia.

Tremor is one of the earliest signs of central nervous system involvement resulting from mercury exposure and occurs from exposure to both the inorganic and organic forms of mercury. [32,35] It is characterized by fine, rhythmical, static trembling, interrupted by sudden, coarse, jerking movements and aggravated by voluntary movement. It usually affects the hands first as a fine "intention" tremor but may also be observed in the face and arms. [16,18,19,31]

Some central nervous system effects as manifested by dysarthria, ataxia, and constricted visual fields, have been regarded as significant signs of organic mercury poisoning; however, these effects occur most prominently with alkyl mercury poisoning. [36]

Poisoning from organic mercury compounds such as phenyl or methoxyethyl mercury compounds, which are the specific ones of major occupational concern, is manifested by symptoms of fatigue, dyspnea, chest and abdominal pain, and vomiting. [37-39] In addition, symptoms of gingivitis, dysarthria, motor weakness, and abnormal reflexes have been noted in a limited number of cases of poisoning from organic mercury compounds. [40] In general, signs and symptoms of aryl and methoxyethyl mercury poisoning resemble those observed for inorganic mercury compounds.

Kark et al [41] reported that symptoms of organic mercury poisoning may occasionally simulate those of inorganic and elemental

mercury poisoning, and conversely, cases of elemental mercury poisoning may rarely manifest signs and symptoms usually attributed to organic mercury. In tabulating the signs and symptoms in 87 cases of organic mercury poisoning reported in the literature since 1940, these authors found considerable overlap between signs and symptoms of mercury toxicity from organic mercury compounds and those usually associated with toxicity from inorganic mercury compounds.

The kidney, in almost all situations, accumulates the highest concentrations of mercury as compared to other organs. [23] Kidney damage may result from excessive exposure to mercury as manifested by the nephrotic syndrome of edema, proteinuria, and the presence of casts or cells in the urine. Such damage may or may not be accompanied by an elevated mercury level in the urine. [16] The nephrotic syndrome may be the only manifestation of mercury intoxication and recovery from the nephrotic syndrome usually follows removal from exposure. In more severe cases of kidney damage, renal failure and oliguria may develop, leading to complete anuria. [42-44]

Dermatitis may occur as a result of exposure to mercury. [45-47] Reported cases have usually followed sustained exposure and have been associated principally with organic compounds but cases may also involve inorganic mercury exposure. [35] Absorption of mercury through the skin can occur [45] and may contribute to the systemic effects of mercury absorption via other routes.

The appearance of a greyish-brown or yellow haze on the anterior surface of the capsule of the lens has been reported by Atkinson, [48] following examination by slitlamp. It appears to be associated with exposure to mercury vapor of long duration, and the depth of color apparently depends somewhat upon the length of time and the amount of mercury to which an individual has been exposed. Its presence may or may not be accompanied by signs of toxic absorption of mercury.

A group of nonspecific signs and symptoms have been associated with intoxication by inorganic mercury. [16,26,28] These include weakness, unusual fatigue, loss of weight, loss of appetite, insomnia, and gastrointestinal disturbances. Their association with mercury poisoning is difficult to assess. However, they may be considered a prelude to the appearance of more specific or severe symptoms of mercury toxicity when they are manifested in individuals having known exposure to mercury. [28]

Epidemiologic Studies

In the industrial setting, exposure to mercury is usually from low levels for long duration, and there are a number of studies in the literature which relate exposure to effect. [8,16,18-21,25-28,35] The exposure has generally been evaluated by measurements of air concentrations; however, analyses of urine or blood for mercury are often reported. Most data are from exposure to mercury vapor by inhalation, but other forms of mercury and routes of exposure are frequently associated with the vapor form. [18,26,28,32,35]

It has not been possible to evaluate the different forms of exposure separately even though, in some cases, attempts were made to differentiate between vapor and aerosols.

Ladd et al [27] reported a study of 74 workers, both miners and smelters, in the cinnabar and native mercury mines of Idria, Yugoslavia. Sixteen workers (22%) exposed to total mercury concentrations from vapor and dust in the mine ranging from 0.16 to 4.89 mg Hg/cu m were found to have signs of mercury poisoning. These environmental levels were determined separately as dust and vapor and reported as combined results. Mercury vapor concentrations ranged from 0.1 to 2.0 mg Hg/cu m in the mines, with a reported range of 0 to 2.0 mg Hg/cu m in the smelter. It was not possible to relate air levels to individual worker exposure since workers were rotated from one work station to another. The workers complained of disturbed sleep, irritability, personality change, salivation, tremor, gingivitis, and tremulous handwriting. Three of the affected miners had lower urine mercury levels (2 - 12 μg Hg/liter) than asymptomatic exposed workers (0 - 1275 μg Hg/liter).

In the same paper, Ladd and co-workers [27] described a study of workers exposed at levels ranging from 0.1 to more than 2.0 mg Hg/cu m in an open-pit cinnabar mine in the Philippines. Mercury vapor concentrations were measured by Kitagawa detector tubes, but dust levels were not determined, although the author indicated that, at times, mercury-laden dust may have been present in high

concentrations. This fact and the knowledge that the upper range of the detector tubes was 2.0 mg Hg/cu m would suggest that the air concentration to which the miners were exposed may have been higher than the 2.0 mg Hg/cu m reported. In 1964, half of the exposed work force of 30 miners had various signs and symptoms suggestive of mercury toxicity, consisting of tremor, gingivitis, salivation, and irritability. These same observations had been noted two years earlier at the same mine in 17 of the workers. As in the Idria study, urinary mercury levels were lower in the symptomatic group of workers (3-1260 μg Hg/liter) than in the exposed asymptomatic workers (75-2175 μg Hg/liter).

West and Lim [49] have presented information on 96 workers in nine mercury mining or milling operations in California. Thirty-one of the 96 workers studied had definite or borderline cases of mercury poisoning. All of these occurred in millworkers and there were no cases in the miners. These findings tended to support the claim that environmental mercury vapor concentrations from mercury sulfide ore in the mines were "negligible", in contrast to those in the milling operations where workers were exposed to both high concentrations of mercury vapor and excessive skin contact with liquid mercury. Exposures to mercury vapor in the milling operations were measured from 0.3 to 1.2 mg Hg/cu m, the maximum reading of the measuring instrument. Therefore, the maximum exposure experienced by these workers is not known but possibly could have been in excess of 1.2 mg

Hg/cu m. The average length of employment for the 31 mill employees was only eight months. Two workers who had been employed more than two years had severe mercury intoxication. It was also found that some millworkers had unknowingly contaminated their living quarters with mercury from their boots and work clothes, and thus were most likely exposed to mercury while away from work.

McGill et al, [50] in a study of chlor-alkali workers routinely exposed to mercury vapor concentrations ranging from 0.08 to 0.10 mg Hg/cu m as measured by a mercury vapor meter, reported that physical examinations showed no evidence of dangerous absorption of mercury among the workers. During hot weather, mercury vapor levels occasionally reached 0.13 mg Hg/cu m. Urine levels for this group of workers were extremely low, ranging from a reported 0 to 157 µg Hg/liter for those who spent full time in the cell room.

Smith et al [28] reported the results of a comprehensive, one year study of 567 workers exposed to mercury in 21 chlor-alkali plants in the United States and Canada. The environmental and medical data for the study were collected by industrial hygienists and medical personnel in the plants and analyzed by the authors. Environmental measurement of airborne concentration of mercury was performed using mercury vapor meters. Instructions for calibration of the survey instruments were provided to all industrial hygienists participating in the study. Precautions were taken to prevent interference from the high magnetic fields found in chlor-alkali plants in the operation of

the mercury vapor meters. Air concentrations of vapor ranged from less than 0.01 to 0.27 mg Hg/cu m. No measurements of total airborne mercury were routinely performed.

Standardized medical examination procedures were developed to minimize inconsistencies between methods of examination, and all workers were examined at least once during the study year. No cases of mercury poisoning were diagnosed during the year at exposure levels ranging from less than 0.01 to 0.27 mg Hg/cu m. There were reports, however, of fifty workers (9%) who complained of loss of appetite, 74 (13%) of loss of weight, and 56 (10%) of insomnia. [51] In addition to these symptoms, an unstated number of workers with tremors was observed and reported by the examining physicians. These signs and symptoms, although not specific for mercury, are among those associated with the clinical picture of chronic mercury intoxication. The distribution of these complaints among different exposure groups was reported by the authors [28] to show statistically strong correlations with the mercury exposure levels. The objective tremors of fingers, eyelids, and tongue were significantly related to mercury exposure levels (reported as P values) ($P = 0.001$). The incidence of abnormal reflexes was the same among controls as among mercury workers as a group, but when exposure was greater than 0.10 mg Hg/cu m, there was an appreciably higher incidence of abnormal reflexes. [28]

A condition described as asthenic-vegetative syndrome, or "micromercurialism", has been reported by Trachtenberg [52] in a

monograph published in 1969. The condition was originally described by Stock [53] on the basis of psychological changes observed in persons chronically exposed to low concentrations of atmospheric mercury. The syndrome was characterized by decreased productivity, increased fatigue and nervous irritability, loss of memory, loss of self-confidence, and, ultimately, by miniature symptomatology of classical mercurialism: muscular weakness, vivid dreams, pronounced decrease of productivity, and depression.

Trachtenberg [52] concluded that clinical "micromercurialism" shows characteristic symptoms of its own in addition to the classical symptoms of chronic mercury poisoning. These symptoms of "micromercurialism" were attributed to disturbances in the cortical centers of the central nervous system and are manifested by functional changes in organs of the cardiovascular, urogenital or endocrine systems. More complete details of this syndrome are discussed by Friberg and Nordberg, [54] based on material taken partly from translations of Russian publications and from information obtained by personal communications with scientists in the USSR.

Of the studies reported by Trachtenberg [52], the study of workers in Kiev exposed to average airborne mercury levels ranging from 0.01 to 0.05 mg Hg/cu m is informative for learning of the effects among Russian workers exposed to low concentration of airborne mercury. See Table XII-6. Differences in incidence of effects between exposed workers and controls noted by Trachtenberg do not

appear to be significant except possibly for the incidence of hyperthyroidism, where a 4.4% incidence was observed in controls and about 14% in exposed workers. Trachtenberg diagnosed hyperthyroidism by observation of enlarged thyroid (probably by palpation) and by increased uptake of radioactive iodine.

It is difficult to evaluate the observations of hyperthyroidism in mercury exposed workers. In earlier studies [18-21] enlarged thyroids were noted but the authors concluded there was no relationship between thyroid disease and exposure to mercury. It has not generally been reported in other studies [28,55] involving careful evaluation of workers exposed to mercury. Possibly it was not considered and therefore not looked for in these studies, but it seems likely that it would have been looked for since so many of the symptoms of mercury could be accounted for by demonstrating hyperactive thyroids.

In the hatter's fur-cutting industry, Neal et al [18] found 43 workers with mercury poisoning classified generally as tremor, psychic irritability, vasomotor disturbances, and oral conditions in 529 employees exposed to mercury-in-air levels ranging from 0.06 to 0.72 mg Hg/ cu m. In this study, mercury vapor concentrations were measured by selenium sulfide mercury vapor detectors, while aerosol levels were measured by impingers, using a 25% alcohol and water mixture as a collecting medium. In a later study of the felt hat industry, [19] these same investigators reported 59 cases of

intoxication by mercury (tremor, psychic disturbances, headaches, drowsiness, insomnia) from among 534 workers examined. Extensive urine mercury determinations were made by a spectrographic method, and approximately 30% of the 59 cases of mercury toxicity showed no mercury in the urine. Forty-nine "borderline" cases of poisoning were reported at environmental mercury concentrations as low as 0.1 mg Hg/cu m. "Borderline" cases were those considered as having mild changes similar to those found with mercury intoxication, but, according to these authors, the number and gravity of the signs or symptoms did not warrant a diagnosis of mercury poisoning. In this study, air concentrations were also measured by a selenium sulfide mercury detector and impinger and workers' exposure ranged from a reported 0.0 to 0.5 mg Hg/cu m.

Studies by Smith and Moskowitz [20] and Smith et al, [21] which were conducted in 1936 but not reported until 1948-50, showed that 85 (39.9%) of the 213 workers exposed to total mercury from less than 0.1 to 0.81 mg Hg/cu m in the fur-felt industry had definite signs of chronic mercury poisoning. Another 58 who had certain characteristic signs or symptoms of mercury poisoning but not so definite to remove all doubt of the diagnosis were considered "borderline" cases by these authors. Of 35 workers exposed to less than 0.1 mg Hg/cu m, 4 had signs or symptoms of mercury poisoning and 10 were considered borderline cases by the authors. Environmental measurements were made

by a selenium sulfide apparatus and a large Greenburg-Smith impinger. The samples were analyzed by dithizone titration.

In contrast to the studies by Neal et al, [18,19] Smith and Moskowitz [20] and Smith et al [21] found that all exposed workers had mercury in their urine. Moskowitz, [56] in reporting a statistical analysis of the cases studied, [20,21] showed that cases of mercury poisoning (tremor, weight loss, gingivitis, headache, loss of appetite) developed in workers exposed for seven years or longer at environmental mercury concentrations of less than 0.1 mg Hg/cu m. He further showed that concentrations of approximately 0.8 mg Hg/cu m produced cases in some individuals within five months.

In Italy, a study by Baldi et al [57] of records of 1,173 hatters revealed 300 cases of mercury poisoning resulting from exposure to concentrations ranging from 0.5 to more than 2.0 mg Hg/cu m. One third of the cases in this exposure range resulted in permanent disability. Some cases of mercury poisoning were reported at levels below 0.5 mg Hg/cu m, however no cases were reported in workers exposed at levels below 0.1 mg Hg/cu m.

In Yugoslavia, Kesic and Haeusler [58] found that two-thirds of 70 female felt hatters, exposed to air levels from 0.25 to 1.0 mg Hg/cu m, showed pronounced symptoms of mercury poisoning. Hematological studies indicated no significant difference in the values of blood elements and hemoglobin levels between these workers and a nonexposed control group.

Clinically negative studies have been reported by Shoib et al [59] and Kleinfeld et al [60] for workers exposed, at levels from 0.032 to 0.40 mg Hg/cu m, to a variety of inorganic mercury compounds in combination with metallic mercury.

Ladd et al [46] studied three plants in which groups of workers were exposed to single phenylmercuric compounds. In two of these plants, workers were exposed to phenylmercuric benzoate (PMB), while in the other, workers were exposed to phenylmercuric acetate (PMA). In one of the plants using PMB, 23 workers were exposed to mercury in air at levels ranging from a reported 0.00 to 0.08 mg Hg/cu m (mercury vapor meter) and presumably to PMB dust on the skin. None of the workers had any signs or symptoms of mercury poisoning. However, virtually all the workers showed the presence of mercury in their urine (range 1 - 788 μg Hg/liter).

In the second PMB plant, air measurements were made for vapor using mercury vapor meters and for total mercury using a Unijet Sampler with potassium iodide and iodine as the collecting solution. The readings given by the two methods of measurement were practically the same, indicating that essentially all the mercury in air was in the form of mercury vapor, and was probably the most significant source of exposure. This would suggest that PMB, like other organomercurials, is unstable and partially decomposes in air to release mercury vapor. At 21 of 30 sampling sites, the air levels were below 0.1 mg Hg/cu m. No signs of mercury toxicity were found

upon examination of the 21 workers exposed. Urine mercury levels were reported to range from 0 to 240 μg Hg/liter.

