criteria for a recommended standard . . . .

OCCUPATIONAL EXPOSURE
TO
ZINC OXIDE

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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Center for Disease Control
National Institute for Occupational Safety and Health
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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. The National Institute for Occupational Safety and Health has projected a formal system of research, with priorities determined on the basis of specified indices, to provide relevant data from which valid criteria for effective standards can be derived. Recommended standards for occupational exposure, which are the result of this work, are based on the health effects of exposure. The Secretary of Labor will weigh these recommendations along with other considerations such as feasibility and means of implementation in developing regulatory standards.

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 zinc oxide by members of my staff and the valuable and constructive comments by the Review Consultants on Zinc Oxide, by the ad hoc committees of the American Academy of Occupational Medicine and the American Academy of Industrial Hygiene, by Robert B. O'Connor, M.D., NIOSH consultant in occupational medicine, and by Bruce J. Held on respiratory protection. NIOSH recommendations for standards are not necessarily a consensus of all the consultants and professional societies that reviewed this criteria document on zinc oxide. 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 zinc oxide. Tabershaw-Cooper Associates, Inc., developed the basic information for consideration by the NIOSH staff under contract No. HSM-99-73-50. John M. Fajen of Stanford Research Institute developed the final document for consideration by the NIOSH staff and consultants under contract No. CDC-99-74-31. Douglas L. Smith, Ph.D., had NIOSH program responsibility for development of the document.

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I. RECOMMENDATIONS FOR A ZINC OXIDE STANDARD

The National Institute for Occupational Safety and Health (NIOSH) recommends that worker exposure to zinc oxide (ZnO) fume or dust in the workplace be controlled by adherence to the following sections. The standard is designed to protect the health and safety of workers for up to a 10-hour workday, 40-hour workweek over a working lifetime; compliance with all the sections of the standard should therefore prevent adverse effects of zinc oxide fume or dust on the health and safety of workers. The standard is measurable by techniques that are valid, reproducible, and available to industry and government agencies. Sufficient technology exists to permit compliance with the recommended standard. The standard will be subject to review and revision as necessary.

"Exposure to zinc oxide" is defined as exposure above half the recommended time-weighted average environmental limit.

Section 1 - Environmental (Workplace Air)

(a) Concentration

Occupational exposure to zinc oxide shall be controlled so that workers are not exposed to zinc oxide at an environmental concentration greater than 5 mg ZnO/cu m determined as a time-weighted average (TWA) exposure for up to a 10-hour workday, 40-hour workweek, with a ceiling of 15 mg ZnO/cu m as determined by a sampling time of 15 minutes.

(b) Sampling and Analysis

Procedures for sampling and analysis of environmental samples shall be as provided in Appendices I and II, or by any equivalent method.

Section 2 - Medical

Medical surveillance shall be made available as specified below for all persons occupationally exposed to zinc oxide.

(a) Preplacement medical examinations shall include:

(1) Comprehensive or interim work history.

(2) Comprehensive or interim medical history.

(3) The examination shall give special emphasis to the respiratory tract. Such tests as chest X-rays and pulmonary function studies may be considered by the responsible physician.

(b) Appropriate emergency health care shall be provided for workers with adverse effects from zinc oxide.

(c) Initial examinations for presently employed workers shall be offered within 6 months of the promulgation of a standard incorporating these recommendations, and at subsequent intervals determined by the responsible physician.

(d) Medical records shall be maintained for persons employed for one or more years in work involving exposure to zinc oxide and shall include information on all required medical examinations and all reported episodes of metal fume fever. Medical records with pertinent supporting documents shall be maintained at least 5 years after the individual's employment is terminated. Pertinent medical records shall be available to the medical representatives of the Secretary of Health, Education, and

Welfare, of the Secretary of Labor, of the employee or former employee, and of the employer.

Section 3 - Labeling (Posting)

(a) The following sign shall be posted in readily visible locations in any work area where there is the likelihood of occupational exposure to zinc oxide:

CAUTION

ZINC OXIDE AREA

Harmful If Inhaled

Use Only With Adequate Exhaust
Ventilation or Approved Respiratory
and Personal Protective Devices.

(b) The posting required under Section 3 (a) shall be printed in English and in the predominant language of non-English-speaking workers, if any, unless they are otherwise trained and informed of the hazardous areas. All illiterate workers shall receive such training.

Section 4 - Personal Protective Equipment

(a) Protective clothing

It is recommended that employees wear coveralls or equivalent during working hours.

(b) Respiratory Protection

(1) Engineering controls shall be used wherever possible to maintain zinc oxide concentrations below the prescribed limits.

Compliance with the permissible exposure limit may not be achieved by the use of respirators except:

(A) During the time period necessary to install or test the required engineering controls.

(B) For nonroutine operations such as a brief exposure to concentrations in excess of the permissible exposure limit as a result of maintenance or repair activities.

(C) During emergencies when air concentrations of zinc oxide may exceed the permissible limit.

(2) When a respirator is permitted by paragraph (b)(1) of this section, it shall be selected and used pursuant to the following requirements:

(A) For the purpose of determining the type of respirator to be used, the employer shall measure, whenever possible, the atmospheric concentration of zinc oxide in the workplace initially and thereafter whenever process, worksite, climate, or control changes occur which are likely to increase the zinc oxide concentrations. This requirement shall not apply when only atmosphere-supplying positive pressure respirators are to be used. The employer shall ensure that no worker is being exposed to zinc oxide in excess of the standard because of improper respirator selection, fit, use, or maintenance.

(B) A respiratory protection program meeting the requirements of 29 CFR 1910.134 and 30 CRF 11.2-1 shall be established and enforced by the employer.

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

(D) Respiratory protective devices described in Table I-1 shall be those approved under the provisions of 30 CFR 11.

TABLE I-1

REQUIREMENTS FOR RESPIRATOR USAGE AT CONCENTRATIONS ABOVE THE TWA OR CEILING LIMIT*

Maximum Use Concentration (Multiples of TWA limit)	Respirator Type for Zinc Oxide
Less than or equal to 5x	Single use (valveless type) dust or fume filter.
Less than or equal to 10x	(1) Air-purifying quarter or half mask respirator with replaceable dust or fume filter or single use (with valve) dust or fume respirator. (2) Type C demand type (negative pressure) supplied-air respirator, with half mask facepiece.
Less than or equal to 100x	(1) Air-purifying full facepiece respirator with replaceable dust or fume filter. (2) Type C demand type (negative pressure) supplied-air respirator, with full facepiece.
Less than or equal to 200x	Powered air-purifying (positive pressure) respirator with applicable replaceable dust or fume filter.
Greater than 200x	Type C continuous flow type (positive pressure) supplied-air respirator.

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* For abrasive blasting in metal cleaning use only Type CE positive pressure supplied-air respirator with hood or helmet.

(E) Respirators specified for use in higher concentrations of zinc oxide may be used in atmospheres of lower concentrations.

(F) The employer shall ensure that respirators are adequately cleaned, and that employees are instructed on the use of respirators assigned to them, and how to test for leakage.

Section 5 - Informing Employees of Hazards from Zinc Oxide

At the beginning of employment in a zinc oxide area, workers shall be informed of the hazards, relevant symptoms of overexposure, and proper conditions and precautions for safe exposure to zinc oxide. Circumstances under which zinc oxide may be generated shall be particularly emphasized. The information shall be kept on file and readily accessible to the worker at all places of employment where zinc oxide may be encountered. Information shall be recorded as specified in Appendix III, "Material Safety Data Sheet," or on a similar form approved by the Occupational Safety and Health Administration, US Department of Labor.