In the plant using PMA, the 23 workers were not continuously exposed to a given level of mercury because they did not remain continuously at a given work location. Samples from nine of the 17 locations tested showed no detectable mercury, while the other areas sampled were found to have air levels ranging between 0.05 and 0.10 mg Hg/cu m. None of the workers at this plant showed signs of toxicity and all workers' urine mercury levels were below 150 μg Hg/liter.

The study of these three plants, involving a total of 67 workers, would suggest that PMA and PMB both have a low toxicity for humans, in terms of industrial exposure, and that what absorption does take place from the air is probably in the form of mercury vapor.

Dinman et al [61] conducted a 5 1/2 year study of 20 workers having a mixed exposure to ethylmercuric and phenylmercuric acetates. Environmental mercury levels were determined by a total mercury method with levels averaging, on a monthly basis, from 0.01 to 0.12 mg Hg/cu m. No significant objective findings of mercury poisoning were made during the entire study period, and the incidence of a variety of subjective symptoms commonly associated with mercury intoxication was not significantly higher than in nonexposed control workers.

Since the kidney is a critical organ for accumulation of mercury, the appearance of renal damage with or without the appearance

of proteinuria would not be an unexpected occurrence in exposed workers.

In reporting on four cases of renal damage among two groups of workers exposed to unspecified levels of inorganic and organic forms of mercury, Kazantzis et al [62] described the appearance of albuminuria and of the nephrotic syndrome. At the time the patients were first seen, all four cases were excreting over 1,000 μg Hg/liter of urine. The albuminuria cleared up, and mercury disappeared from the urine after the workers were removed from exposure.

These findings suggest that chronic exposure to levels of mercury may occur which are insufficient to produce gross albuminuria or signs or symptoms of mercury poisoning yet are sufficiently high to produce low levels of proteinuria. Such a possibility was investigated by Joselow and Goldwater. [63] A group of 52 workers exposed to several inorganic mercurials were examined for total urinary protein. The mean urinary protein of the group was significantly higher than that of a group of 34 nonexposed controls (9 mg protein/100 ml of urine for the exposed group and 5.3 mg protein/100 ml of urine for the controls). In the exposed group, the urinary protein correlated ($r = 0.41$) with the urine mercury levels but only weakly with blood mercury levels ($r = 0.24$). However, the authors concluded that this correlation was found only on a group basis. This would suggest that the amount of protein found in the

urine of individual workers would not be an accurate index of their exposure to inorganic mercury.

The estimation of worker exposure to mercury is usually through evaluation of the workroom air concentrations to which he is exposed. In addition to receiving exposure at work, individual workers may be subjected to mercury exposure beyond their normal workday as a result of their work activity. Such exposure has been reported by several investigators and may be from inhalation, skin absorption or ingestion. [26,49,54] This type of exposure contributes an unknown factor to the total worker exposure.

Benning [26] reported gross contamination of the workplace and of workers' clothing which was worn home. Poor personal hygiene and work practices also resulted in these workers taking a certain amount of mercury contamination home with them.

West and Lim, [49] in their investigation of workers milling cinnabar, found that some of the mill workers were exposed to mercury away from work because they had unknowingly contaminated their living quarters with mercury from their boots and work clothes.

In reporting a study of workers in scientific glassware manufacturing plants, Danzinger and Possick [64] found no cases of mercury poisoning among 75 workers exposed to mercury in air levels ranging from a reported 0.00 to 0.30 mg Hg/cu m. These investigators reported frequently observing mercury particles in workers' clothing, especially when made of knitted fabric. This also occurred if the

workers were not wearing aprons. Such particles would be shaken from their clothes at home. They also observed one female worker having particles of mercury imbedded in the makeup on her face.

It is recognized that workers' exposure to mercury may continue beyond the workplace because contaminated work clothes are worn home, or because of poor personal hygiene or work practices; however, these factors do not appear to have been given adequate consideration by investigators in relating exposure to levels of mercury in biological tissues or to the appearance of symptoms. Such exposure may be exceedingly difficult to assess with any degree of accuracy. It could, however, account for some of the lack of correlation between reported air levels and reported urine or blood mercury levels. This could partially explain the good correlation when comparing groups of workers with exposure, and poor or no correlation of individuals within the same exposure group.

Animal Toxicity

To help understand the toxicological effects of mercury, a number of investigators have studied the toxicological and biochemical actions of mercury in various animal species.

(a) Absorption and Transportation

Hughes [65] hypothesized that elemental, as opposed to ionic (ie, oxidized) mercury, is transported in solution in the blood lipids to diffuse readily through lipid cell membranes into the cells of such tissues as the brain, before being oxidized. This has been confirmed

in the rat by Magos [66] by the intravenous injection of radioactive metallic mercury. Diffusion occurred rapidly and twenty percent of the mercury was exhaled through the lungs within 30 seconds, and a high concentration rapidly developed in the brain. Intravenous injection of an equivalent amount of mercuric chloride was followed by exhalation of a much smaller fraction (2%) and one-tenth of the concentration in the brain of that obtained with exposure to the vapor form. Similar results were obtained in rats, rabbits, and monkeys. [67] Diffusion of elemental mercury into the tissues and across cell membranes is apparently facilitated by its lipid solubility and its lack of electrical charge. [65,68] After absorption by the body, elemental mercury is oxidized to the mercuric ion Hg^{++} and thereafter behaves toxicologically as that ion. [31,68]

The dust or aerosols of inorganic mercuric salts are absorbed via the respiratory tract in amounts or at sites dependent upon their particle size and solubility in biological fluids. [68] Mercuric salts are rather poorly absorbed from the gastrointestinal tract, either following direct ingestion or secondarily from dust in swallowed sputum from the lungs. Clarkson [69] has shown that only about 2% of inorganic mercury is absorbed from the gastrointestinal tract of the rat following ingestion.

Using rats and radioactive mercuric chloride injected intravenously, Cember et al [70] have shown that, initially, three-fourths of the mercury became bound to the red blood cells and one-

fourth was bound to the serum proteins, particularly the alpha globulins of the plasma. With the passage of time and at the higher of the two dose levels employed (1.2 mg Hg/kg and 0.12 mg Hg/kg), mercury transferred from the erythrocytes to the plasma so that the later distribution was one-fourth in the red blood cells and three-fourths in the plasma. At the lower dose level, the initial partition persisted unchanged. This differs from some results in humans; Lundgren et al, [71] in their studies of the distribution of mercury in the blood elements in human subjects occupationally exposed to mercury vapor, reported a ratio of whole blood mercury/plasma mercury of 1.3 (range 0.9 to 2.4). They claimed that this corresponds closely to the distribution of inorganic mercury salts.

Animal experimental work using oral, intravenous, and intramuscular administration in chicks, rats, and dogs indicates that phenylmercuric acetate (PMA) is absorbed unchanged and transported intact by the blood. [72] In the blood of rats, phenylmercuric chloride is initially largely bound to erythrocytes but within 4 days, about a third of the erythrocyte mercury content seems to transfer to the plasma. [73] PMA is absorbed from the gastrointestinal tract of the rat to a greater extent than inorganic mercury salts [74] and, in the diet, is more toxic on long-term feeding to the rat than is mercuric acetate. [75] However, Ladd and his co-workers [46] suggest from epidemiological studies that phenylmercurials constitute less of an occupational hazard to man than other forms of mercury.

Several investigators [76-78] report from animal work that the distribution and behavior of methoxyethyl mercury is very similar to that of phenyl mercurials.

(b) Distribution in Tissues

The differential distribution of mercury among the various tissues and organs of the animal body, following the administration of the different classes of mercury compounds, shows considerable interspecies variation and some observations in animals are supported by autopsy findings in human victims of either occupational or of accidental mercury poisoning. [79-83]

Comparative studies have been made of the amount of elemental mercury accumulated in different organs, especially the brain after exposure to mercury vapor, as opposed to an equivalent amount of inorganic mercury salt. [67,81-83] In these experiments, a mercury content of the animal brain about 10 times higher than that following administration of inorganic mercuric (ionic) salts was found after exposure to elemental mercury vapor in mice, [82] in guinea pigs, [83] and in rats, rabbits, and monkeys. [67]

Tissue and cell-type distribution of elemental mercury within the central nervous system, using a micro-autoradiographic technique, has been studied in rats and mice by Cassano et al. [84] This work showed a greater concentration of mercury in the gray than in the white matter, with the highest levels in certain neurons of the cerebellum, the spinal cord, the medulla, the pons, and the midbrain.

In the cerebellum, there was selective localization in the Purkinje cells and in neurons of the dentate nucleus.

Elemental mercury is slowly oxidized to ionic mercuric mercury in the organism, partly in the blood (mainly in the erythrocytes), and partly in the tissues, [85] and therefore, its tissue distribution partly resembles that of inorganic ionic mercury with high concentrations in the kidneys and liver, the mucous membranes of the intestinal tract, and in the testes.

The tissue distribution of mercury in various small mammals, following single-or multiple-dose administration of radioactive inorganic mercury salts, has been studied. Berlin and Ullberg [81] examined whole body sections of mice autoradiographically, following a single intravenous injection of radioactive mercuric chloride. They found that mercury accumulated in the kidney, liver, myocardium, intestinal mucosa, upper respiratory tract, oral mucosa, interstitial tissue of the testis, skin, bone marrow, and the placenta. The degree of accumulation was most marked in the kidney and liver. Accumulation also occurred in the brain, but the uptake was much slower than in other organs. Slow elimination and considerable retention were found in parts of the brain and in the interstitial tissue of the testes, the skin, the buccal mucosa, and in the kidney. These authors pointed out that many of these tissue localizations are consistent with clinical effects observed in man.

Similar results in rats were reported by Friberg [86] following prolonged daily subcutaneous injection of labeled mercuric chloride. In addition, he noted an increase in the initial concentration of mercury in liver, spleen, and brain when exposure was prolonged, but not in renal mercury content.

With a single oral dose of radioactive mercuric acetate in rats, the highest concentrations of mercury were found in the kidneys, next, in the liver, the lung, and the heart. [74] Accumulation in other organs was comparatively small.

Autoradiographic whole-body sagittal section study [87] of the distribution of radioactive PMA in mice was compared directly with the distribution of radioactive mercuric chloride, already described. [81] For the first few days, the distribution of the phenylmercury was more distinctive, persisting longer in the blood, and accumulating more in the liver and less in the kidneys than did the inorganic salt. More phenylmercury was retained in the skeletal muscles. However, after 16 days, the distribution came to resemble very closely that of inorganic mercury in most tissues, including a late and moderate accumulation in parts of the brain. This is consistent with the observation that, in the mammalian organism, phenylmercurials are metabolized to inorganic mercury. [72]

Similar results were observed by Gage [88] in the rat by chemical analysis of organs and tissues, at various time intervals, after repeated subcutaneous injections of an aqueous solution of PMA.

One important difference from the mouse, however, was that phenylmercury penetrated the brain so little that the level was too low to be measured.

In almost all instances, the observed tissue distributions of the different mercury compounds are consistent with the clinical manifestations of toxicity, both in man and other animals, giving support to the concept of different critical target organs for different classes of mercury compounds, as well as for acute as opposed to chronic exposure. [89]

Druckrey et al [90] have shown that metallic mercury can produce sarcomas in rats after intraperitoneal injection. The sarcomas developed without exceptions at those places which had been in direct contact with the metal which could be identified marcroscopically and microsopically in all the tumors. No tumors were observed in remote organs even though serious absorptive effects were present.

(c) Biotransformation of Mercury

It has been held for a number of years that the fundamental biologic activity of mercury stems from the strong affinity of ionic mercury for, or reactivity with, sulfhydryl or thiol groups, -SH. An extensive discussion of this activity has been presented by Hughes [65] and much of the following is based upon his discussion.

Sulfhydryl groups abound in biological material and occur so widely in protein that free ionic mercury can have only an ephemeral existence in any living organism, being bound almost continuously to

proteins. The affinity of different sulfhydryl groups or ligands for ionic mercury varies, influenced by adjacent structures of the protein molecule. If two sulfhydryl groups lie adjacent on the peptide chain at a suitable spatial interval, one mercury ion will become bound at both sites with or without deformation of the chain. Otherwise, the mercury ion will combine with two sulfhydryl groups on neighboring protein molecules, thereby binding them together. Ligands of different affinities will form mercury bonds of differing strengths and will compete for available mercury. According to Hughes, [65] this is the basis for the transfer of mercury from one binding site to another, and from one protein to another. The physiological disturbance caused by the binding of mercury to a protein will vary according to the site of binding, and the function of the protein. The binding of mercury to purely structural proteins, such as the keratin of the hair and nails, causes minimal functional disturbance, whereas, the binding of mercury to sulfhydryl groups in the prosthetic group of an enzyme may be expected to cause maximal disturbance with possible total blockage of the function of that enzyme.

A number of mammalian enzymes are known, from in vitro experiments, to be sulfhydryl-group-dependent for their activity. Their activity may be blocked by the addition of ionic mercury but may be regenerated by addition of an excess of cysteine or another -SH containing amino acid to the system, which has a greater affinity for the bound mercury. The detectable biochemical disturbances, resulting

from the mercury inhibition of certain -SH dependent enzyme systems, have been investigated as possible bases for biological monitoring of mercury absorption by occupationally exposed workers, at levels insufficient to cause symptoms or clinical signs of mercurialism.

Wada et al [91] studied inhibition of delta-aminolevulinic acid dehydratase (ALAD) and cholinesterase (ChE) among workers with no clinical symptoms of mercury poisoning. These authors concluded that there was a significant relationship (P = less than 0.01) between urinary levels of mercury and the values of the decrease of ALAD and ChE. However, the correlation found for ALAD activity was so weak as to be of no value in practical assessment of reponse of individuals to mercury. On the other hand, ChE activity was markedly decreased among workers who excreted more than 200 μg/gm creatinine of mercury, but there was poor correlation between ChE activity and duration of exposure. They concluded that the decrease in activity of these enzymes became prominent above 200 μg/gm creatinine of urinary mercury and suggested that this level would be the maximum permissible concentration of urinary mercury in chronic exposure to inorganic mercury.

Verity and Reith [92] studied the effects of mercury within cells for interference with the integrity of lysosome membranes which contain essential thiol groups. Exposure of lysosomal preparations to inorganic and organic mercurials induced an irreversible damage of the membrane with resulting enzyme activation. The lysosomal hydrolase

preparations reacted differently at constant mercury levels, suggesting a different pattern of binding, unique for each enzyme studied.

The affinity for thiol groups is not only exhibited by bivalent free mercury ions of inorganic mercury. In organomercurials, such as the alkyl, alkoxy and aryl series, although the carbon-mercury bond is nonionic (covalent) and of varying stability in biological systems, the mercury atom still retains a free valency electron, ie, the mercury halogen or other anion bond is ionic. Organomercury salts ionize to from monovalent cations. [93]

Thio-ligand binding of mercury may explain the toxic effects of mercury in the ultimate target tissues, and might suggest the reasons for the different modes of absorption, transport within the body, and excretion of the different chemical forms. Thus, the speed of absorption of nonionic elemental mercury vapor into the blood lipids might be explained by its lipid solubility, and by its relatively ready penetration into cells of the central nervous system, by diffusion through the lipid-rich cell membranes, unimpeded by electric charge or binding to large molecules.

Once inside cells, it slowly becomes oxidized to the ionic form which then binds with intracellular proteins, and can leave the cell only with difficulty. [65]

The relatively poor absorption of inorganic mercury from the intestine may be explained by its binding to proteins in the

intestinal contents, rather than to proteins in the first mucosal cells it penetrates. Once in the blood, inorganic mercury is bound both to plasma proteins and within the red cells, which are particularly rich in thiol groups, in approximately equal proportions in man. So tightly bound is the mercury that it can transfer only slowly into most tissues by exposure to tissue ligands of greater affinity than those in the blood. The fact that it cannot diffuse freely is indicated by the fact that only about 1% of the mercury in the plasma is "ultrafilterable". [94]

Organomercurials are readily absorbed from the gastrointestinal tract, perhaps helped by the lipid solubility of their hydrocarbon moiety. Miller et al [72] have shown, from experiments in chicks, rats, and dogs, that aryl (predominantly phenly) mercurials undergo biotransformation rather rapidly after absorption and suggest that this form of mercury has about the same order of toxicity as inorganic mercury. In the blood, organomercurials are bound to the extent of about 90% to the thiol ligands of hemoglobin, and of the red cell stroma, [95] and in the case of the alkyl compounds, are taken up to a lesser extent by the kidney and accumulate more in the brain than the aryl compounds. As mentioned before, the aryl (ie, phenyl) mercury compounds are metabolized fairly rapidly into inorganic mercury, as the aryl carbon-mercury bond seems to be relatively unstable under biological conditions. The different behavior of alkyl, as opposed to inorganic mercury, may be explained partly by the lipid solubility of

the hydrocarbon moiety and partly by differential affinity of the single available valency for thiol binding. [96]

(d) Excretion

After the first few days of exposure, little distinction can be drawn between the excretion of elemental mercury and ionized inorganic mercury, into which the elemental form is oxidized prior to excretion. [66,97]

Basically, mercury, in whatever form it enters the body, is potentially excreted by the kidney, by the liver in the bile, by the intestinal mucosa, by the sweat glands, by the salivary glands, by the lungs, in the hair, nails and in the feces, and from the skin both by volatilization and by desquamation. [66,94,95,97,98,100]

In cocks, rats, and dogs, kidney accumulation and urinary excretion of mercury, following administration of phenylmercury salts and methoxymethyl mercury hydroxide, are so similar to the fate of inorganic mercury salts that these types of organomercurials appear to be handled by the kidney in the same way. [72,78,100,101] Using PMA in rats, Gage [88] showed that after a single dose, organic mercury initially appears in the urine for about two days to be followed by the later appearance of inorganic mercury. He inferred that the circulating PMA which enters the kidney is, in part, rapidly excreted unchanged in the urine and, in part, converted to inorganic mercury which is subject to the delay in the renal tubular cells seen in other experiments.

Although mercury may be eliminated from the body by several routes, ie, lungs, urine, feces, sweat, skin, the principal routes of excretion of mercury from the body are through the urine and feces, with the bulk of the excretion in urine. As a consequence, renal retention and excretion of mercury has been the subject of interest of a number of investigators for several reasons. [86,88,97] First, renal excretion is an important route of elimination of mercury from the body of man and many other mammals. [8,45,86,88] Second, the fact that the kidney accumulates more mercury per unit weight than any other organ, following inhalation of mercury vapor or administration of inorganic mercury and organomercurials, has been demonstrated in several animal species. [86,88,89,100,102] Therefore, the speed with which the kidneys extract mercury from the blood must have a significant regulating effect on the blood level and, consequently, on the body distribution of mercury. [97] Moreover, the kidney is the critical organ after acute exposure to inorganic mercury salts, and an acute nephrosis is occasionally seen following occupational exposure in man, as well as acute anuria or nephrosis following accidental ingestion. [103-105] Third, the urine is the most conveniently collected of all human excreta, and attempts continue to be made to use urine mercury levels as a practical guide to absorption and total body burden of mercury in the occupationally exposed. However, there are severe limitations in the use of urine mercury levels for this objective. (See discussion in Correlation of Exposure and Effects).

Of the mercury carried by the blood to the kidneys, it is that part which is in the plasma which is most directly available for excretion. In rabbit experiments, only about 1% of the plasma mercury was passed on ultrafiltration. Experimental evidence from the dog indicates that the little mercury which may be filtered by the glomerulus is reabsorbed. [96] Similarly, most ionic mercury in the plasma of man is bound to the plasma proteins which do not pass the glomerular filtration mechanism in the normally functioning kidney.

The exact mechanism of uptake of mercury from the plasma and its subsequent release into the tubular lumen is not clear, although experimental work suggested that mercury is secreted by renal tubules. A higher affinity for mercury of tubular cell ligands than of the plasma ligands, coupled with passive diffusion along a concentration gradient, is postulated from work in cocks. [106] That the reabsorption of mercury from the tubular fluid into the tubular cells might be by a metabolic transport mechanism is indicated by the work of Clarkson and Magos [107] with rats given the metabolic inhibitor, sodium maleate, followed by injection of 100 μg Hg as the mercury-cysteine complex. These investigators found that tubular-cell-bound mercury was released, not only into the urine, but also into the blood and thence to other organs which accumulate mercury. The possibility that the extraction of mercury by the kidney from the blood in the peritubular capillaries is an energy-dependent metabolic process was

also strongly indicated by experiments in the rat using another metabolic inhibitor, 2,4-dinitrophenol. [108]

It appears that the net renal excretion of mercury by the kidney is the excess of glomerular filtration (very minor) plus tubular excretion over tubular and collecting tubule reabsorption. Whether the sites of excretion and reabsorption are the same, under different milieus of pH or mercury concentration gradients, or separate (eg, excretion by the proximal, reabsorption by the distal, tubules) is still undetermined. [96]

Gage [109] has shown that renal excretion of mercury involves two phases: (1) the removal of mercury from the blood (clearance) and its accumulation in the renal tissue, predominantly the renal tubular cells, and (2) the net excretion of mercury into the urine (elimination). The two processes do not necessarily proceed uniformly or synchronously. On commencement of initial mercury exposure, there is a delay of maximal excretion until the kidney has accumulated a certain burden. In intermittent exposures (as in most occupational exposure), this delay mechanism may result in the occurrence of peak excretion during periods of nonexposure. Gage [109] also postulated a mechanism whereby some mercury continues to be excreted for a considerable time after cessation of exposure, suggesting that the metal may undergo irreversible incorporation into cell proteins, after which the rate of excretion would be dependent upon the metabolic turnover of protein.

The complexities of renal excretory mechanisms for mercury, revealed by animal studies, lend support to the observed difficulties in relating urine mercury levels in man to levels of exposure, absorption, and the imminence of toxic accumulations in the critical organs. Such difficulties would be even more evident in the case of "spot" urine samples as opposed to composite or 24-hour samples. This could be one explanation of the reason for high urine mercury levels in workers who show no signs or symptoms of illness from mercury while low levels may be found in some workers with symptoms. Based on his experiments in the rat, Gage [109] suggests that an approximate assessment of the total mercury absorbed during a working week would be obtained if it were possible to make a total seven-day collection of urine. The practicality of this procedures on a routine basis is, of course, open to question.

Although measurement of mercury in urine has been a principal method for estimating absorption and excretion of mercury, that which is eliminated by other routes may account for some of the disparity between extent of exposure and the amount of mercury found in urine. For example, fecal excretion of mercury which enters the body in inorganic form makes up a significant portion of total body excretion. [110,111] It represents the excess of mercury excreted in the saliva and swallowed, plus mercury secreted in the bile and the succus entericus, plus mercury bound in epithelial cells of the entire alimentary tract which are shed into the gut lumen, over the total

mercury absorbed from the gut, principally the small intestine. In the first few days of de novo exposure of rats, both to inorganic mercury salts and mercury vapor, fecal excretion exceeds renal excretion. Renal excretion equals or surpasses fecal excretion only in the second and longer phase. [110,111] The importance of fecal excretion should not be overlooked.

Correlation of Exposure and Effect

(a) Acute Intoxication

Tennant et al [80] reported one death and symptons of chills, nausea and general malaise, tightness in the chest and vague respiratory symptoms among eight workers exposed to large quantities (several tons) of mercury following an accidental rupture of tubing in a mercury boiler. The workmen were exposed to the warm mercury for about five hours without respiratory protection. No measurement of levels of mercury vapor were made until five days later at which time levels ranging from 0.4 to 0.8 mg Hg/cu m were found in the area of the boiler. This would suggest that levels at the time of exposure may have been substantially higher and probably reached the saturation point.

Four workers exposed to mercury while cleaning a storage tank probably inhaled mercury vapor concentrations from 1.5 to 1.7 mg Hg/cu m at breathing zone height as determined by a simulation experiment performed following the accidental exposure. [112] It was estimated

that exposure for only 2.5 to 5 hours to between 1 and 3 mg Hg/cu m had caused the four cases of acute mercurial pneumonitis.

Environmental levels from accidental exposures are generally unavailable, as in the case of the poisoning of a family from a gas space-heater freshly painted with a mixture containing approximately 65% by volume of mercury, [79] and from a home attempt at gold extraction. [113] The mother involved in the space-heater accident excreted up to 1.31 mg Hg/liter of urine during her one month's stay in the hospital. The man involved in the gold extraction excreted 557 μg Hg/24 hours by the second hospital day and was still mildly dyspneic on exertion one year after exposure.

(b) Chronic Intoxication

Neal et al [19] studied the working conditions of workers in the fur-felt and felt hat industries in New England who were exposed to average levels of mercury in air ranging from 0.02 to 0.5 mg Hg/cu m. Workers were found to have a variety of signs or symptoms including tremor, psychic disturbances, headache, drowsiness, insomnia, and weakness. They concluded that 0.1 mg Hg/cu m "probably represents the upper limit of safe exposure". However, these investigators reported cases of intoxication at 0.1 mg Hg/cu m and at all higher levels. In addition, three cases had borderline symptoms at exposures of around 0.08 mg Hg/cu m, and 15 cases had borderline or first stage mercurialism (similar, but less severe symptoms) at concentrations ranging from 0.08 to 0.15 mg Hg/cu m. Also, their 1937 report [18]

found mercury intoxication in 6% of the workers exposed at approximately 0.09 mg Hg/cu m of air. Therefore, their conclusions might be open to challenge.

Kesic and Haeusler [58] found 47 of 70 female workers, exposed to air levels ranging from 0.25 to 1.0 mg Hg/cu m, in a felt hat factory, had pronounced symptoms of chronic mercury toxicity. Benning [26] has reported severe cases of mercury poisoning in 52 of 90 workers (gingivitis, irritability, tremor, weight loss) at exposure levels between 0.2 and 0.75 mg Hg/cu m, while Bidstrup and co-workers [25] observed clinical mercury poisoning (tremor, erethism) in 27 of 161 workers exposed to levels ranging from 0.003 to 1.67 mg Hg/cu m. One of the cases with tremor was reported to have been exposed at levels from 0.005 to 0.06 mg Hg/cu m.

Turrian et al [114] found signs or symptoms of central nervous system involvement (headache, impaired memory, low concentrating ability, mental disorders) in 33 of 58 factory workers exposed to environmental mercury vapor concentrations ranging from 0.01 to 0.6 mg Hg/cu m. In 15 of the cases, the exposure ranged between 0.01 to 0.06 mg Hg/cu m. See Table XII-7.

Rentos and Seligman [55] reported cases of mercury poisoning (sore gums, tremor, gingivitis, personality changes) in 18 of 83 workers with average daily exposures between 0.08 and 0.68 mg Hg/cu m (mean = approximately 0.5), but no symptoms in other workers exposed to average daily concentrations of less than 0.02 mg Hg/cu m. A high

incidence of cases of poisoning was observed in those workers (17 of 54) who received average daily exposure of 0.31 mg Hg/ cu m. No cases were observed in those workers who received average daily exposures of less than 0.2 mg Hg/cu m. These authors concluded that a threshold limit value of 0.1 mg Hg/cu m was supported, even though a safety factor of no more than 2 was present. Friberg and Nordberg [54] maintained, however, that the Rentos and Seligman data indicated that mercury poisoning occurred at exposure levels greater than 0.2 to 0.3 mg Hg/cu m, and that no conclusions could be drawn in regard to exposure at concentrations between 0.02 and 0.2 mg Hg/cu m.

A study of chlor-alkali plant workers, reported by Smith et al, [28] is noteworthy for its standardization and completeness and provides valuable information on correlation of exposure and effects. Correlations of symptoms with air, blood, and urine concentrations of mercury were presented.

The study [28] demonstrated a strong statistical group correlation between urine mercury levels and such signs or symptoms as weight loss, loss of appetite, tremor, insomnia, shyness, and nervousness. However, this correlation was not as strong as one demonstrated between urine levels and mercury air concentrations ranging from 0.01-0.27 mg Hg/cu m. The correlations for urine and air mercury levels are given in Table XII-8 and shown in Figure XII-2. On a group basis, a good correlation may be seen between the urinary

mercury concentrations and the environmental levels although a considerable individual variation is present.

From the data presented in Table XII-9, it can also be seen that a positive group correlation exists between exposure to mercury air concentration levels and worker blood levels. This is in agreement with similar findings reported by Goldwater et al. [115] Data, as shown in Figure XII-3, also taken from Smith et al, [28] show a ratio of approximately 0.3 between blood and urine mercury levels on a mg/liter basis. Such findings are in agreement with data presented by Benning [26] from which a median quotient of 0.31 between blood and urine levels was calculated by Friberg and Nordberg. [54]

The relationship between the prevalence of certain signs and symptoms (tremor, nervousness, loss of appetite, loss of weight, insomnia) and the degree of exposure observed in the Smith study can be seen in Figure XII-4. Although the symptom of loss of weight was not confirmed by actual weight measurement, the findings reveal a clear dose-related response to mercury exposure and demonstrate the potential effects of even minimal exposure to mercury. The authors concluded, "The data presented here show no significant signs or symptoms in persons exposed to mercury vapor at or below a level of 0.1 mg/m^3. However, the data do raise a question regarding the adequacy of the safety factor provided by a TLV of this magnitude."

McGill et al, [50] in a report on another study involving 60 men in a chlor-alkali operation, showed that urine mercury levels, over

the 6-year period of plant operation, were usually between 80 and 250 µg Hg/liter of urine. Exposure levels ranged from 0.08 to 0.1 mg Hg/cu m. These investigators reported finding no evidence of dangerous absorption of mercury under conditions prevailing in this plant. The distribution of urine mercury levels showed a consistent positive relationship to three exposure groups based on the average amount of time spent in the chlor-alkali cell room, ie, 30 to 40 hours per week, 2 to 10 hours per week, and a control group with no exposure. One worker who spent 20 hours per week in the cell room was included in the 2-10 hour per week exposure group. The overall range of urine mercury levels at the time of the study was a reported 0 to 157 µg Hg/liter of urine.