Section 6 - Work Practices

(a) Where a local exhaust ventilation system is used, it shall be designed, maintained, and utilized to limit the amount of zinc oxide dispersed into the workplace. Air from such an exhaust ventilation system should not be recirculated into the workroom environment or discharged outside the plant unless adequately cleaned to meet applicable air pollution codes.

(b) Local exhaust ventilation, located as close as practicable to the operation, shall be used whenever welding, cutting, or related high-temperature operations are performed in tanks or other enclosed locations.

(c) General Housekeeping

(1) Vacuuming shall be used wherever practicable and no dry sweeping or blowing shall be performed.

(2) Emphasis shall be placed upon prompt cleanup of dust, periodic repair of equipment, and proper storage of materials.

Section 7 - Sanitation Practices

Sanitation requirements shall include the following and shall comply with 29 CFR 1910.141:

(a) Hand washing facilities with soap and clean towels.

(b) Locker for clothing.

Section 8 - Monitoring and Recordkeeping Requirements

Workroom areas shall not be considered to have zinc oxide exposure if environmental levels, as determined on the basis of an industrial hygiene survey or by the judgment of the compliance officer, do not exceed half of the recommended TWA limit. Records of these surveys, including the basis for concluding that air levels are at or below half of the TWA limit, shall be maintained until a new survey is conducted. Workroom areas where there is exposure to zinc oxide shall be monitored in accordance with the specifications contained in the following subsections:

(a) Semiannual requirements: Employers shall monitor environmental levels of zinc oxide at least every 6 months, except as otherwise indicated by the judgment of a professional industrial hygienist. Also, surveys shall be repeated when any change in operations, processes, worksite, climate, or control indicates a need for reevaluation or at the discretion of the compliance officer. Samples shall be collected in the breathing zone of workers in accordance with the numbers specified in Table I-2. Sampling shall take into consideration variations in exposure arising in welding, burning, or related operations because of work on materials having various types of coatings of zinc or zinc compounds. The minimum number of representative TWA determinations for an operation or process shall be based on the number of workers exposed as provided in Table I-2 or as otherwise indicated by a professional industrial hygienist.

TABLE I-2

SAMPLING SCHEDULE

Number of Employees Exposed	Minimum Number of Employees Whose Individual Exposures Shall Be Determined
1-20	50% of the number of workers
21-100	10 samples plus 25% of the excess over 20 workers
over 100	30 samples plus 5% of the excess over 100 workers

(b) If semiannual samples show the environmental concentration of zinc oxide to be in excess of the recommended limits, suitable controls shall be initiated to reduce the exposure level to, or below, the recommended standard. In such cases monitoring shall continue at 30-day intervals until 2 consecutive surveys indicate the recommended limits are no longer exceeded. Periodic review and evaluation of environmental and medical data shall be performed to determine the effectiveness of control measures.

(c) Records of all sampling and of medical examinations shall be maintained for at least 5 years after the individual's employment is terminated. Records shall indicate the type of respiratory protective devices, if any, in use at the time of sampling. Records shall be maintained so that they can be classified to the extent possible by the employee. 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 diseases arising from exposure to zinc oxide fume or dust. The criteria 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 (NIOSH), after a review of data and consultation with others, formalized a system for the development of criteria upon which standards can be established to protect the health of workers 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 used as a final goal.

These recommendations for a standard for zinc oxide fume or dust are part of a continuing series of criteria being developed by NIOSH. The proposed standard applies only to occupational exposures to zinc oxide as applicable under the Occupational Safety and Health Act of 1970.

Although zinc oxide is manufactured and utilized in substantial quantities, the occupational exposures of principal concern are those to freshly formed zinc oxide fume produced by subjecting zinc or some of its compounds to high temperatures. Education of potentially exposed workers to be on the alert for unexpected sources is therefore important.

III. BIOLOGIC EFFECTS OF EXPOSURE

Extent of Exposure

Occupational contact with zinc oxide may occur either through its use in the manufacture of some product or through its formation as a fume as a result of subjecting either zinc or alloys containing zinc to high temperatures. The principal use of zinc oxide is as a white pigment in rubber formulations where it is also a vulcanizing aid. In 1971, shipments of zinc oxide in the United States were approximately 227,000 tons, about 55% of which was for use in rubber. [1] Next in consumption level to rubber formulation is the photocopying process, followed by the replacement of lead carbonate by zinc oxide as a white pigment in paints, chemicals, and ceramics. Zinc oxide is also used in lacquers and varnishes, as a filler for plastics, in cosmetics, pharmaceuticals, glass, matches, and in dentistry. [1-3]

Total zinc consumption in the United States in 1971 was about 1.7 million tons, of which approximately 1.3 million tons were slab zinc. The zinc content of ore and concentrates used directly to make pigments and salts was about 125,000 tons. Galvanizing consumed 38% of the slab zinc, with 12% going into brass products, 3% as zinc oxide, and 40% into dye casting alloys. [1]

The principal health hazard of zinc oxide arises from inhalation of its fume which is encountered in brass foundries, galvanizing, smelting, welding of galvanized metal or metal coated with zinc compounds, and other processes where zinc is exposed to temperatures exceeding its melting point. The freshly formed fume is considered especially hazardous because of its small particle size, ranging between 0.01 and 0.4 μm. [3-6] Zinc oxide is a white or yellowish-white, amorphous, odorless powder. Its physical characteristics are presented in Table X-1. Table X-2 lists potential occupational exposures to zinc and its compounds as presented by Gafafer. [7] Results of individual samples from welding operations are shown in Tables X-3, X-4, X-5, and X-6. NIOSH estimates that 50,000 individuals in the work force have potential exposure to zinc oxide.

Historical Reports

Metal fume fever, both the most common and the most important manifestation of occupational zinc oxide fume toxicity, is as old as the metallurgy of brass which began before the Christian era. [8] According to Meiklejohn, [9] the earliest recognition that metal fume fever, associated with the melting and casting of brass, was a result of the inhalation of zinc oxide fume, was by Thackrah. [9] Thackrah also described gastrointestinal and respiratory symptoms in brass founders.

Many further reports and clinical descriptions of metal fume fever were made during the remainder of the 19th century. In the opinion of Drinker, [8] these episodes may have been largely due to zinc oxide fume, a fact possibly not recognized by the authors of that time.

In 1910, Lehmann [10] reported from Germany the experiments upon himself and 3 others, all of whom subjected themselves to fumes from the combustion of chemically pure zinc. All subjects experienced what Lehmann described as metal fume fever. Analyses of 100-liter samples of the experimental chamber area air, filtered through cotton, showed the presence of 0.1-0.4 mg of ZnO/liter(100-400 mg ZnO/cu m). Lehmann postulated that zinc oxide might produce the characteristic symptoms of dryness and irritation of the throat with coughing and dyspnea, also pains in the muscles and joints, and general malaise very similar to influenza. Fever then developed, typically associated with the sensation of chills. [8,11-14] These symptoms were thought to be induced by the destructive action upon the epithelial cells of the respiratory passages, followed by absorption of the products of this destruction which were pyrogenic in effect. He also described experiments in which he failed to produce analogous effects in animals by intratracheal injection of zinc oxide powder.

Since 1910, metal fume fever, specifically zinc fume fever, and speculations about its pathogenesis, have received almost all the attention devoted to occupational zinc oxide toxicity in the literature.

Effects on Humans

(a) Theoretical Considerations

In considering the toxic effects of a metallic salt, it is necessary to study the toxicology of the metal and its ion. Zinc, unlike its neighbors in group II-B of the periodic table, cadmium and mercury, plays a vital metabolic role as a trace element in biological systems. [15-17]

The widespread distribution of zinc in the environment has been mentioned in most of the major reviews. [16-21] According to Schroeder and his associates [15], "Zinc is omnipresent in living organisms and ranks with the most abundant of the trace metals in man."