In a study of mercury mining and smelting operations, West and Lim [49] performed urinalyses on 83 of 96 California cinnabar millworkers exposed to mercury in air levels ranging from 0.3 to more than 1.2 mg Hg/cu m and showed 35 workers to have urine mercury levels above 300 µg Hg/liter as analyzed by the dithizone method. Of these 35, 23 had definite signs or symptoms of mercury toxicity (tremor, muscle weakness, weight loss, nervousness, insomnia, bleeding gums) and two had "borderline" symptoms. Severity of symptoms was roughly related to urine mercury levels. In 13 of the 23 symptomatic workers urine mercury levels ranged from 320 to 7,100 µg Hg/liter of urine (median = 1,200). However, nine workers without symptoms also had

high urine mercury levels ranging from 200 to 1,100 μg Hg/liter of urine (median = 460).

In contrast to the study by West and Lim, [49] Ladd and his co-workers [27] reported that cinnabar workers in the Philippines and Yugoslavia showed urine mercury levels to be lower, on the average, in workers with mild symptoms of mercury toxicity than in asymptomatic exposed workers. Fifteen symptomatic workers (tremor, gingivitis, irritability in the 1964 Philippine survey where exposure levels ranged from a reported 0 to more than 2.0 mg Hg/cu m showed urine mercury levels ranging from 3 to 1,260 μg Hg/liter (mean = 389). Urine mercury levels for asymptomatic workers ranged from 75 to 2,175 μg Hg/liter (mean = 652).

In miners in the Yugoslav study, [27] 16 symptomatic workers (irritability, personality change, salivation, tremor) and 57 asymptomatic workers who were exposed to total mercury (vapor and dust) concentrations ranging from 0.16 to 4.89 mg Hg/cu m had urine levels ranging from 2.0 to 601 μg Hg/liter (mean = 255) and 0 to 1,275 μg Hg/liter (mean = 276), respectively. These low urine mercury levels in symptomatic workers lend support to the hypothesis of Copplestone and McArthur [116] that "mercurialism might be due to an inability to excrete mercury rather than simply to exposure."

While this hypothesis does not seem to have been pursued by other investigators, it might explain the paradoxical situation with urine levels. However, it does not explain the lower blood levels

reported by Ladd et al [27] in the same study where blood determinations showed similar results with a range of 0.6-24.0 μg Hg/100 ml whole blood (mean = 10.6) in the symptomatic workers and a range of 0.9-30 μg Hg/100 ml whole blood (mean = 13.5) in the asymptomatic workers. This would suggest that one might suspect the accuracy of some of the analyses in the study, or it may point to the fact that blood mercury levels may not be directly related to toxicity or that mercury levels in critical tissues are not affected by blood levels.

Vostal [96] has noted that differences in the red blood cell-to-plasma distribution of mercury in whole blood play an important role in urinary mercury excretion, ie the higher the plasma levels, the greater the level in the kidney. This could explain the good correlation between the blood and urine levels of exposed workers found in the Smith et al study [28] Furthermore, humans exposed to elemental mercury vapor and to inorganic mercury compounds show red blood cell-to-plasma ratios which seldom vary more than by a factor of two, [71,117] whereas organic mercurials have ratios reportedly as high as twenty. [71] Friberg and Nordberg, [54] have also pointed out that the average ratio of urine mercury levels (μg Hg/liter) and atmospheric mercury (mg Hg/cu m) is of the same order of magnitude (about 2) as reported in early studies by Storlazzi and Elkins, [118] who found an average ratio between urinary mercury and atmospheric mercury of 2.6. for group exposure.

In spite of this relationship, individual urinary excretion of mercury fluctuates considerably, independently of exposure . Wide diurnal and day-to-day variations have been reported. [7,8,119] Figure XII-5, reported by Friberg, [119] shows variations in excretion of mercury during a 24-hour period. Threefold changes in mercury excretion over a 24-hour period were not uncommon and a nearly 5-fold change may also be noted. A concentration of about 0.1 mg/cu m in air for a 40-hour week exposure corresponds to about 0.2 mg Hg/liter of urine as shown for group exposure by Friberg and Nordberg [54] and Storlazzi and Elkins, [118] However, environmental concentrations of mercury cannot be confidently related on an individual basis to urine mercury levels because of the extreme fluctuations.

Moskowitz, [56] in commenting upon previous work reported by Smith and Moskowitz [20] and Smith et al, [21] stated that the mean urinary excretion of mercury is directly related to the concentration of mercury in the air to which workers are exposed. This applies to groups of large population, groups of 15 to 20 not being sufficiently large to use in making statistical comparisons. Moskowitz also noted that variations of excretion within any exposure group were exceedingly large so that individual findings or the findings of small numbers cannot be used to determine intensity of exposure or the presence of mercury toxicity. He also found that the average urine mercury levels tended to decrease with increase in duration of exposure. However, the difference was not statistically significant.

The above studies and those reviewed earlier demonstrate that the higher the concentrations of mercury in air the greater the likelihood that an exposed worker will develop signs or symptoms of mercury intoxication although one cannot be assured that toxicity will develop at high exposure levels.

IV. ENVIRONMENTAL DATA

Sampling and Analytical Methods

Various methods of sampling for mercury in air and analysis of these samples have been considered and the recommended methods are described in Appendix I and II.

The recommended methods for sampling air involve the use of scrubbers to remove mercury vapor and mercury compounds. [120,121] More specifically, the recommended method incorporates two bubblers, each containing a solution of sulfuric acid and potassium permanganate as the collecting media. Although there is some inconvenience involved in the use of bubblers, their use is justified because of uncertainties in sampling and analysis of nonelemental mercury by other methods as discussed below.

The recommended method for analysis of the sample is flameless atomic absorption spectrophotometry. Both colorimetric dithizone methods and atomic absorption methods give similar results in parts added/parts found studies [122-124] and comparison studies. [124-126] However, the speed in analysis which atomic absorption spectrophotometry affords, without any loss in accuracy and precision, makes it the method of choice as a reference method for analysis of mercury in bubbler solutions when properly standardized and calibrated.

It is imperative that calibration curves be constructed using conditions as close as possible to the actual samples. For example, when flameless atomic absorption is selected, the acid permanganate solutions must be used in the bubblers used for calibration. Calibration curves that are constructed for the dithizone method must also be obtained from acid-permanganate solutions spiked with appropriate mercury compounds.

No single detailed method of analyzing for mercury compounds has been collaboratively tested by numerous laboratories, but the atomic absorption method described in Appendix II represents a culmination of several flameless atomic absorption methods developed and used by various investigators. [126-131]

The sampling and analysis of mercury are particularly complex because of the numerous forms in which mercury may exist in the air. The interconvertibility of the various forms of mercury further complicates sampling and analysis. Mercury metal is not highly reactive but does form numerous compounds of varying thermal and chemical stabilities. Mercury reacts to form inorganic and organic compounds. Common oxidation states of mercury are Hg(I) and Hg(II), although only Hg(II) forms organic mercurials. The compounds of mercury generally have very high volatility compared to those of the alkaline earth metals, and collection of mercury compounds is complicated by their high vapor pressures. Accordingly, it is questionable whether particulates of certain mercurials will remain

unvolatilized if collected on simple filters because of the large volumes of unsaturated air which are drawn over the filters.

The chemical stabilities of mercury compounds after collection are important considerations because the relatively easy conversion of one mercurial to another may have a significant effect on the volatility and method of analysis.

The volume of literature regarding the sampling and analysis of mercury attests to the difficulties which are encountered in sampling for mercury. Only in recent years has it been possible to determine, with reasonable accuracy, the form in which mercury exists in the environment. This determination is possible, in part, because of such developments as chromatography and mass spectrometry. These forms of analysis may soon make it possible to clearly and routinely differentiate among the different forms of mercury.

Many analytical methods have been used for the determination of mercury and a review of the literature on this subject has been completed by Smith.[132] Sampling for mercury in air is much more difficult than the subsequent analysis. For best results, sampling and analysis must be considered simultaneously, covering the whole range of types and concentrations of mercury hazards which may be present in the occupational environment.

The choice of method of analysis is largely dependent upon what method of sampling is employed. In addition, the degree to which the

sampling method collects the different forms of mercury provides the basis for the usefulness of the entire procedure.

The methods which have been reported for sampling of mercury in air are many but are separable into two basic categories, a) those methods which remove mercury and mercury compounds from air by scrubbing, and b) those methods which collect an air sample. [133]

The scrubber type of sampling utilizes bubblers, filters, adsorbants, and amalgamable collectors.

The category of bubblers may include impingers, bead-packed towers, and a wide variety of scrubbing solutions. These scrubbing solutions are used to collect the mercury either discriminately or indiscriminately, and frequently to convert the mercury to an easily determinable form such as Hg(II). The most popular scrubbing solutions are acidic permanganate, iodine-potassium iodide, and iodine-HCl with acidic permanganate being used the most frequently in industrial hygiene surveys. Collection efficiencies for all mercury contaminants have not been reported for all of these scrubbing solutions. However, for mercury vapor and inorganic compounds of mercury, efficiencies greater than 90% have been reported. For organic mercurials, except short chain alkyl mercurials, [122,134,135] collection efficiencies for these solutions appear to be greater than 80%.

Uncertainties which still exist in the collection efficiencies for organic and inorganic compounds stem primarily from inadequate

methods of standardization and uncertainties in methods of analysis. With a very few exceptions, experimenters have not prepared standard dust chambers of mercury compounds and tested collection efficiencies of scrubbing solutions with these chambers. [134]

Filters have been used with scrubbers to collect various mercury contaminants in air. Elemental mercury vapor has been determined by filtering through papers impregnated with selenium, selenium sulfide and potassium iodide. [130,136,137] Particulates have been filtered by cellulose filter papers, fibrous glass filters, asbestos wool and quartz wool. [138,139] However, collection efficiencies of all of these media have not been determined and may be highly variable.

Adsorbants are among the most popular collectors and range from charcoal to sea sand. Evaluation of the collection efficiencies of these devices for compounds of mercury are also lacking. Also lacking are evaluations of collection efficiencies for particulates or dust which contain mercury.

Amalgamable collectors are also very popular but have been demonstrated to be efficient only for the collection of elemental mercury vapor. If compounds and dust are collected in a separate pyrolysis tube, presumably the mercury in compounds and dust can also be determined. Some work has been done on this method, [138] but a thorough documentation is lacking at this time. Amalgamable collectors, which have been reported to collect mercury, include gold

and silver in various forms. [138,139] The efficiencies of these methods of collection are not well documented.

The second category of sampling involves collection of a direct air sample. There are two general methods of direct air sampling. The first involves a static sample, commonly known as a grab sample, which may be collected in a plastic bag or syringe. This method has not been used or documented extensively for collection of mercury and mercury compounds. [140] The second method is a dynamic monitoring method in which air containing mercury is drawn directly through monitoring instruments called mercury vapor meters. Both hand-held portable units and remote units have been used. To date, these instruments have been designed to monitor only elemental mercury vapor.

Of all the methods for monitoring of mercury, hand-held mercury vapor meters have been used the most extensively. Of all methods used, these are probably the least foolproof. There are a number of major difficulties which may be encountered with mercury vapor meters: 1) standardization must be done prior to monitoring mercury with mercury vapor meters, and this is easily overlooked; 2) they respond to many other substances in the air such as dust, cigarette smoke, humidity, ozone, and sulfur dioxide and common organic solvents such as acetone, [31] the presence of which may not be known; 3) some types of mercury vapor meters reverse in response to high concentrations of mercury vapor, indicating meter readings much lower than true mercury

vapor concentrations [135]; 4) they may be affected by high magnetic fields that may exist in chlor-alkali plants; 5) the volume of air sampled by a hand-held mercury vapor meter is small and usually gives a poorly representative sample of the environment. Typically, the volume of air sampled may be 100 ml or less.

Mercury vapor monitors with remote sensors have been used and have problems similar to those of the hand-held type except that 1) problems due to magnetic fields are alleviated, and 2) a large volume of air is sampled and thus provides more representative sampling. With these remote monitors, samples of air are conveyed via Teflon or PVC tubes from sampling ports in the contaminated environment to the monitor. Generally, the sampling points are located in the breathing zone of workers on a grid system, whereby the various parts of the work environment are sampled sequentially. However, the influence that contamination which may enter and contaminate tubing may have upon subsequent instrument reading does not appear to have been evaluated, and the reliability of these sampling systems has not been documented. Tubing which would be required in a remote sampling system could introduce unknown contaminants and make such a system impractical. In summary, there are many problems associated with the use of mercury vapor meters for determining air concentrations of elemental mercury vapor. In addition, mercury vapor meters do not monitor for compounds of mercury which may be present in the environment.

From the above, it can be seen that for accurately determining concentrations of mercury in air, one must consider not only the form in which the mercury may be present but a multitude of other factors which can have major influence upon the results. The sampling and analytical methods recommended in Appendices I and II have been selected to minimize these factors.

Environmental Levels and Engineering Controls

Numerous studies can be cited to identify environmental levels of mercury found in the work environment of various mercury-using industries. [25,26,28,49,116] A review of these studies shows there have been wide ranges of mercury exposures encountered by workers at their places of employment.

Benning [26] reported levels of total mercury, ranging from 0.20-0.75 mg Hg/cu m, in the workroom atmosphere of a company using copper amalgam compound in manufacturing carbon brushes for electric motors. No industrial hygiene practices, from either an engineering or sanitation standpoint, were in effect at this plant, so that there were most likely multiple exposures of workers to mercury at the plant through inhalation, skin absorption, and ingestion. In addition, mercury-contaminated work clothing was worn home, permitting a certain amount of mercury to be carried into the home. The installation of ventilation control measures reduced the air concentrations to a range of 0.05-0.07 mg Hg/cu m of total mercury. Even with this reduction of airborne concentration, high levels of mercury in worker urine samples

continued. They were reduced, however, upon institution of strict sanitation requirements for plant housekeeping, handwashing, eating arrangements, and initiation of health orientation programs for employees. For example, one worker showed a reduction from 1,810 to 330 μg Hg/liter of urine after these measures were introduced. This experience indicates the need for evaluation of the total environment for effective control of the hazards associated with exposure to mercury. Reliance on the control of the atmospheric levels of mercury will not, by itself, necessarily assure that absorption of mercury by the worker will be sufficiently reduced if workers have poor personal hygiene or work practices which permit them to be exposed through routes other than inhalation.

Copplestone and McArthur [116] reported effective reductions of airborne mercury levels after installation of ventilation control measures in a company manufacturing jewelry. The peak reading in the general air of this plant reached a high of 0.35 mg Hg/cu m during the summer months. Almost immediately after installation of an improved ventilation system, these levels dropped to 0.03 mg Hg/cu m.

An investigation of the environment of workshops repairing direct current electric meters by Bidstrup et al [25] showed the significance an "enclosed" environment may have upon the concentration of mercury in air. Air levels of mercury vapor were measured during the summer months when the workshops were open to outside ventilation

through windows and again during winter months when the windows were closed.

In two workshops the concentration of mercury in the general atmosphere during the summer reached 0.223 mg Hg/cu m and 0.23 mg Hg/cu m, respectively. At work stations, levels as high as 1.6 mg Hg/cu m were recorded. In the other workshops studied the general atmosphere concentrations during the summer ranged from 0.005 to 0.067 mg Hg/cu m. Sampling in these other workshops during the winter months with the windows closed showed that the general atmosphere in most of the shops exceeded levels of 0.2 mg Hg/cu m, while at work stations, levels significantly above this were frequently recorded.

In the one shop which had mercury vapor concentrations of 0.223 mg Hg/cu m in the general atmosphere (range for all locations sampled was 0.08-1.6 mg Hg/cu m) during the summer months, ventilation equipment was installed prior to winter sampling. The winter samples in that shop ranged from 0.003-0.1 mg Hg/cu m. The environmental conditions observed in this study emphasize the effectiveness of ventilation for reducing airborne concentrations of mercury. In addition, it illustrates the impact which changes brought about by seasonal conditions may have upon concentrations of mercury in the atmosphere of the workplace.

One of the largest users of metallic mercury is the chlor-alkali industry in which brine is electrolyzed in large cells with mercury as the cathode. Although the mercury is totally enclosed most of the

time, many tons of the metal are present and, inevitably, mercury vapor enters the ambient air during overhaul or cleaning of equipment and from accidental leaks; thus, exposure to elemental mercury vapor is potentially a major hazard to chlor-alkali workers. Because chlorine gas is frequently present in the atmosphere and reacts with mercury vapor to produce chlorides of mercury, the potential exposure to mercury chlorides also exists. [28]

Smith et al [28] reported on the results of numerous mercury in air determinations in 21 chlor-alkali plants in the U. S. and Canada. The actual range of the time-weighted average of samples collected was 0.001 to 2.64 mg Hg/cu m, with the highest reading in the cell bed grinding operations. The average air concentration was 0.065 mg Hg/cu m with more than half (59%) having exposure at or below 0.05 mg Hg/cu m. These results would indicate that engineering controls can limit airborne concentrations of mercury in chlor-alkali plants to the standard recommended in this document.

The above studies illustrate that effective control of the work environment to limit airborne concentrations of mercury to 0.05 mg Hg/cu m is feasible. In those instances where ventilation systems were installed or improved, [25,26,116] the reduction of airborne levels of mercury to or below a level of 0.05 mg Hg/cu m of air was prompt. In addition, the study of Benning [26] is significant for showing that the worker plays an important role in controlling his own

exposure to mercury by being aware of the hazards inherent in mercury and having good work and personal hygiene practices.

V. DEVELOPMENT OF STANDARD

Basis of Previous Standard

Among the first hygienic guides for controlling exposure to mercury in the United States was the Threshold Limit Value (TLV) of 0.1 mg Hg/cu m recommended by the American Conference of Governmental Industrial Hygienists. [141] This TLV was based primarily on the results of the studies by Neal et al [18,19] of workers in the felt-hat and fur-cutting industries in 1937 and 1941. [8] Neal's [19] report concluded that no cases of mercury poisoning were found among workers exposed to less than 0.1 mg Hg/cu m, but that cases did occur at all ranges of exposure above this level. In addition, the incidence of mercury poisoning increased with the length of occupational exposure. "Borderline" cases of mercury intoxication at levels below 0.1, ie, at 0.08 mg Hg/cu m; a 20% of incidence of tremors was reported in workers exposed at 0.08 mg Hg/cu m for 20 years. However, this recommendation has been in effect for almost 30 years in this country.

In a large scale study of workers exposed to concentrations of mercury vapor from less than 0.01 to 0.27 mg Hg/cu m in chlor-alkali plants in North America and Canada, Smith et al [28] concluded, "The data presented here show no significant signs or symptoms in persons exposed to mercury vapor at or below a level of 0.1 mg/m^3. However, the data do raise a question regarding the adequacy of the safety

factor provided by a TLV of this magnitude." Following publication of the Smith study and a review of prior documentation, the American Conference of Governmental Industrial Hygienists recommended a reduction in the TLV to 0.05 mg Hg/cu m for inorganic elemental mercury, inorganic mercury, and nonalkyl organomercury compounds. [142]

The American National Standards Institute (ANSI) [143] recommended in 1943 as a mercury standard (Z37.8-1943) a level of 0.1 mg Hg/cu m based on the studies of Neal et al, [18,19] and subsequently reconfirmed this level in 1971. [144] However, in 1972, ANSI Z37.8-1972 [145] lowered this standard to 0.05 mg Hg/cu m based upon the studies of Smith et al [28] and made it applicable to mercury vapor and all mercury compounds except alkyl mercury compounds, even though the authors [28] concluded, "The implications of the results of this study on the current threshold limit value of 0.1 mg Hg/cu m are to some extent dependent on matters of judgment rather than fact. The data indicate that with respect to most of the symptoms [complaints reported by workers], the dose-response relationship does not exhibit sufficiently high incidence to warrant concern until the present threshold limit value is exceeded... The data presented here show no signs or symptoms in persons exposed to mercury vapor at or below a level of 0.1 mg Hg/cu m. However, the data do raise a question regarding the adequacy of the safety factor provided by a TLV of this magnitude."

A committee of the International Symposium on Maximum Allowable Concentrations of Toxic Substances in Industrial Environments held in Stockholm (1968) reviewed the available evidence on mercury toxicity and recommended the subdivision of mercury and its compounds into three categories based primarily upon toxicological properties. [68]

The committee's recommendations for Maximum Allowable Concentration (MAC) for mercury vapor in the industrial environment was 0.05 mg Hg/cu m. For inorganic mercury compounds and phenyl and methoxyethyl mercury compounds, a level of 0.10 mg Hg/cu m was suggested. The greater toxicity of alkyl mercury compounds (methyl and ethyl mercury salts) was recognized and no air level was recommended, but the committee concluded that with a continuous eight-hour exposure to 0.01 mg Hg/cu m of alkyl mercury compounds in air, the total level of mercury in blood would not usually exceed 10 μg Hg/100 ml of blood.

The maximum allowable concentration for metallic mercury in the USSR is 0.01 mg Hg/cu m. [146] This standard was established more than 30 years ago and was based upon observations in mercury-using industries and of exposed workers. [147] The data upon which this standard is based are not available, however, the level is in keeping with the philosophy in Russia that occupational health standards be established at levels at which no detectable effects will be observed in workers. [148]

The workroom air standard for inorganic mercury established under the Occupational Safety and Health Act of 1970 (part 1910.93 of Title 29 published in the Federal Register, Volume 37, Number 202, pages 22139-22144, dated October 18, 1972) is 0.1 mg Hg/cu m. This ceiling limit is based on the ANSI Z37.8-1943 (R-1971) standard. [144]

Basis for Recommended Environmental Standard

Two approaches can be taken for deriving an environmental standard for mercury: establish a direct relationship between environmental exposure and worker response or establish an indirect relationship between mercury excretion, signs and symptoms of mercury poisoning, and environmental levels.

Studies have indicated the lack of substantiating evidence for the second approach. Several investigators [7,8,20,21,26,28, 50,54,56,115,116,119] have attempted to measure the amount of mercury in urine or blood as an index of worker exposure. These attempts demonstrate that there is a lack of reliability in correlation between levels of mercury in the urine or blood of a worker and the extent of his exposure or the appearance of symptoms. The disagreement of correlation of average ratios between urinary mercury and atmospheric mercury has been and continues to be unresolved. Earlier reports [54,118] suggested ratios of about 2.0 and 2.6. A recent paper by Bell and his co-workers [149] indicates that the ratio is 1.

The derivation of an environmental limit for worker exposure to mercury vapor and inorganic and organic (nonalkyl) compounds of

mercury is complicated by the lack of specificity of effects seen at the lowest doses. Such effects as loss of appetite, insomnia, and those of nervous system involvement including tremor, psychic disturbances, and "nervousness" are manifested in other diseases, but may occur with significant frequency among workers exposed to mercury. Thus, the demonstrations of a higher incidence of effects with increasing levels of mercury exposure could be a basis for deriving an environmental limit.

The study by Smith and co-workers [28] in chlor-alkali plants of workers exposed primarily to mercury vapor showed a positive correlation between exposure levels and symptoms of neurologic involvement (tremor, "shyness", and "nervousness"), loss of weight, and loss of appetite. The workers studied were exposed at TWA levels ranging from less than 0.01 mg Hg/cu m to 0.27 mg Hg/cu m, with most (84.5%) exposed at less than 0.1 mg Hg/cu m; approximately 60% of the total were exposed to less than 0.05 mg Hg/cu m. Significances of correlations were reported as probability (P) levels. The correlation between tremors involving the fingers, eyelids, and tongue and air levels from 0.1 to 0.27 mg/cu m was significant at $P = 0.001$. There was a significantly higher incidence of abnormal reflexes at exposure levels above 0.1 mg Hg/cu m. Thus, it was shown that there was a dose-response relationship among these workers, with the incidence of signs and symptoms of neurologic involvement increasing with exposure level.

A review of the data of Smith et al [28] shows there were effects in workers exposed at levels under 0.1 mg Hg/cu m. See Figure XII-4.

There was a high incidence of effects in workers exposed at 0.24 mg Hg/cu m and above (Figure XII-4). In the 0.11 to 0.14 mg Hg/cu m exposure group, there was incidence of weight loss and objective tremor; at lower levels the incidence of these signs was similar to that of the control group. Other effects observed or complaints reported (loss of appetite, insomnia, shyness, decrease in diastolic blood pressure, frequency of colds, history of nervousness, and diarrhea) were not markedly different in the three lower exposure groups (controls, 0.01 to 0.05 and 0.06 to 0.10 mg Hg/cu m) but there was a slight increase in complaints of appetite loss and insomnia in the 0.06 to 0.10 mg Hg/cu m exposure group compared to the two lower exposure groups.

Symptoms (subjective effects) as a rule are generally more sensitive than signs (objective effects) in the appearance of effects and thus the appearance of such symptoms as loss of weight and insomnia are indicative that evidence of toxicity is occurring between 0.06 and 0.1 mg Hg/cu m exposure level.

Bidstrup and co-workers [25] have reported signs of mercury intoxication (tremor, psychic disturbances) in 1 of 16 workers exposed to mercury vapor between 0.005 and 0.06 mg Hg/cu m. Duration of exposure was 19 years. Turrian and associates [114] noted signs and

symptoms of tremor and erethism in 5 of 26 workers exposed to levels between 0.01 and 0.06 mg Hg/cu m (see Table XII-7). At least 15 workers in this same exposure group exhibited symptoms of central nervous system involvement (headache, low concentrating ability, mental irritability). The average length of exposure was 9 years but minimum duration of exposure for the workers cannot be estimated. Other workers, Smith and Moskowitz, [20], Smith et al, [21] and Moskowitz, [56] concluded that mercury intoxication occurred in workers exposed at less than 0.1 mg Hg/cu m but did not report the lower exposure levels at which these effects occurred.

McGill et al [50] found no evidence of dangerous absorption of mercury in workers in one chlor-alkali plant study. Air levels over a period of 6 years varied between 0.08 and 0.13 mg Hg/cu m as measured by a mercury vapor meter. Information concerning the extent of the medical examination and the number and location of environmental samples was not reported. The range of environmental levels is small in comparison to the levels (less than 0.01 to 0.27 mg Hg/cu m) reported by Smith et al [28] in a study of 21 chlor-alkali plants. The reported findings in this paper do not parallel the findings of other investigators. [20,21,26,28,56]

The demonstration by Smith et al [28] of a significant occurrence of signs of toxicity at a level below 0.1 mg Hg/cu m and the occurrence of cases of toxicity between 0.005 and 0.06 mg Hg/cu m by Bidstrup et al [25] and Turrian et al [114] between 0.01 and 0.06

mg Hg/cu m indicate the need for an environmental standard for protecting the health of exposed workers of 0.05 mg Hg/cu m. With regard to the Trachtenberg [52] findings among the workers in Kiev, exposed to low concentrations (0.01-0.05 mg Hg/cu m), it is concluded that his report of hyperthyroidism should be investigated and confirmed before being used as a criterion for establishing an environmental standard for mercury.

Because of the prevalence in the general population of nonspecific signs and symptoms which can be associated with mercury, it is difficult, if not impossible, to establish a level at which no effects are observed. This is illustrated by the studies of Smith and his co-workers [28], Bidstrup and her associates [25], Turrian et al [114] and of Trachtenberg. [52] Effects between 0.005 and 0.06 mg Hg/cu m were found in these studies. The problem is further complicated because the validity of sampling and analytical methods on which the air levels are based cannot be determined conclusively; thus effects cannot be correlated with a high degree of confidence. Until better methods are established that will permit more specific identification of the effects of exposure to low levels of mercury, a specific level at which a standard should be established cannot be identified; but it is concluded that the standard should be at least as low as 0.05 mg Hg/cu m.

The possibility that mercury-contaminated clothing or hands are sources of increased worker exposure to mercury has been suggested by

several investigators [26,49,64,149] especially when work clothing is worn for much longer than the normal workday. According to Bell and his co-workers [149] this may result in excessively long exposure to mercury. This possibility has not been proved but if true, it can be controlled by change of clothing after exposure. For this reason, a strong recommendation for a daily change of work clothes is made by NIOSH.

VI. WORK PRACTICES AND SANITATION

The unusual physical properties of mercury make it difficult to control the potential hazards which are inherent in its use. A recognition of these hazards by workers is one of the most important aspects of its control. [26]

In addition to the management of the environment by process controls, administrative controls should also be instituted for regular and emergency work practices to avoid unnecessary contact with mercury. Several investigators [16,26,29,150-153] have stressed the importance of cleanliness of the work environment and the need for workers to give scrupulous attention to personal hygiene for the control of exposure to mercury. Their recommendations and conclusions are applicable to most situations where exposure to mercury may occur.

Work clothes which are to be worn during working hours only should be provided for all workers exposed to mercury. [26]

Workmen should shower before changing into street clothes. Because mercury is difficult to remove from the skin, it is essential that warm showers and soap be provided and used.

Work clothing should take the form of coveralls, as opposed to shirts and trousers, and have a minimum of seams, with no cuffs or pleats. Clothing should also be of a nonwoven or tightly woven fabric, which exhibits a minimum tendency to absorb mercury. [64]

Shoe covers, rubber boots or shoes which can be washed should be provided where floor contamination is a problem.

Work clothing should be changed daily, and separate lockers must be provided for work clothes and street clothes. Contaminated clothing should be stored in covered containers or vaporproof bags pending laundering.

Laundering of such work clothes should be provided by the employer, and precautions taken to minimize exposure of laundry workers to mercury.

All spills of mercury should be cleaned up immediately. Vacuum cleaning is an effective method for removal of mercury. However, vacuum cleaners should be equipped with charcoal filters so that mercury vapor will not be discharged into the workroom air. Sweeping should be be avoided as it creates dust and tends to break up any elemental mercury into even smaller particles, thereby increasing the rate of vaporization. Mercury vapor depressants, such as calcium polysulfide, have proved successful in controlling production of mercury vapor from spills. [153] The use of compressed air to blow elemental mercury or dust off equipment or clothes must be avoided, as blowing will increase the airborne level of mercury vapor and disperse mercury even more widely in the workplace.

Containers of elemental mercury must be kept covered with vapor tight covers when not in use. This may be accomplished by a tight

fitting cover or by covering the surface of the mercury by an aqueous layer to prevent vaporization.