Schroeder et al [15] listed and evaluated the findings of zinc in human tissue samples he and his colleagues [22] collected from 13 areas of the world. Five-eighths of the total body pool of zinc was stored in striated muscle. The highest concentrations (4900-9200 $\mu g/g$) were observed in the prostate, liver, and kidneys. Noting that variations were great, they estimated a daily turnover of 12.6 mg of zinc for humans. Intake was estimated to be 12.0 mg from food, 0.5 mg from water, and 0.1 mg from air. Output was estimated [15] to be 10.6 mg in feces, 0.5 mg in urine, 0.5 mg in sweat, and 1.0 mg each in semen and menstrual blood. These figures are in the same range as those of Drinker et al, [23] which were 0.25-2 mg (average 0.89 mg) daily in urine, and 2.67-19.9 mg (average 9.8 mg) in feces daily. Foods considered by Schroeder et al [15] to be good sources of zinc included seafoods, meats, whole grains, dairy products, legumes, and nuts. Zinc, with cadmium, is present in a wide variety of foods in concentrations ranging from less than 1 $\mu g/g$ in egg white to over 1000 $\mu g/g$ in oysters. All drinking waters examined contained zinc. The authors concluded [15] that "Zinc compounds are relatively nontoxic to living organisms, especially mammals."

Zinc deficiencies in villagers in the Middle East have been described by Prasad. [24] He hypothesized that these deficiencies might involve hypopituitarism or might have a direct effect on DNA synthesis, as severe growth retardation and sexual hypofunction were among the deficiencies noted. Addition of zinc supplement to the diet of affected males led to growth and development of gonads and of secondary sex characteristics.

Using extraction and absorption techniques, Vikbladh, [25] demonstrated zinc in 2 fractions of blood serum, one of which is firmly bound and the other more loosely bound to a serum protein. Lowered zinc levels in blood serum have been observed during the febrile stage of infectious diseases in humans. Also in patients with "leukemias, malignant tumours, hepatogenic icterus, chronic polyarthritis, and chronic arthritis." Low serum zinc values in cases of untreated pernicious anemia were increased to normal levels by liver therapy.

(b) Effects of Inhalation

There are many excellent clinical descriptions of zinc fume fever in the literature, for example those of Drinker [8] in 1922, Kehoe [11] in 1948, Rohrs [12] in 1957, Fishburn and Zenz [13] in 1969,and Anseline [14] in 1972.

From 4-12 hours after exposure to freshly formed fumes of zinc oxide, the subject first begins to notice an unusual taste in the mouth. This may be described as a sweetish or "metallic" taste, or it may be some alteration of familiar tastes, including tobacco smoke, which then becomes undesirable. There are also dryness and irritation of the throat with coughing and dyspnea, feelings of weakness, fatigue, pains in the muscles and joints, and general malaise very similar to the prodromal syndrome of a severe coryza or influenza. Fever then develops, typically associated with the sensation of chills. [8,11-14] The body temperature is usually around 102 F but may reach 104 F. There may be febrile shivering or rigors which may be malaria-like in intensity. Historical trade terms such as "metal fume fever," "brassfounders ague," "brass chills," "spelter shakes," "galvo," "zinc chills," "zinc ague," and "Monday-morning fever" [8,11,14,26] refer to this feature. The subject usually sweats profusely, during which process the body temperature begins to fall; occasionally, the chills and sweating may be associated with convulsions. Severe pain in the chest, aggravated by breathing, have been described. [13] Clinical and symptomatic recovery is usually complete in 24-48 hours. [13] Blood taken during the acute phase of the illness has shown a polymorphonuclear leukocytosis, with the total white cell count rarely going above 20,000 cells/cu mm. The erythrocyte sedimentation rate does not seem to be significantly raised. There may be transient increases in certain serum enzyme levels, especially in the lactic acid dehydrogenase. Fishburn and Zenz [13] found an elevation in isoenzyme Factor 3 but a normal total serum lactic dehydrogenase in a typical case of zinc fume fever. Anseline [14] noted an elevation of the pulmonary isoenzyme for lactic acid dehydrogenase in the serum of another case. During the acute phase, the chest X-ray was either normal or showed merely an increase in bronchiovascular markings. [12,14]

A remarkable feature of zinc fume fever is the rapid development of tolerance to which the term "tachyphylaxis" (literally "quick immunity") was given by McCord [26] in 1960. The author stressed that this "immunity" was both quickly gained and quickly lost. In practical terms, this phenomenon means that a zinc or brass worker is more likely to experience zinc fume fever on his first day back at work after a weekend break or a vacation than during subsequent consecutive days of exposure, hence the term "Monday-morning fever." [11] However, it is a short-lived tolerance and reexposure on consecutive days may lead to repeated attacks of zinc fume fever. [26] The mechanism of zinc fume fever, and of metal fume fever in general, is still the subject of speculation. [10,26,27] Other types of metal fume fever, clinically identical to zinc fume fever, have been attributed to the fumes of other metals including cadmium, [12] copper, [28] and magnesium oxide. [29] Experimental evidence for some of the hypothetical mechanisms is discussed later in this chapter under Animal Toxicity. It was suggested by McCord [26] in 1960, and supported by Stilinovic and Grubisic [30] in 1970, that metal fume fever was an immunologic disease.

Mogilevskaya [31] in 1959 reported inflammation of the upper respiratory tract (nasopharyngitis and laryngitis) in 13 of 19 workers employed in zinc powder factories. These changes developed after 2-3 years of work. The author suggested that zinc and zinc oxide powder caused the alterations in the upper respiratory tract, the bronchi, and the peribronchial tissues. It was concluded that persons with diseases of the respiratory tract should be protected or excluded from exposures to zinc powders. Workers involved with zinc or zinc oxide powders and dusts should, according to Mogilevskaya, be given periodic medical examinations with emphasis on the ear, nose, and throat, and X-ray examination should be included. Dzukaev and Kochetkova [32] also reported fibrous changes in the lungs of workers in a zinc oxide production plant. They noted deformation, strengthening, and thickening in the X-rays of the lower and middle areas of the lungs. Details were not given and the supporting animal experiments are questionable because the suspension injected intratracheally into the laboratory animals contained 11-15% lead oxide. The reports [31,32] suggest a potential danger from zinc oxide powder when inhaled over prolonged periods of time.

Following the experimental exposures to pure zinc oxide fume of Lehmann [10] and 3 other subjects described under Historical Reports, Sturgis, Drinker, and their co-workers [5,6,29,33] in 1927 published a series of 4 reports on experimentally induced metal fume fever in humans.

The first report by Sturgis et al [5] in 1927 concerned 2 male subjects aged 32 and 39. Both had previous exposures to unmeasured concentrations of zinc oxide fume, and both experienced metal fume fever on several occasions during the preceding 2 years. With this previous experience, the subjects inhaled the oxide for a length of time and in a manner which each knew would produce a typical reaction of only moderate severity. Both were exposed in the same exposure chamber to an average concentration of 600 mg/cu m of high purity zinc oxide fume calculated as elemental zinc. One subject breathed for 5 minutes at 6 respirations/minute, then for 5 1/2 minutes at 12 respirations/minute. The other breathed for 12 minutes at 15 respirations/minute. It was calculated that the first subject retained 24 mg of zinc and the second 37 mg of zinc during these exposures. Both developed metal fume fever, the maximum febrile reaction being reached in the first subject about 7 hours after exposure, in the second subject about 4 hours after exposure. The body temperature of both subjects returned to normal within 12 hours. The white blood cell counts (WBC) of both individuals peaked (approximately 17,000/cu mm) at about the same time as the peak body temperature was attained. In both cases, the WBC count peaked again at a similar level almost exactly 24 hours after inhalation and remained high for the following 12 hours. In both subjects, the vital capacities, measured at 4-hour intervals, declined synchronously with the rise in body temperature and the initial rise in WBC count. The vital capacity of the first subject was decreased by as much as 18% of baseline and in the second subject there was a diminution of 53%, a seemingly drastic reduction. In both cases, the vital capacity had returned to baseline within 36 hours after exposure. Significant changes in blood pressure and chest X-rays were not found.