The floor and work surfaces of all areas where mercury is used should be made nonporous and free from cracks or joints. Floors should be sloped to drains equipped with water traps which will store the mercury under water until collected and reclaimed. [151]

Waste mercury or waste material contaminated with mercury should be placed in tightly covered or vaporproof containers, pending removal or disposal. Disposal or reclamation of mercury should be undertaken only by those adequately trained in handling these types of contaminated materials.

All food and tobacco must be excluded from mercury work areas, and workers should be required to thoroughly wash their hands before eating or smoking. [26] Handwashing facilities for use by workers should be near the work location.

Only those persons having a need to be there should be permitted in mercury work areas, and each mercury processing area should be separate from other areas where possible.

VII. COMPATIBILITY WITH EMISSION STANDARDS

A national emission standard for mercury has been published by the Environmental Protection Agency (38 FR 8820). This standard is based upon specific operations and physical conditions, and is limited to emissions into the atmosphere. The standard specifies that emissions from stationary sources which process mercury ore to recover mercury and facilities which use mercury chlor-alkali cells to produce chlorine gas and alkali metal hydroxide shall not exceed 2,300 grams of mercury during a 24-hour period as measured in accordance with techniques set forth in the standard. This amount would limit the air concentration in the vicinity of emission sites to a daily level, averaged over 30 days, of 1 μg Hg/cu m. [10]

The standard is based upon information derived from many sources, including health effect levels, meteorology, technical analysis of control capability, and consideration of economic impact. The overriding considerations in developing the standard were health effects and the Environmental Protection Agency adopted the approach that mercury vapor and the more toxic methyl mercury are equal and additive.

A concentration in the air at or below 1 μg Hg/cu m is believed sufficient to protect the health of the public from illness due to inhalation of mercury with an ample margin of safety. [10]

There is no direct comparison possible between the proposed national emission standard for mercury and the recommended criteria for occupational exposure that the levels of exposure to the general public of varying health status and age on a 24-hour day, 7-day week, basis should be substantially lower than occupational standards based on an 8-hour day, 40-hour work week. However, the amount of mercury which an individual absorbs from the general atmosphere will be superimposed on that which he would receive from his occupational exposure. This additional amount is not expected to adversely affect workers when occupational levels are not above the 0.05 mg/cu m recommended in this document.

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IX. APPENDIX I

METHOD FOR SAMPLING OF MERCURY IN AIR

Elemental mercury vapor and mercury compounds are collected in an impinger and fritted bubbler in series, each containing acidic permanganate solution.

Equipment for Air Sampling

1. Stopwatch.
2. Constant rate vacuum pump with built-in rotameter.
3. Filtration adapter ₹ 24/40 joint. Two required.
4. 50-ml test tube and stopper ₹ 24/40 joint.
5. 150-ml ₹ 24/40 pear-shaped flasks. Two flasks are required for each air sample.
6. Solid borosilicate glass reagent bottle stopper, ₹24. One required for each 150-ml flask.
7. Fritted-glass bubbler tube, extra-coarse porosity.
8. Nonfritted bubbler tube.
9. Two No. 3 rubber stoppers bored to hold the tubes.

A complete set of glassware should be reserved solely for this sampling procedure and stored in a clean place when not in use. Only borosilicate glassware should be used. Clean all glassware initially by washing with brushes and a metal-free nonionic detergent, rinsing thoroughly with tap water until visibly clean. Then wash the complete inner surfaces with concentrated nitric acid. Rinse three to four

times with tap water, and then with deionized or distilled water. Once cleaned in this manner with concentrated nitric acid, glassware need only be rinsed three to four times with deionized water immediately after use and washed with 4 N nitric acid immediately before each subsequent use.

Reagents

All reagents should be prepared from reagent-grade materials.

1. 0.5 N potassium permanganate

Dissolve 7.90 g potassium permanganate crystals in water and dilute to 500 ml in a volumetric flask. Mix thoroughly and store in the volumetric flask protected from light. Discard when a precipitate of brown manganese dioxide develops.

2. 2.0 N sulfuric acid

Slowly add 56.2 ml of concentrated sulfuric acid to approximately 800 ml water in a 1-liter volumetric flask and mix. Because heat is evolved, sulfuric acid should be added to water with caution. Cool to 20 C, dilute to 1 liter, mix thoroughly, and store in the flask.

Sample Collection

The gas scrubbing devices recommended are shown in Figure XII-6. Similar devices may be used if they can be shown to have equivalent collection efficiencies for elemental mercury vapor, mercury compounds, and mercury-laden dust.

The absorbing solutions, 25 ml of 0.5 N potassium permanganate and 25 ml of 2.0 N sulfuric acid, are added to the pear-shaped flasks and stoppered with the glass stoppers. The time between addition of absorbing solution and the completion of sampling should not exceed 4 hours at room temperature. At higher ambient temperature, the bubbling solutions should be cooled by appropriate means. In the field, transfer the adapters and bubbling tubes to the flasks and stopper the test tube. Attach the bubblers to the sampling pump with tubing, forming a series arrangement with the fritted bubbler downstream from the nonfritted bubbler. Sample air at 2 liters per minute until 60 liters of air have been scrubbed. Measure the sampling time precisely. Remove the bubbler tubes and rinse the inside and outside of the tubes into the sample flasks with water from a polyethylene wash bottle. The same bubbler tubes are used for additional air samples.

The sampling pump must be checked for proper calibration prior to use.

The sampling routine will provide a 30-minute sample. Samples must be taken in a manner to allow the determination of a time-weighted average exposure in the workers breathing zone.

Samples should be returned to the laboratories for analysis as soon as possible.

X. APPENDIX II

METHOD FOR ANALYSIS OF MERCURY IN AIR

Equipment

1. Photometric analyzer.
2. Rapid response strip-chart recorder.
3. Automatic digital disc integrator, or planimeter.
4. Voltage regulator.
5. Rotameter.
6. Filtration adapter ₹ 24/40 joint.
7. 150-ml ₹ 24/40 pear-shaped flasks. One flask is required for each standard.
8. 3-way glass stopcock.
9. Fritted-glass bubbler tube, coarse porosity. One No. 3 rubber stopper bored to hold the tube.
10. Tygon, rubber, and borosilicate glass tubing.
11. Glass wool.
12. All-glass midget impinger.
13. Mercury vapor chemical cartridges.
14. Automatic dispensing bottle.
15. Pipettes, wash bottles, graduated cylinders, reagent bottles, glass-stoppered volumetric flasks, clamps, supports, rings, drying tubes, and other equipment and glassware as may be necessary.

Glassware is cleaned prior to use in a manner identical to that in Appendix I. Open vessels of reagents and sample solutions must be covered to protect from contamination by dust.

Reagents

All reagents should be prepared from reagent-grade materials.

1. Concentrated nitric acid (16 N)

2. Anhydrous magnesium perchlorate

3. Tin(II) chloride solution

Dissolve 250 g tin(II) chloride dihydrate in 500 ml deionized water. Carefully add with stirring 500 ml concentrated hydrochloric acid. Transfer to a dispensing bottle, add a few pieces of mossy tin and refrigerate. This solution is stable for about 2 months.

4. 0.5 N potassium permanganate

Prepare as in Appendix I

5. 2.0 N sulfuric acid

Prepare as in Appendix I

6. Stock mercury solutions

A. Weigh 2 to 3 grams (about 0.15 ml) oxide-free reagent-grade mercury to the nearest 0.1 mg into a clean, dry, tared 10-ml beaker. Immediately transfer to a 1-liter volumetric flask containing 100 ml concentrated nitric acid. Wash the beaker with 4 or 5 five-ml rinses of concentrated nitric acid, adding the rinsings to the flask. Add 100 ml concentrated nitric acid and about 500 ml water. Swirl and allow to come to room temperature. Dilute to 1-liter, mix thoroughly, and transfer to a clean, dry, glass bottle. Seal tightly. This solution is stable for at least one year.

B. Transfer 25.00 ml of solution A to a 1-liter volumetric flask containing 500 ml water and 50 ml concentrated nitric

acid. Dilute to the mark and mix thoroughly. This solution is stable for at least two months.

7. Working Standard Solution

Prepare a dilution of 0.100 µg Hg/ml by transferring an appropriate aliquot of solution B to a 1-liter volumetric flask containing 25 ml concentrated nitric acid and about 300 ml water. Dilute to 1 liter and mix thoroughly. This solution must be made fresh daily.

Preparation of Standard Curve

1. Turn on the mercury-vapor detection instrument and allow to warm up for 30 minutes. Adjust the flow rate of the compressed air line to 2 liter/min and constantly purge the gas cell with mercury-free air.

2. Adjust the zero and full-scale span of the instrument.

3. To six 150-ml pear-shaped flasks add 25 ml of 0.5 N potassium permanganate with a 25-ml graduated cylinder.

4. Add 25 ml of 2.0 N sulfuric acid to each flask with a 25-ml graduated cylinder.

5. With a pipette, add 0.00, 1.00, 2.00, 3.00, 5.00, 7.00 ml of the 0.100 µg Hg/ml working standard. Swirl each flask.

6. Turn on the recorder and recheck the instrument zero and full-scale span. Integrate with the recorder. A stable, noise-free base line is necessary.

7. Add 10 ml tin(II) chloride solution to the first flask (control blank) from the dispensing bottle. Swirl and immediately insert into the analysis train. The solution should be colorless; if

it is not, prepare a new control blank by adding more tin(II) chloride solution.

8. Rotate the stopcock of the three-way valve to flush air through the flask and into the vapor detector. After 2-3 minutes, or when the recorder pen returns to the base line, remove the flask from the bubbler tube and rotate the stopcock so the gas cell is constantly being purged with air.

9. Repeat steps 7 and 8 for the rest of the mercury-spiked standards. The pen response to mercury vapors occurs in a few seconds, and the mercury is usually flushed in 2-3 minutes, indicated by return of the pen to the base line.

A complete set of standards must be run along with every set of air-sample scrubber solutions.

Analysis of Samples

It is recommended that samples be analyzed the same day they are collected. The analytical equipment arrangements used are shown in Figure XII-7.

1. Combine the two air-scrubber solutions from a single sampling in a 200-ml volumetric flask with washings. Dilute to the mark and mix thoroughly. If there is precipitate adhering to the flasks, it may be necessary to reduce the permanganate with a few milliliters of 10% hydrogen peroxide before transferring the solutions to the volumetric flask.

2. Transfer duplicate aliquots to pear-shaped flasks. If necessary, dilute to about 50 ml with water.

3. Follow steps 7, 8, and 9 in the standardization procedure. Larger aliquots may be necessary in some cases where the concentration of mercury in air is very low. Generally, the greater the area under the recorded curve, the higher the accuracy and precision.

Calculations

Determine the area under the curve representing the mercury-spiked standards and the air samples with a planimeter. Repeat and average the results. Plot the mean area against µg Hg per standard on normal graph paper connecting the points with a straight line. Determine the amount of mercury in each air sample solution aliquot from the standard curve.

$$\text{mg Hg/cubic meter of air} = \frac{\frac{200\ A}{B} - C}{DE}$$

Where A = Average µg Hg found by analysis of aliquots of air sample scrubber solution

Where B = Volume of aliquot in milliliters

Where C = µg Hg in the control blank

Where D = Time of sampling period in minutes

Where E = Flow rate of bubbler in liters/min.

XI. APPENDX III

MATERIAL SAFETY DATA SHEET

The following items of information, applicable to any product or material containing mercury shall be provided in the appropriate section of the Material Safety Data Sheet or approved form. If a specific item of information is inapplicable (ie, flash point), initials "n.a." (not applicable) should be inserted.

(a) The product designation in the upper left hand corner of both front and back to facilitate filing and retrieval. Print in upper case letters as large as possible.

(b) Section I. Source and Nomenclature.

(1) The name, address, and telephone number of the manufacturer or supplier of the product.

(2) The trade name and synonyms for a mixture of chemicals, a basic structural material, or for a process material; the trade name and synonyms, chemical name and synonyms, chemical family, and formula for a single chemical.

(c) Section II. Hazardous Ingredients.

(1) Chemical or widely recognized common name of all hazardous ingredients.

(2) The approximate percentage by weight or volume (indicate basis) which each hazardous ingredient of the mixture bears to the whole mixture. This may be indicated as a range of maximum amount, ie, 10-20% V; 10% max. W.

(3) Basis for toxicity of each hazardous material (eg, established OSHA standard), in appropriate units and/or LD50, showing

amount and mode of exposure and species or LC50 showing concentration, duration, and species.

(d) Section III. Physical Data.

(1) Physical properties of the total product including boiling point and melting point in degrees Fahrenheit; vapor pressure, in millimeters of mercury, vapor density of gas or vapor (air = 1), solubility in water, in parts per hundred parts of water by weight; specific gravity (water = 1); percentage volatile (indicate if by weight or volume) at 70 Fahrenheit; evaporation rate for liquids (indicate whether butyl acetate or ether = 1); and appearance and odor.

(e) Section IV. Fire and Explosion Hazard Data.

(1) Fire and explosion hazard data about a single chemical or a mixture of chemicals, including flash point, in degrees Fahrenheit; flammable limits, in percent by volume in air; suitable extinguishing media or agents; special fire-fighting procedures; and unusual fire and explosion hazard information.

(f) Section V. Health Hazard Data.

(1) Toxic level for total compound or mixture, relevant symptoms of exposure, skin and eye irritation properties, principal routes of absorption, effects of chronic (long-term) exposure, and emergency and first-aid procedures.

(g) Section VI. Reactivity Data.

(1) Chemical stability, incompatibility, hazardous decomposition products, and hazardous polymerization.

(h) Section VII. Spill or Leak Procedures.

(1) Detailed procedures to be followed with emphasis on precautions to be taken in cleaning up and safe disposal of materials leaked or spilled. This includes proper labeling and disposal of containers with residues, contaminated absorbants, etc.

(i) Section VIII. Special Protection Information.

(1) Requirements for personal protective equipment, such as respirators, eye protection, protective clothing, and ventilation, such as local exhaust (at site of product use or application), general, or other special types.

(j) Section IX. Special Precautions.

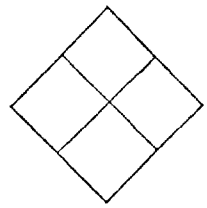
(1) Any other general precautionary information, such as personal protective equipment for exposure to the thermal decomposition products listed in Section VI, and to particulates formed by abrading a dry coating, such as by a power sanding disc.

(k) The signature of the responsible person filling out the data sheet, his address, and the data on which it is filled out.

PRODUCT DESIGNATION

MATERIAL SAFETY
DATA SHEET

Form Approved
Budget Bureau No.
Approval Expires
Form No. OSHA



SECTION I SOURCE AND NOMENCLATURE	
MANUFACTURER'S NAME	EMERGENCY TELEPHONE NO.
ADDRESS (Number, Street, City, State, ZIP Code)	
TRADE NAME AND SYNONYMS	CHEMICAL FAMILY
CHEMICAL NAME AND SYNONYMS	FORMULA

SECTION II HAZARDOUS INGREDIENTS						
BASIC MATERIAL	APPROXIMATE OR MAXIMUM % WT. OR VOL.	ESTABLISHED OSHA STANDARD	LD 50		LC 50	
			ORAL	PERCUT.	SPECIES	CONC.

SECTION III PHYSICAL DATA			
BOILING POINT	°F.	VAPOR PRESSURE	mm Hg.
MELTING POINT	°F.	VAPOR DENSITY (Air=1)	
SPECIFIC GRAVITY (H_2O=1)		EVAPORATION RATE (_____=1)	
SOLUBILITY IN WATER	Pts/100 pts H_2O	VOLATILE % Vol.	% Wt.
APPEARANCE AND ODOR			

SECTION IV FIRE AND EXPLOSION HAZARD DATA		
FLASH POINT METHOD USED	FLAMMABLE (EXPLOSIVE) LIMITS	UPPER LOWER
EXTINGUISHING MEDIA		
SPECIAL FIRE FIGHTING PROCEDURES		
UNUSUAL FIRE AND EXPLOSION HAZARDS		

PRODUCT DESIGNATION

SECTION V HEALTH HAZARD DATA	
TOXIC LEVEL	CARCINOGENIC
PRINCIPAL ROUTES OF ABSORPTION	SKIN AND EYE IRRITATION
RELEVANT SYMPTOMS OF EXPOSURE	
EFFECTS OF CHRONIC EXPOSURE	
EMERGENCY AND FIRST AID PROCEDURES	

SECTION VI REACTIVITY DATA
CONDITIONS CONTRIBUTING TO INSTABILITY
CONDITIONS CONTRIBUTING TO HAZARDOUS POLYMERIZATION
INCOMPATIBILITY (Materials to Avoid)
HAZARDOUS DECOMPOSITION PRODUCTS

SECTION VII SPILL OR LEAK PROCEDURES
STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
WASTE DISPOSAL METHOD

SECTION VIII SPECIAL PROTECTION INFORMATION	
VENTILATION REQUIREMENTS LOCAL EXHAUST	PROTECTIVE EQUIPMENT (Specify Types) EYE
MECHANICAL (General)	GLOVES
SPECIAL	RESPIRATOR
OTHER PROTECTIVE EQUIPMENT	

SECTION IX SPECIAL PRECAUTIONS
PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE
OTHER PRECAUTIONS

Signature _____ Address

Date

Table XII-1

MERCURY PRODUCED IN THE UNITED STATES, BY STATES

	Producing mines	Flasks	Value (Thousands)* Dollars
1970			
California	51	18,593	$7,582
Idaho	1	1,038	423
Nevada	13	4,909	2,001
Oregon	5	274	112
Alaska, Arkansas, New York, Texas, Washington	9	2,482	1,012
Total	79	27,296	11,130
1971			
California	38	13,233	3,869
Idaho	1	1,057	309
Nevada	8	1,589	465
Alaska, Arkansas, New York, Oregon, Texas	8	1,748	511
Total	55	17,627	5,154

Adapted from reference [1]
*Values Calculated at Average New York Price
Flask =76 pounds

Table XII-2

Mercury Consumed in U.S. - 76 Pound Flask

USE	1967	1968	1969	1970	1971
Agriculture	3,732	3,430	2,689	1,811	1,477
Amalgamation	219	267	195	219	W
Catalysts	2,489	1,914	2,958	2,238	1,141
Dental Preparations	2,386	3,079	2,880	2,286	2,387
Elec. Apparatus	16,223	19,630	18,490	15,952	16,938
Elec. Preparation of Chlorine & Caustic Soda	14,306	17,453	20,720	15,011	12,262
Genl. Laboratory Use	1,940	1,989	1,936	1,806	1,809
Ind. & Control Instruments	7,459	7,978	6,655	4,832	4,871
Paint--Antifouling	152	392	244	198	414
--Mildew Proofing	7,026	10,174	9,486	10,149	8,191
Paper & Pulp Mfgr.	446	417	588	226	W
Pharmaceuticals	283	424	712	690	682
Redistilled (1)	-	-	-	-	-
Other (2)	12,856	8,275	9,134	5,858	2,300
Total Known Uses	69,517	75,422	76,657	61,276	52,472
Total Uses Unknown			715	227	3
GRAND TOTAL	69,517	75,422	77,372	61,503	52,475

Adapted from reference [1]

(1) "Redistilled" used in industrial instruments, dental preparations, and electrical apparatus and after 1967 reported in the category for which it was used.

(2) "Other" includes mercury used for installation of chlor-alkali plants for 1963 and later dates.

W = Withheld to avoid disclosing individual company confidential data; included order "Other"

Table XII-3

Contingency Forecasts of Demand for Mercury
by End Use, Year 2000
(76-pound flasks)

End Use	Demand 1968	U.S. Forecast Base 2000	Demand in Year 2000 United States Low	High
Alkalies and chlorine	17,000	60,000	40,000	60,000
Electrical (batteries, apparatus, and lamps)	20,000	33,000	25,000	40,000
Mechanical measuring devices	8,000	13,000	10,000	17,000
Plastic materials and resins	2,000	7,000	5,000	10,000
Paints and allied products	11,000	18,000	15,000	20,000
Agricultural chemicals, n.e.c.	3,000	5,000	3,000	5,000
Medicinals, botanicals and dental supplies and equipment	3,000	5,000	5,000	8,000
Other uses	11,000	18,000	17,000	20,000
Total	75,000	. . .	120,000 (Median 150,000)	180,000

Adapted from reference [2]

Table XII-4

Physical Properties of Mercury

Atomic Number	80
Atomic Symbol	Hg
Atomic Weight	200.61
Freezing Point	-38.87 C
Boiling Point	356.90 C
Density	13.546 g/ml (20 C)

Vapor Pressure at Various Temperatures

Temperature Degree		Vapor Pressure (mm of Hg)	Mercury Concentration
C	F		(µg Hg/cu m)
0	32.0	.000185	2,180
10	50.0	.000490	5,880
20	68.0	.001201	13,200
24	75.2	.001691	18,300
28	82.4	.002359	25,200
30	86.0	.002777	29,500
32	89.6	.003261	34,400
36	96.8	.004471	46,600
40	104.0	.006079	62,600

Adapted from reference [3]

Table XII-5

Occupations considered to frequently include exposures to mercury

amalgam makers	fur processors
bactericide makers	gold extractors
barometer makers	histology technicians
battery makers, mercury	ink makers
boiler makers	insecticide makers
bronzers	investment casting workers
calibration instrument makers	jewelers
cap loaders, percussion	laboratory workers, chemical
carbon brush makers	lampmakers, fluorescent
caustic soda makers	manometer makers
ceramic workers	mercury workers
chlorine makers	miners, mercury
dental amalgam makers	neon light makers
dentists	paint makers
direct current meter workers	paper makers
disinfectant makers	percussion cap makers
disinfectors	pesticide workers
drug makers	photographers
dye makers	pressure gage makers
electric apparatus makers	refiners, mercury
electroplaters	seed handlers
embalmers	silver extractors
explosive makers	switch makers, mercury
farmers	tannery workers
fingerprint detectors	taxidermists
fireworks makers	textile printers
fungicide makers	thermometer makers
fur preservers	wood preservative workers

Adapted from reference [4]

TABLE XII - 6

Incident of Medical Effects in Russian Workers
Exposed to Mercury

Group	I		II		III *	
Numbers of workers	376		130		68	
Airborne conservations mg Hg/cu m	0.01-0.05		0.01-0.04		$\leq$0.01	
Effects reported	No.	%	No.	%	No.	%
Enlarged thyroid	55	14.6	18	13.8	3	4.4
Chest pain or "Colic", palpitations	109	29	47	36	27	40
Vascular dystonia	124	33	40	31	19	28
Functional shifts in liver	60	16	35	27	14	21
Gastrointestinal - loss of appetite, substernal distress nausea, vomiting	41	11	33	25	-	-
Bleeding gums	39	10.3	27	21	11	16

* Control population

Derived from Reference [52]

TABLE XII - 7

Symptoms Observed in 58
Mercury Workers

Air Concentration mg Hg/cu m	0.01-0.06	0.05-0.23	0.3-0.6
Number of workers	26	15	17
Average age	39.6	42.1	40.0
Average exposure, years	9.1	16.7	7.4
Tremor	19%	20%	29%
Erethism	8%	33%	29%
Impaired memory	0%	13%	18%
Demographia	8%	27%	18%
Gingivitis	42%	40%	35%
Bad teeth or dentures	46%	67%	41%

From Reference [114]

Table XII- 8

Relationship of Mercury Exposure to Mercury Levels in Urine, Uncorrected for Specific Gravity*

TWA** Exposure level groups (mg/cu m)	Number of workers	Percentage of group within urine level range (mg/l)					
		<0.01	.01-.10	.11-.30	.31-.60	.61-1.0	1.00
Controls 0.00	142	35.2	62.7	2.1	0	0	0
< 0.01	29	6.9	86.2	6.9	0	0	0
0.01-0.05	188	6.9	66.0	24.5	2.7	0	0
0.06-0.10	91	0	62.6	30.8	6.6	0	0
0.11-0.14	60	3.3	18.3	31.7	16.7	23.3	6.7
0.24-0.27	27	0	14.8	29.6	44.5	7.4	3.7

*Expressed as percentage of each exposure level group within designated ranges of urine mercury levels

**Time-weighted averages

From reference [28]

Table XII-9

Relationship of Mercury Exposure to Blood Mercury Levels*

TWA exposure Level groups (mg/cu m)	Number of Workers	Percentage of group within blood level range (µg/100 ml) <1	1-5	6-10	10
Controls 0.00	117	69.3	30.7	0.0	0.0
< 0.01	27	33.3	63.0	3.7	0.0
0.01-0.05	175	20.6	74.9	4.0	0.6
0.06-0.10	77	10.4	81.8	6.5	1.3
0.11-0.14	53	3.8	22.6	26.4	47.2
0.24-0.27	26	0.0	19.2	26.9	53.9

*Expressed as percentage of each exposure level group with designated ranges of blood mercury levels

Adapted from reference [28]

Table XII-10

Time-weighted Average Exposures
for Mercury Exposed Workers

Exposure Levels (mg/cu m)	Number of Workers	Percent of Exposed Workers
< 0.01	58	10.20
0.01-0.05	276	48.70
0.06-0.10	145	25.60
0.11-0.14	61	10.70
0.15-0.23	--	--
0.24-0.27	27	4.8

Adapted from reference [28]

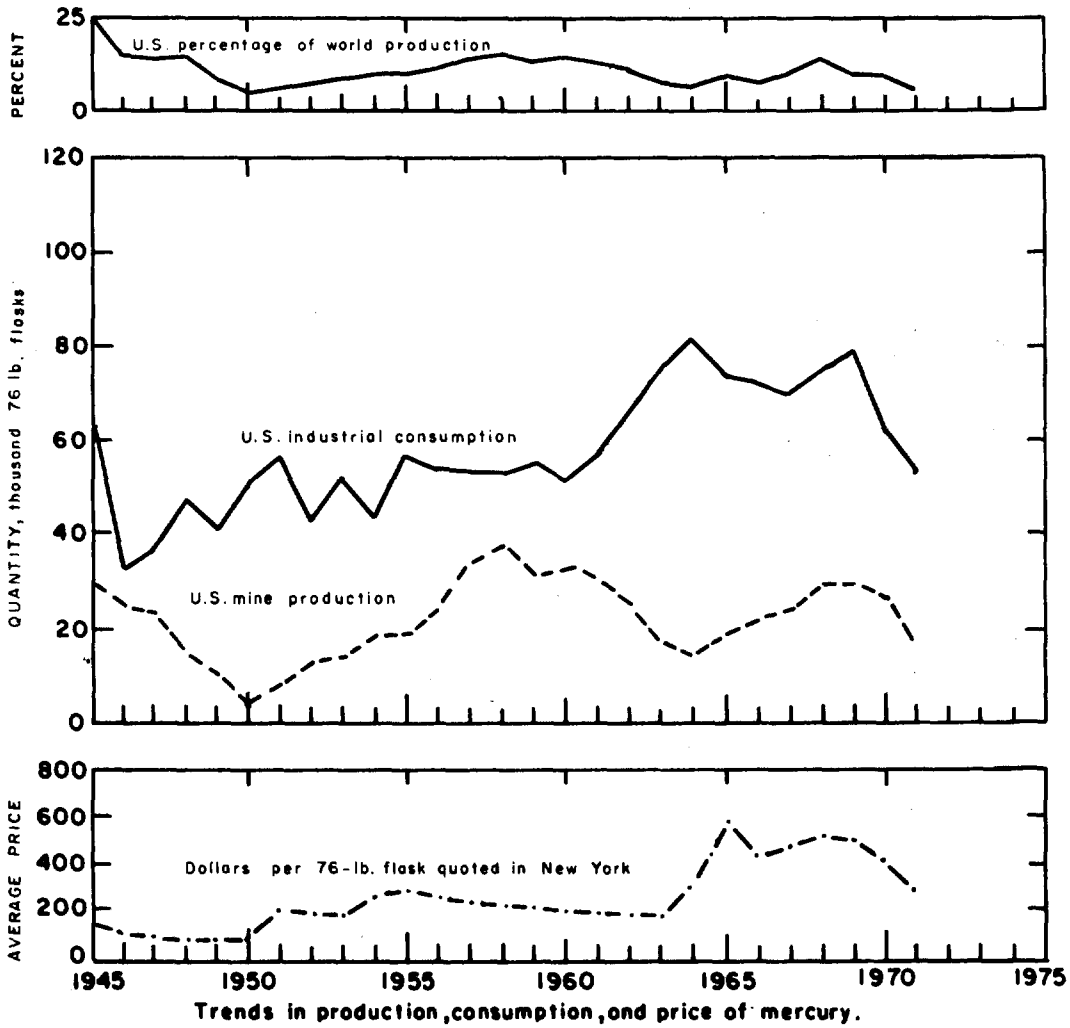


Figure XII-1

Trends in Production, Consumption and Price of Mercury

From Reference [1]