The second report in the series by Drinker et al [33] covered the same experimental subjects as previously. Estimations were made on the zinc content of the air at a brass foundry for about 5 hours. Subsequent analyses of samples showed that one of the subjects could have inhaled an average of 52 mg Zn/cu m air. That night the subject experienced symptoms of metal fume fever. The following day he worked for 3 hours in an environment containing an average of 330 mg/cu m of Zn and he experienced some of the prodromal symptoms of metal fume fever in the afternoon. On the third day he returned to the same foundry where he was presumably reexposed to similar concentrations of zinc oxide fume as on the previous 2 days, but this time he experienced no untoward reactions. Experimental exposures were then repeated upon the first subject of the earlier report. On the first day he was exposed to zinc oxide at 430 mg Zn/cu m of air for 8 minutes. He developed metal fume fever that night, his temperature peaking about 13 hours after exposure. Twenty-four hours after the first exposure, he was reexposed at 610 mg Zn/cu m and experienced a much milder attack of metal fume fever, peaking at about 12 hours after exposure. The WBC was also followed at 4-hour intervals, peaking at about 15,000/cu mm on the first day about 4 hours before the fever peak. On the second day the WBC was much higher (19,000/cu mm), falling to 11,000/cu mm about 4 hours after exposure and rising again to 17,000/cu mm synchronously with the second fever peak. Both the body temperature and the WBC count then gradually declined over the following 48 hours. It was concluded that acquired resistance to the effects of zinc oxide fume inhalation had occurred, thereby attenuating or preventing the fever altogether, despite reexposure on consecutive days.

In their third experimental report, Drinker et al [29] described in passing an experimental exposure of 2 subjects to a well dispersed cloud of very fine zinc oxide powder, the particles of which were of the order of 0.15 μm in size. They observed that such a cloud of very fine zinc oxide dust had approximately the same capacity for causing metal fume fever as the freshly formed fume. Most of this report, however, was devoted to an experimental demonstration that magnesium oxide fume in concentrations ranging from about 4-6 mg/cu m caused a metal fume fever that was clinically indistinguishable from that produced by zinc oxide fume.

In the fourth experimental report in this series, Drinker et al [6] estimated the threshold dose of inhaled zinc oxide, in the form of fume, necessary to induce metal fume fever. They postulated that the occurrence of metal fume fever was determined by the depth of penetration of the oxide particles into the lung, the alveoli being the site of action, with alveolar penetration being increased by slower and deeper inspiration. This postulate was based upon the observation that of 8 subjects inhaling the same concentration of zinc oxide fume for about the same period of time, 5 men who were breathing very deeply at 6 respirations/minute developed typical metal fume fever. Two of the women who were breathing at a rate and depth described as normal developed only minimal symptoms although they had actually inhaled as much oxide as the men. The remaining female subject with low minute volume did not develop any symptoms. The authors explained the difference in symptoms by the degree in alveolar penetration by the zinc oxide particles as influenced by the manner of breathing, ie, slow maximal-depth breathing leading to greater particle retention than that resulting from breathing at a normal rate and depth for the same minute volume. It was determined experimentally [6] by measuring the zinc oxide content of both the inhaled and the exhaled air and assuming that approximately 1/2 of the inhaled zinc oxide fume was retained in the respiratory tract of the subjects.

A series of 27 inhalation experiments were then conducted [6] at different concentrations of freshly generated zinc oxide fume at varying durations of exposure and different respiration rates and minute volumes. One of the men was subjected to 11 experiments, varying the above experimental conditions, another to 5 experiments, 2 males and 1 female to 2 experiments each, and the remaining 3 males and 2 females to 1 experiment each. From the results obtained from 7 males and 3 females, a dose-response relationship was determined by plotting the calculated retained dose against rise in body temperature. A concentration of 15 mg/cu m of zinc oxide was suggested as the threshold limit for an 8-hour workday. However, this figure does not seem to have been derived from the extensive dose-response calculations described. It appears that an average concentration of 14 mg/cu m, below which fever was not observed, was derived from the report of Batchelor et al, [34] and that the selection of 15 mg/cu m [6] as a TLV was based upon Batchelor's work with zinc oxide powder, not zinc oxide fume. Drinker et al [6] and Batchelor et al [34] used the concentration of 15 mg/cu m as the threshold limit because they found that the men exposed for 8 hours to zinc oxide powder of that concentration in Batchelor's study did not ordinarily acquire fever.

(c) Gastrointestinal Effects

There are several reports in the literature suggesting that prolonged occupational exposure to zinc oxide fume may be associated with gastrointestinal disturbances. [35-37] In an insufficiently documented paper on occupational disease of zinc workers in the galvanizing trade, McCord et al [35] in 1926 described histories obtained from workers employed in galvanizing processes for 5-22 years which were suggestive of gastric or duodenal ulcers or hyperchlorhydria. No physical examinations of the workers were performed. The attribution of exposure to zinc is questionable because exposure was diverse and included hydrogen sulfide, arsine, arsenic, mineral acids, ammonia, ammonium chloride, lead, antimony, cadmium, aluminum, as well as zinc, zinc oxide, and zinc salts. [35]

In 1934, Kapp [36] reported 2 cases of gastrointestinal disturbances in zinc workers. One was a 29-year-old mechanic with a history of metal fume fever who spent a few hours 3-4 times each month cutting apart galvanized objects with an oxygen torch. The other was a galvanizer. After one prolonged exposure ("a few hours") to zinc oxide fume, the mechanic did not recover promptly from the metal fume fever but complained the following day of pressure in the stomach region, nausea, and weakness. Aspirated gastric fluid contained leukocytes. The symptoms responded to a medical ulcer regimen. The galvanizer was exposed for several hours each day to fumes from an oven in which zinc was melted and ammonium chloride was heated. Symptoms of coughing, vomiting, and cramp-like pains in the upper abdomen developed gradually within 6 months. The temporary symptoms of the 2 workers gave the impression of zinc-fume fever and suggested possible gastrointestinal effects from repeated or prolonged exposure to zinc fumes.

In 1936, Chrometzka [37] reported observations on 58 electric welders, 18 of whom were seen during episodes of metal fume fever, and the remaining 40 after the symptoms had disappeared. The welding operations were performed on sheets of galvanized iron. Many of the workers complained of pressure or distention of the stomach, loss of appetite, and, in the more advanced cases, cramp-like pains in the upper abdomen. In 12 of the 58 cases the stomach distress was the most pronounced complaint after the fever period. Gastritis was diagnosed in only 1 case, but 12 others had signs of gastric irritation which included acidity, high mucous production, disposition to bleeding, mucous membrane desquamation, and leukocyte infiltration. Ulcers could not be demonstrated in any of the patients, not even with recurrence of poisoning. Four of the patients complained of periodic diarrhea.

In 1969, Hamdi [38] reported a study of 12 Egyptian brass foundry workers who were heavily exposed to zinc oxide fumes for 4-21 years. No environmental data were given. The zinc content of aspirated gastric juice was determined from 8 of the exposed workers and from 7 unexposed controls. There was a statistically significant increase of zinc concentration in their basal fasting gastric juice, in red blood cells, and in whole blood compared to the controls. It was suggested that the increase in zinc concentration in the gastric secretion might have accounted, in part, for gastric complaints present in 10 of 12 workers. The author suggested that other factors such as other environmental contaminants could have been responsible for the pains reported.

McCord et al [35] in 1926, and Du Bray [39] in 1937 have postulated chronic systemic toxic effects from the absorption of zinc following exposure to zinc oxide fume and other zinc compounds but Drinker and Fairhall [40] in 1933, and Hamilton and Hardy [41] in 1949, in review articles on the toxicology of zinc, have expressed doubts as to the existence of chronic systemic effects. To quote Hamilton and Hardy, [41] "On the whole the great weight of evidence is against the existence of chronic industrial zinc poisoning, and the ill health of workers in zinc when it exists should be traced to other sources."

In 1973, Guja [42] reported a prevalence of what was described as a clinically latent dysfunction of the liver in 60% of workers (15 out of 25) exposed to 50 mg ZnO/cu m, measured as zinc. Of the 15 men with evidence of liver dysfunction, (abnormal levels of alanine aminotransferase and cholinesterase were analysed), 3 had radiological evidence of a peptic ulcer. The workers also complained of debility, abdominal pain, acid rebound, heartburn, and loss of weight. The urinary uropepsin levels were significantly higher in the 25 workers exposed to zinc oxide than in 25 unexposed controls. In the opinion of Guja, a raised urinary uropepsin level may be indicative of toxic damage to the gastrointestinal tract.

(d) Effects on the Skin

Zinc oxide is a constituent of many topical dermatological preparations [43] and has demonstrated a low potential for skin irritation. In 1921 Turner [44] reported that 14 out of 17 men employed in the manufacture of zinc oxide either had or had experienced in the past an occupational dermatitis known in the trade as "oxide pox," which was referred to as a dermatoconiosis due to zinc oxide powder. The lesions were described as small red projecting papules, 2-3 mm in diameter, hard and shotlike on palpation, with a white central plug. There was an areola of inflammation at the base of the papule. On the 2nd or 3rd day of the eruption, the central portion of the papule began to soften and develop into a pustule causing intense itching. In 10 of the cases, the skin of the affected parts was dry, and in 4 cases it was moist and eczematous. The eruption usually persisted for a week or 10 days, gradually subsiding and drying up. In 13 of the cases, the pubic region, scrotum, and inner surfaces of the thighs were affected. In 4 cases the axilla and inner surfaces of the arms were also involved. Secondary infection, mostly by Staphylococcus aureus, was thought to play a significant role in the pathogenesis of the skin lesions. Blood agar cultures of material from the lesions were 90% positive for Staphylococcus. It was concluded that zinc oxide had combined with debris and bacteria to block sebaceous glands, resulting in irritation and eventually infection. The workers in the factory reported that the lesions did not occur if they took daily baths. It is evident that the skin disorders in zinc oxide workers occurred mainly because of lack of personal hygiene.

Epidemiologic Studies

In 1926, Turner and Thompson [45] published an extensive survey of the health hazards of brass foundries with some epidemiologic findings but no quantitative environmental data were presented. Qualitative sampling established the presence of zinc as well as iron, cadmium, manganese, antimony, and traces of lead, arsenic, and tin in the airborne dust. Of the 102 brass foundry workers interviewed, 26% had attacks of "brass foundrymen's ague" on the average of once a week, 13% once a month, 17% once a year, 11% twice a week, 14% twice a month, 6% twice a year, 2% three times a month, 1% three times a year, and 10% about four times a year. Eighty-eight percent of the men asserted that the attacks occurred only during the winter months (when natural ventilation was inadequate) and 12% said that they were affected without regard to the seasons. All said that during inclement weather they were almost certain to have an attack. Another observation in this report was that a syndrome, similar to "brass foundrymen's ague," was seen in men engaged in the manufacture of zinc oxide powder. Four out of 8 men engaged in the bagging of the freshly formed and still warm oxide dust gave positive histories of "oxide chills" and 7 out of 9 men in the packing room had similar symptoms. No actual cases of the syndrome were observed by the investigator, but several case histories were obtained by questioning the employees. A definite similarity was noted in the symptoms and severity of attacks found in brass foundrymen and the oxide chills reported by the men engaged in the manufacture of zinc oxide powder. The symptoms common to both brass foundrymen and oxide workers consisted of irritation and dryness of the nose and throat, frequent headaches, and occasional digestive disturbances including constipation. It was considered by the authors [45] that the entire sequence of symptoms in all stages was so constant in both situations that the basic causative factor must have been the same.

In 1926, Batchelor et al [34] published a report with epidemiologic features and minimal environmental data on the effect of metallic zinc, zinc oxide, and zinc sulfide on the health of workers. The industrial processes included the smelting of zinc ore for spelter (ingots) and for zinc oxide, and the manufacture of zinc oxide, of paint pigment (lithopone, 30% zinc sulfide and 70% barium sulfate), and of zinc dust. Out of a total of 1,620 men employed in the plant, 24 were singled out for special study. These 24 men were defined as having been exposed to zinc metal or zinc oxide, measured as zinc, ranging from 0.03 to 3.7 mg/cu ft (1-131 mg/cu m) for periods ranging from 2 to 35 1/2 years. They were described as being "...on the whole a vigorous, healthy lot of men, giving no histories of significant past illnesses and showing only such general physical conditions as one would expect to find in any similar group of men of the same ages, of the same social status, and doing approximately the same amount of physical work in an atmosphere with a moderate amount of dust, but with no exposure to zinc...." The 24-hour urinary and fecal zinc levels in the zinc workmen differed from 24-hour urine and fecal zinc excretion values for normal (unexposed) subjects on an ordinary mixed diet. The authors' summary conclusion on these measurements was: "...zinc workers absorb and excrete zinc in amounts considerably over the normal, and they maintain constantly a blood zinc content slightly higher than normal...abnormal amounts of zinc may enter and leave the body for years without causing symptoms or evidence, which can be detected clinically or by laboratory examination, significant of gastrointestinal, kidney or other damage...." [34] Data on excretion levels have been cited in the section on Effects on Humans of this document.

In 1944, Hammond [46] reported on the incidence of metal fume fever in the crushed stone industry. In this industry, zinc containing from 1.6 to 2.2% lead was used to bind and fill voids about the various crushers. When molten zinc was poured in the repairing and relining of the crushers, environmental zinc levels ranged from 8 to 12 mg/cu m, with a mean of 10 mg/cu m from 4 measurements. No metal fume fever was observed or recorded during these operations. However, during oxyacetylene torch cutting procedures in the removal of old linings, much higher environmental levels for zinc oxide (as zinc) were measured, ranging from 320 to 545 mg Zn/cu m, with an average of 465 mg Zn/cu m from 5 samplings. Moreover, mean environmental levels of 12.4 mg/cu m of manganese and 1.6 mg/cu m of lead were also noted. The cutters were usually inside the crushers for 1-3 hours without ventilation. It was reported that at one time or another the workers engaged in cutting or burning out of old liners under these conditions experienced metal fume fever.

Animal Toxicity

(a) Inhalation

In 1910, Lehmann [10] reported the results of experiments conducted in 1906 in which rabbits were exposed to zinc oxide by inhalation or by intratracheal injection. Lehmann was unable to produce metal fume fever in the animals by either route, inhalation or intratracheal injection.

In 1926, Turner and Thompson [45] reported studies on guinea pigs to test Lehmann's hypothesis. Monkeys were rejected as being too difficult to handle. An exposure cage was designed to produce a condition similar to that encountered in brass foundry practice, with the additional advantage that the intensity and duration of exposure were reasonably controlled. Temperature, pulse, and respiration rate of the guinea pigs were observed prior to a 1-hour exposure at levels of zinc oxide ranging from 30 to 72 mg/cu ft (1060.0-2543.0 mg/cu m) and again for 46 hours after exposure.