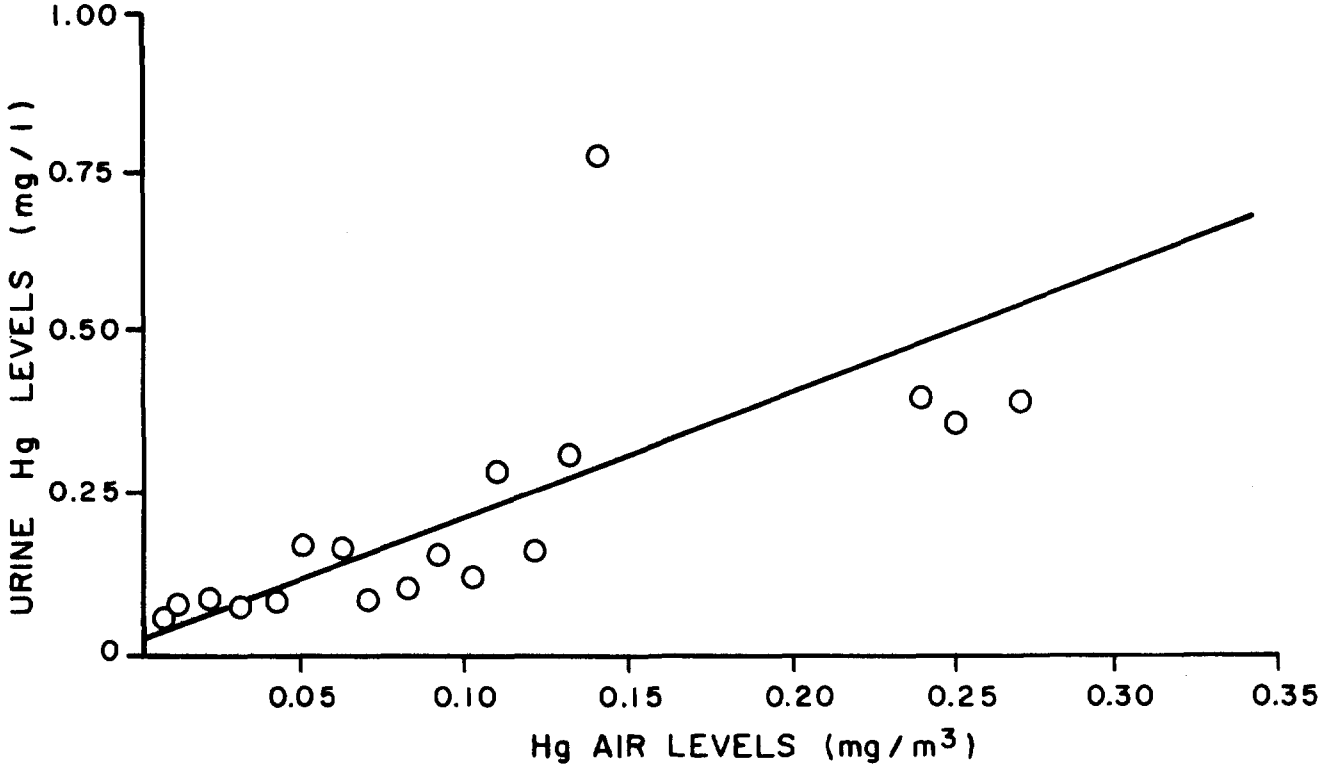


Figure XII-2

Concentrations of Mercury in Urine (uncorrected for specific gravity) in Relation to Time-Weighted Average Exposure Levels

From Reference [28]

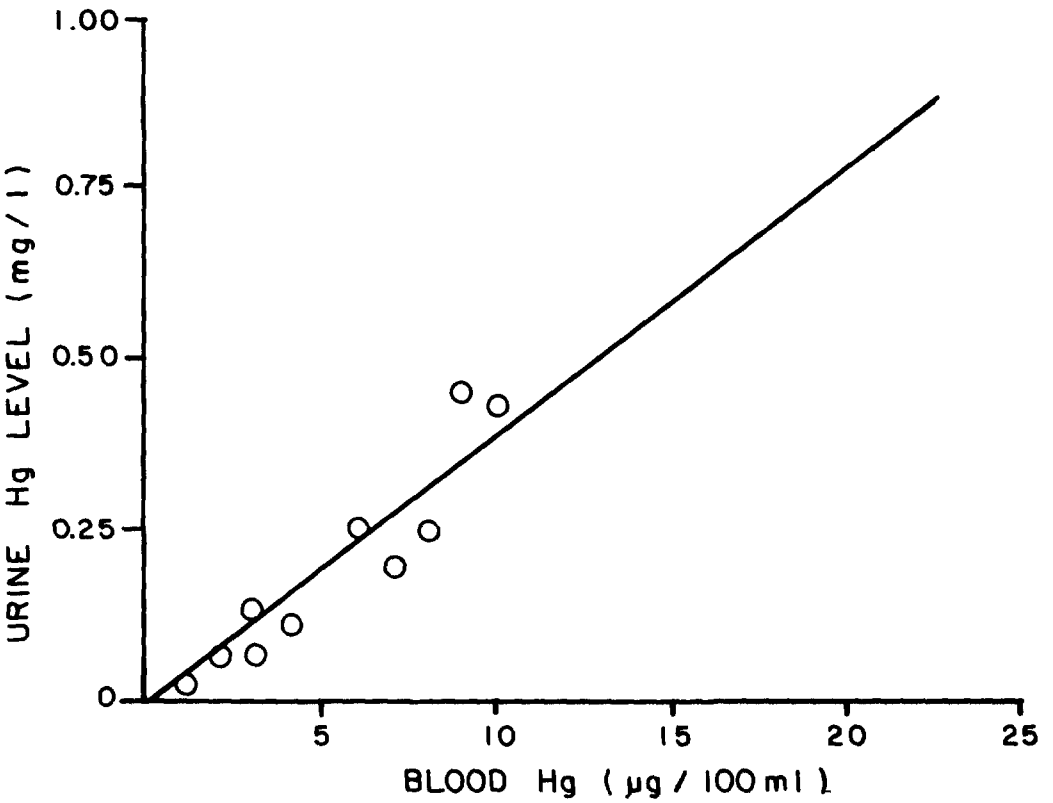


Figure XII-3

Relationship of Concentrations of Mercury in Blood and in Urine (uncorrected for specific gravity)

From reference [28]

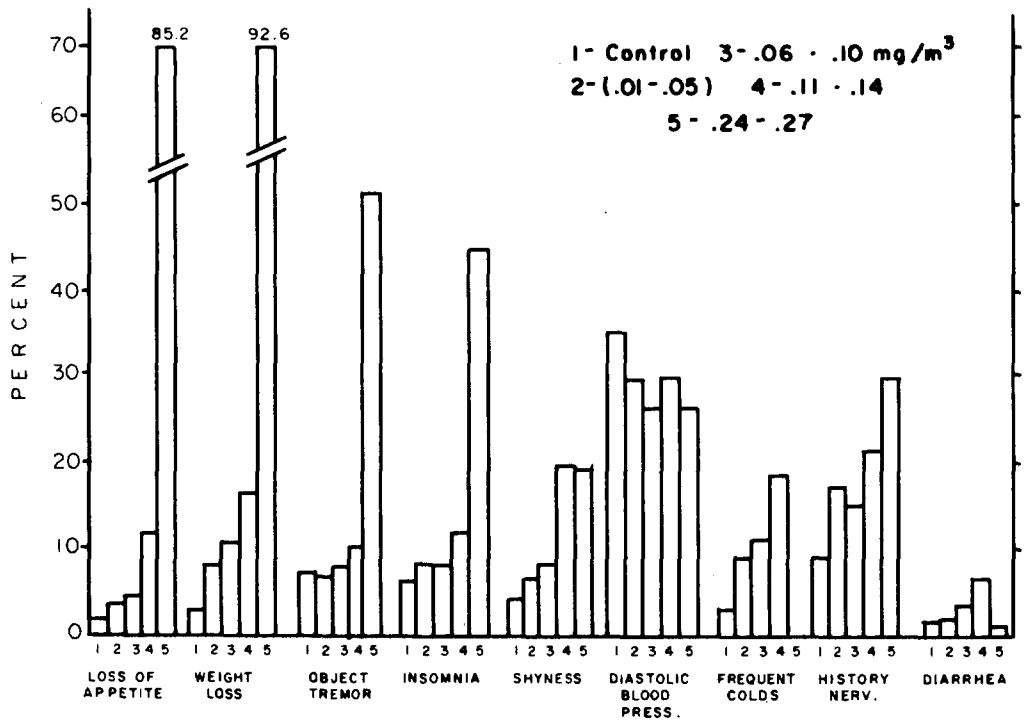
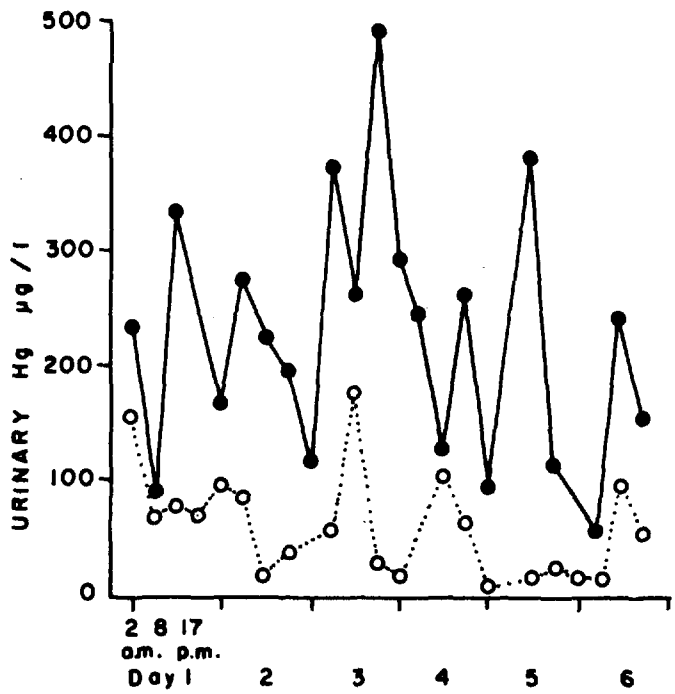


Figure XII-4

Percentage Prevalence of Certain Signs and Symptoms among Workers Exposed to Mercury in Relation to Degree of Exposure

From Reference [28]



Exposure to mercury had ceased one to two months previously.

Figure XII- 5

Variations within the 24-hour Excretion of Mercury in Two Workmen with Mercury Poisoning

From reference [119]

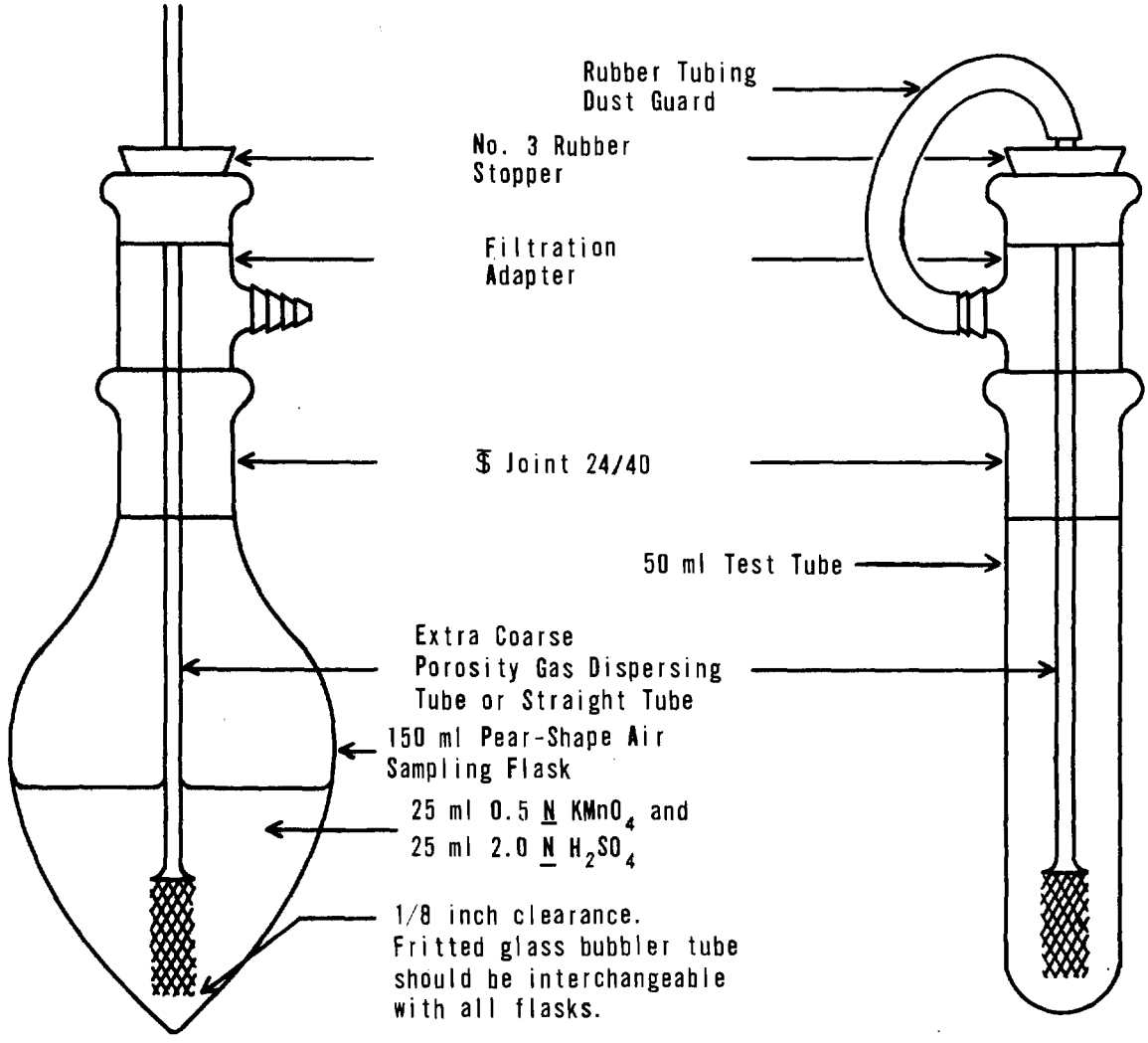


Figure XII-6

Collecting Bubbler for Particulates and Mercury Vapor [120]

A. Compressed air
B. Glass wool filter
C. Potassium iodide - activated charcoal filter
D. Flowmeter
E. 3-Way stopcock
F. Fritted glass bubbler flask and adapter
G. All-glass midget impinger
H. "Anhydrone" - glass wool filter
I. Optical gas cell
J. Mercury vapor detector or atomic absorption spectrophotometer
K. Strip chart recorder
L. Voltage regulator
M. Exhaust to hood or acid permanganate bubbler

Make all connections with "Tygon" tubing.
Keep connections as short as possible.

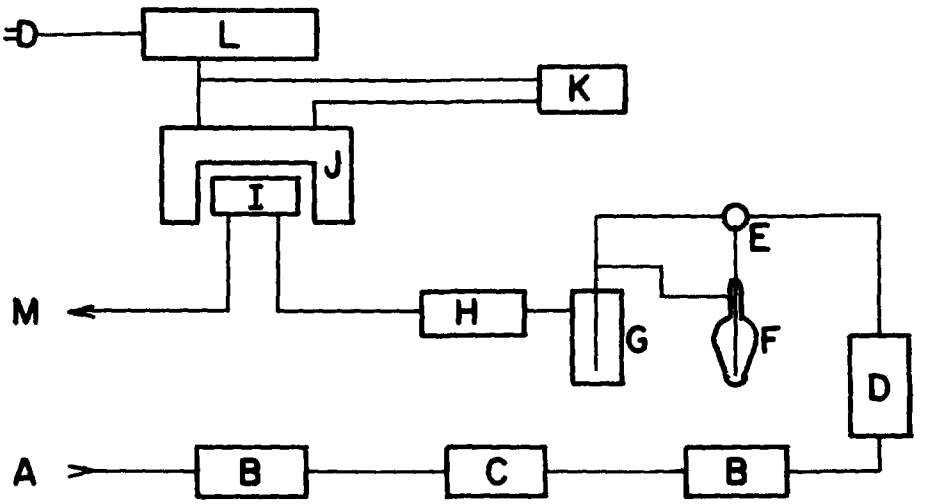


Figure XII-7

Desorption Train for Removing
Mercury from Collection Bubbler
[126]

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