They exhibited "air hunger," with labored and convulsive breathing for about 4 hours after removal from the exposure cages. Their temperatures were subnormal, being most depressed 3-4 hours after exposure. From 8 to 9 hours after exposure, the temperatures were above normal, reaching a peak at 16 hours and returning to normal after 24 hours. When the animals were removed from the exposure cage, their respiration was slow and labored, but increased to a rate above normal for about 42 hours. Microscopic studies of lung tissue from exposed animals showed "infiltration of endothelial cells and polymorphonuclear leukocytes," which were described as being similar to that observed in bronchopneumonia.

Turner and Thompson [45] exposed 6 healthy guinea pigs at 29 mg/cu ft (1024 mg/cu m) of zinc oxide fumes for 1 hour daily for 3 days, followed by 2 days of no exposure, then 6 additional days of 1-hour daily exposure. The animals showed "unmistakable evidence of an accumulative reaction" and required 3-6 days to recover from the effects, which included respiratory irritation, irregular heart action, and weight loss. In further experiments, animals exposed continuously at 70.9 mg/cu ft (2503 mg/cu m) of zinc oxide fume died within 2-5 hours of the start of the exposure. Both the lung tissue and the stomach tissue contained an average of 48 mg ZnO/animal suggesting that as much zinc oxide had been ingested as had been inhaled.

Drinker et al [47] reported in 1925 that zinc oxide was more effectively introduced into the lungs of experimental animals when administered with 10% carbon dioxide.

In 1928, Drinker and Drinker [48] reported results of experiments in which cats, rats, and rabbits were exposed for 15 minutes-3 1/4 hours at levels of zinc oxide fume ranging between 110 and 600 mg/cu m. The animals showed prolonged temperature depression but no subsequent rise above normal. In addition a delayed but definite increase in polymorphonuclear leukocytes was found. This contrasted with the earlier work of Turner and Thompson. [45] Chemical analyses using an unspecified method of Fairhall's [49] (either gravimetric, turbidimetric, or colorimetric) showed that the quantity of inhaled zinc did not vary directly with the length of exposure, but that most of the zinc accumulated during the first 15-45 minutes of exposure. [48] Cats inhaled proportionately more zinc than did rats. Zinc was removed rapidly from the lungs of cats and rats, returning to normal levels within 4 days after exposure. Zinc concentrations increased in the liver, gall bladder, bile, kidney, and pancreas. It was concluded [48] that the "characteristic reaction of animals to the inhalation of freshly formed metal fume products" was "a fall rather than a rise in temperature...." This statement was partially based on experiments with magnesium oxide in which similar results were obtained.

In 1928, Schmidt-Kehl [50] reported experiments in which rabbits were exposed to freshly formed zinc oxide fume. Serum extracts were prepared from the bronchial and tracheal mucous membranes of rabbits which had inhaled zinc oxide fume. No temperature changes resulted when an extract was injected into the ear vein of an unexposed rabbit. Another experiment was performed using rabbit serum which had been sprayed into an atmosphere of zinc oxide fume. The serum (20-25 cc) was injected into the ear vein and the maximum temperature increase as compared with the controls was present 2-12 hours after the injection and ranged between 0.5 and 1.6 degrees F above normal. The author [50] concluded that either a feverinducing zinc and protein combination had formed, or that proteins of the respiratory tract were altered by zinc oxide and became pyrogenic.

In 1960, Pernis et al [51] criticized existing hypotheses regarding the mechanism of zinc metal fume fever and suggested an alternative formation of endogenous pyrogens. Rabbits exposed first to acetic acid and then to zinc oxide fumes were tested for cross-tolerance between metal fumes and endotoxins. Tolerance to endotoxin did not extend to the pyrogenic effect of zinc oxide fumes. They [51] concluded that these results contradicted the suggestion of Kuh et al [27] that metal fume fever was due to endotoxins from bacteria present in the respiratory tract. Pernis et al [51] drew attention to the infiltration of polymorphonuclear leukocytes noted in the lungs of guinea pigs by Turner and Thompson [45] and in cats by Drinker and Drinker [48] in 1928 and noted that conditions existed in the lungs of the experimental animals which permitted contact between leukocytes and zinc oxide particles, perhaps resulting in the release of endogenous pyrogen, thereby causing metal fume fever.

Mogilevskaya [31] in 1959 reported the intratracheal administration to rats of a 1-ml suspension containing 50 mg of zinc oxide powder in sterile physiological solution. All animals survived and no untoward effects were noted. Some of the rats were killed 8 months after the administration of the powder and others after 12 months. Microscopic changes observed in the lungs included hyperplasia and sclerosis of lymphatic follicles, deformations of the bronchi, and occasional peribronchial pneumonia. The changes observed were distinct from those associated with other types of metal dust. Specifically, there was no observation of a nodular process, of diffused sclerosis, or of acute toxic action. Pathological changes due to zinc dust were also observed in the upper respiratory tracts of the animals. [31]

Dzukaev and Kochetkova [32] in 1970 administered zinc oxide in sodium chloride solution intratracheally to 38 rabbits at a dose of about 40-80 mg/kg of body weight. Changes were observed in the lungs of the animals, but the zinc solution contained as much as 15% lead, which raises a question concerning their conclusion that the observed changes were due to the zinc oxide.

A review of the literature by Stilinovic and Grubisic [30] in 1970 led these authors to the conclusion that the mechanism of zinc fever onset was still one of speculation.

(b) Ingestion

Turner and Thompson [45] fed guinea pigs daily doses of a zinc oxide suspension in pure olive oil. The total dose over a 12- to 15-day period varied from 600 mg to 80 g/animal. Eight of 16 animals died between the 2nd and the 11th day after ingestion of the mixture. Pulse rates were increased and respiratory rates in some animals were slower than normal. In sick animals respiration was faster than normal and temperatures lower than normal. At necropsy, animals' lungs were found to be congested. Fatty infiltration and parenchymatous degeneration were observed in the livers and kidneys. Control animals fed olive oil alone or zinc oxide in chopped carrots did not exhibit these changes. The authors concluded that zinc oxide, in itself, was probably innocuous when ingested, and that the fatalities resulting from the ingestion of the zinc oxide-olive oil mixture were due to either mechanical disturbances to the digestive system or to a toxic compound formed from the combination of the 2 substances.

In 1927, Drinker et al [52] conducted long-term feeding experiments with cats and dogs to determine the effects of ingested zinc oxide. The animals received zinc oxide daily in the form of dry powder mixed with the food. The doses were administered daily for 35-53 weeks, ranged from 175 mg to 1 g for the cats and 500 mg to 1 g for the dogs. The authors found no "significant clinical symptom nor obtained any significant laboratory evidence of damage" in the animals. Zinc was excreted mainly in feces. The same authors [52] reported another study in which cats and dogs were fed zinc oxide in food. Three cats receiving high doses showed a weight loss and loss of appetite, which the authors attributed to the disagreeably sweetish taste of the oxide-containing food. Zinc concentrations did not increase in fat, brain, spinal cord, heart, muscle, spleen, thyroid gland, or blood. Zinc increased in the liver, the gall bladder, the gastrointestinal tract, and the kidneys. Fibrous changes were observed in the pancreas of 3 cats given high doses. There was no other clinical or laboratory evidence of damage.

Sadasivan [53] fed rats supplemental pure zinc oxide at levels of 0.5 and 1.0%, both with a stock diet and with a high-fat, low-protein diet. He observed reduction in the weight and fat content of the rat livers. Greater reduction with rats on the high fat diet suggested lipotropic activity of the zinc. At the 1% level, zinc oxide caused a lowered food intake. There was evidence that bone development and mineralization were adversely affected by zinc. This was evident by reduced dry weight and ash content of the bones.

Further experiments by Sadasivan [54] showed that urinary and fecal nitrogen excretion were increased in rats given zinc oxide supplements.

Urinary excretion of phosphorus and sulfur decreased, but fecal excretion of phosphorus and sulfur increased. Urinary excretions of uric acid and creatinine increased with the zinc-supplemented diet.

Grant-Frost and Underwood [55] conducted studies on the interaction between dietary zinc oxide supplements and copper in rats. Rats receiving 0.5% zinc as zinc oxide showed markedly reduced growth, food consumption, hemoglobin levels, copper retention, and body fat. These factorially designed experiments suggested to the authors that the effect of zinc on growth was due to reduced food consumption. Zinc appeared to reduce the copper concentrations in blood and tissues and may have antagonized absorbed copper at the cellular level, according to the authors, [55] who also concluded that the anemia was caused by a zinc-induced copper deficiency.

Witham [56] fed rats a basal diet with 0.4% zinc as zinc oxide and fed controls the basal diet alone. Assays of the homogenized livers from animals killed at 6 weeks showed reduction in the cytochrome oxidase activity in treated animals. The author presented evidence to support the view that this is due to zinc-induced copper deficiency.

(c) Injection

To further test the hypothesis of Lehmann [10] that metal fume fever might have resulted from absorbed lung proteins, Turner and Thompson [45] injected lung extracts from healthy animals, with and without zinc oxide, and extracts of lung from animals exposed to zinc oxide into healthy unexposed animals. The temperatures and pulses of animals given lung extract from healthy unexposed animals were affected in much the same way as temperatures and pulses of animals exposed to zinc oxide fume had been.

Addition of zinc oxide to the lung extract and use of extract from lungs of animals exposed to zinc oxide did not evoke additional effects.

Correlation of Exposure and Effect

The most commonly described and best documented effect of exposure to freshly formed zinc oxide fume in man is the syndrome of metal fume fever.

The first measured exposure to zinc oxide fume recorded is that reported by Lehmann in 1910. [10] Lehmann subjected himself and 3 colleagues to an experimental atmosphere containing from 100 to 400 mg ZnO/cu m of air, and all 4 subjects developed metal fume fever.

Batchelor et al [34] studied the maximum and minimum airborne zinc oxide dust levels in the workplaces of 24 men, out of a total work force of 1,620. The 3 most heavily exposed men were reported never to have had "zinc chills" because 2 of them in fact were exposed to metallic zinc dust in the 6.2-130 mg/cu m range and the 3rd was exposed (16.6-58 mg/cu m as zinc) to highly aggregated "old" zinc oxide, of presumably large particle size. Nine of the 24 men observed were stated to have had the "shakes" within the first few days of their exposure to the suspended oxide. Three of the 9 experienced a recurrence of "shakes" once or twice after the first week or two of employment. Only 1 man in the series remained away from work because of metal fume fever.

The report by Hammond [46] on the incidence of metal fume fever during the overhaul of stone crushers involving the use of zinc and zinc alloys as a binder and filler established 2 basic ranges of zinc oxide fume exposure. At airborne levels of 8-12 mg/cu m of zinc oxide no cases of zinc fume fever were recorded. At airborne levels of 400-870 mg/cu m of zinc oxide and duration of exposure ranging from 1 to 3 hours, all of the unstated number of exposed workers were said to have had zinc fume fever at one time or another following such exposures. The metal fume contained, besides zinc, 12.4 mg/cu m of manganese and 1.6 mg/cu m of lead. It is difficult to say what role, if any, the manganese and lead fumes might have played in causing the reported symptoms.

The human experimental reports of Sturgis, [5] Drinker, [33] and their colleagues in 1927 offered data on small numbers of subjects. Sturgis et al [5] produced metal fume fever in 2 male adult volunteers by exposing them at a measured average concentration of 600 mg/cu m of high purity, freshly generated zinc oxide fume, 1 for 10 1/2 minutes and the other for 12 minutes. Based on the different rates of respiration of the subjects, it was calculated that one must have retained about 24 mg and the other 37 mg of zinc. Typical febrile reaction occurred followed by marked leukocytosis which persisted for 12 hours after the body temperature returned to normal.

Drinker et al [33] investigated the exposure of a technician in a brass foundry at an average concentration of zinc oxide fume of 52 mg/cu m measured as zinc, for 5 hours. This exposure resulted in an attack of metal fume fever the following night. The next day the same individual was exposed at an average of 330 mg as Zn/cu m for about 3 hours. He experienced no ill effects on the 2nd day, supporting the theory of short-term tolerance or relative immunity to zinc fume fever.

Drinker et al [29] also reported a rise in temperature in 2 volunteers exposed to finely ground zinc oxide powder (0.15 μm particle size) dispersed in air as a stable cloud. The concentration so achieved was however not reported. This paper suggests that zinc oxide does not have to be generated from zinc metal fume to produce metal fume fever.

Drinker et al [6] conducted 27 experimental exposures on 7 male and 3 female volunteers, varying the concentration of the freshly generated zinc oxide fume, durations of exposure, respiration rates, and minute volumes. Using rise in body temperature of the subjects as the critical response, they constructed a dose-response slope. They proposed a threshold limit of 15 mg/cu m ZnO for an 8-hour exposure.

There are few animal studies reported which contribute to the correlation of exposure and effect in quantitative terms. Turner and Thompson [45] in 1926 reported exposures of guinea pigs for 1 hour to zinc oxide concentrations ranging from 1,000 to 2,600 mg/cu m. The animals exhibited "air hunger" and labored breathing. Their body temperatures were depressed below normal for the first 3-4 hours after exposure, but the animals then became febrile, reaching a peak after 16 hours.

Drinker and Drinker [48] in 1928 conducted experiments in which cats, rats, and rabbits were exposed from 15 minutes to 3 1/4 hours at levels of zinc oxide fume ranging from 110 to 600 mg/cu m. These animals showed prolonged depression of body temperature, but no subsequent rise above normal. The degree and duration of the temperature depression depended on the species of the animal and on the severity and duration of exposure.

Several investigators [35-38] have attributed gastrointestinal effects to zinc oxide at unknown levels of exposure. However these reports have not been substantiated by later studies. [34,41,57] In particular, a study by Natvig [57] in 1937 of 100 workers with a history of repeated attacks of metal fume fever found no evidence of gastrointestinal diseases.

IV. ENVIRONMENTAL DATA

Environmental Concentrations

Pegues [58] conducted a series of samplings to demonstrate ventilation on welding operations. The tests were performed in large buildings described as having excellent ventilation "which was probably much better than in most welding shops." To ascertain the influence of ventilation, some tests were conducted in an enclosure, 6 feet by 10 feet, made of a tarpaulin 6 feet wide, and open at the top. In this enclosure both electric arc and oxyacetylene welding were performed on steel with either zinc silicate or galvanized coatings. Samples were collected at various distances from the welding operation, generally 2-3 feet away. During electric welding on zinc silicate coated steel, 5 samples had amounts of zinc equivalent to zinc oxide concentrations ranging from 64.0 to 199.0 mg/cu m, with an average of 120.0 mg/cu m. Seven samples of oxyacetylene welding on the same steel showed zinc oxide concentrations between 17.0 and 46.0 mg/cu m, and an average of 27.0 mg/cu m. Four samples collected during the welding of galvanized steel with the electric arc showed zinc oxide concentrations between 31.0 and 185.0 mg/cu m, with an average of 109.0 mg/cu m, while oxyacetylene welding on galvanized steel produced a range of 30.0-107.0 mg/cu m in 5 samples, with an average of 64.0 mg/cu m. However, without the enclosure, 4 breathing zone samples employing both materials and both types of welding showed concentrations between 7.0 and 20.0 mg/cu m. Nevertheless, 8 room air samples 3 feet and 20 feet downwind from the welder produced concentrations of zinc oxide ranging from 5.0 to 31.0 mg/cu m, and 3 outdoor samples were reported to have between 2.0 and 13.0 mg/cu m. Results of individual samples are shown in Tables X-3, X-4, X-5, and X-6.

Studies by Boekholt [59] demonstrated the effect of exposures from the use of local exhaust ventilation in enclosed spaces. Air samples collected during ship construction in Holland showed comparatively low concentrations of zinc oxide. In these investigations, welding was being done on steel plates coated with a zinc dust paint 20 µm thick in tanks having a depth of about 16 meters, with ventilation accomplished by flexible exhaust tubes placed close to the cloud of welding fume. Samples in the welders' breathing zone showed concentrations of 10 and 11 mg/cu m. Results in welding bays were also reported to show concentrations in the breathing zone of 5-13 mg/cu m. Results of individual samples are shown in Tables X-7 and X-8. The effectiveness of local exhaust ventilation is dependent on how close to the welding operation the exhaust tube opening can be placed, as well as on the volume and velocity of the air exhausted.

Stalker [60] studied lead and zinc fume hazards in 4 brass foundries, but presented little data on zinc concentrations, stating only that levels in excess of 15 mg/cu m were found in just 1 of the foundries. In that instance, however, he found an average of 182 mg/cu m for melting operations.

Elkins, [61] summarizing findings of investigations in Massachusetts covering more than 18 years starting in 1937, gave data listed in Table IV-I for zinc concentrations associated with selected operations. The years when the measurements were taken were not stated, however, the limit used in Massachusetts during the entire period was 15 mg/cu m.

TABLE IV-1

ZINC CONCENTRATIONS IN SELECTED OPERATIONS

Operation	No. of Samples	No. of Hazardous Concentrations
Galvanizing	8	0
Metal melting	12	4
Metal pouring	66	29
Welding	7	1

Steel and Sanderson, [62] investigating toxic fumes produced from various types of coated welding electrodes, found zinc oxide concentrations produced by burning such electrodes to range from 1.07 to 2.76 mg/cu m. While such concentrations were not considered high, if such coated welding electrodes were used, these concentrations would be added to the existing zinc oxide concentration released when welding any zinc coated metals.

Environmental Sampling and Analytical Methods

Common techniques for collecting particulate matter have been used successfully for sampling fumes and dust containing zinc. While the electrostatic precipitator is quite efficient, [63] filtration is recommended here, both because of its greater simplicity and because it lends itself to breathing zone sampling. Likewise, membrane filters are preferable to paper filters for personal monitoring by the procedure given in Appendix I. [64] A mixed cellulose ester membrane filter (or equivalent) with a pore size of 0.8 μm provides a highly retentive matrix for particulates and is recommended as an efficient collector of particles encountered in freshly formed zinc oxide fume. The cellulose ester membrane filter is attached to the battery operated personal sampling pump worn by the worker, permitting sampling without interference to the worker.

Chemical methods for the analysis of zinc content of samples have been thoroughly studied and extensively used for many years, and though relatively slow, they are satisfactory. [2,49,61,65-83] The methods most generally used employ dithizone separations. Margerum and Santacana [66] tested 8 methods, [67,70-73,78,79,84] employing radiozinc to aid in determining efficiencies, and recommended a dithizone method using bis(2-hydroxyethyl)dithiocarbamate (also called diethanol dithiocarbamate) as a complexing agent, as proposed by Serfass and Levine. [84] Very satisfactory results were obtained even in the presence of substantial amounts of 10 other metals as impurities--Cd, Co, Cu, Hg, Ni, Fe, Pb, Mn, Cr, and Sn.

Instrumental methods have also been used for the determination of zinc. These have included X-ray spectroscopy, [85] polarography, [86] and atomic absorption. [86,87] Because of speed and accuracy the atomic absorption method is replacing the dithizone method. [87] Appendix II presents details for a recommended atomic absorption method. This is based on Method No. 173 of the Physical and Chemical Analysis Branch of NIOSH. [88]

Control of Exposure

Since the principal hazard of zinc oxide is its fume, control efforts are directed primarily against the operation or processes in which zinc is subjected to elevated temperatures. Included in these process galvanizing, brass foundry operations, and welding. In each of these, effective control usually depends upon suitably designed and properly utilized local exhaust ventilation. [89,90] In welding and similar operations, the nature of the work may require the employee to change the location of his work frequently. Under such circumstances the exhaust system must accompany him. This may require the use of flexible exhaust ducts or other arrangements which enable the hood or the duct opening to be placed at the most effective location, preferably within a few inches of the flame or arc.

In foundry operations, careful design and location of exhaust hoods are required to control fumes from furnaces without interfering with operations. Unless centralized pouring is used, there is likewise a need for a flexible exhaust system which can accompany the pouring.

Since galvanizing is usually performed at a fixed location, the operations lend themselves to standard exhaust ventilation principles and practices. [89,90]

In some instances, general ventilation may prove sufficient to keep fume concentrations within the limits specified in the standard. Reliance should not be placed upon the natural ventilation, however, unless tests under conditions of minimal ventilation have conclusively demonstrated that the standards are met.

Where exhaust ventilation is required, the design principles presented in the 1974 edition of Industrial Ventilation - A Manual of Recommended Practice [89] or subsequent editions and in Fundamentals Governing the Design and Operation of Local Exhaust Systems, Z9.2-1971 (ANSI), [90] should be used.

Where dust problems may arise from production, processing, packaging, or other handling of zinc oxide, conventional ventilation, enclosure, and housekeeping procedures should usually suffice for adequate control.

V. DEVELOPMENT OF STANDARD

Basis for Previous Standards

Cook, [91] in his comprehensive listing of Maximum Allowable Concentrations of Industrial Atmospheric Contaminants published in 1945, cited 15 mg Zn/cu m as the Maximum Allowable Concentration (MAC) for zinc oxide then used by California, Massachusetts, New York, Utah, and the United States Public Health Service. As the basis for this MAC, Cook cited Drinker et al [6] as having found that 14 mg/cu m of zinc oxide, measured as zinc, produced no reaction on the average subject after an exposure of 8 hours. Drinker et al [6] did not specifically define "average," but apparently referred to a healthy adult of either sex, "breathing at an average rate of 9 liters a minute." They recommended a concentration of 15 mg/cu m as the threshold limit.

The paper by Drinker et al, [6] cited by Cook, [91] did not state clearly how the 15 mg/cu m was derived. It seems that it was not based on the dose-response slope calculated by Drinker. [6] Drinker referred to the work by Batchelor et al [34] but examination of the Batchelor paper does not reveal any specific statement regarding absence of effects at concentrations of zinc oxide below 14 or 15 mg/cu m. Sampling in industrial environments as described by Batchelor et al [34] led to a generalization by Drinker et al [6] that metal fume fever was not observed at levels below 14 mg/cu m. This was apparently the basis for the 15 mg/cu m standard.

In 1946, the American Conference of Governmental Industrial Hygienists (ACGIH) published their first list of MAC's in which they endorsed the value of 15 mg/cu m for "zinc oxide fume." [92] The ACGIH MAC recommendation for zinc oxide fume, though the terminology eventually changed to Threshold Limit Value (TLV), remained at 15 mg/cu m until 1962 when it was revised downward to 5 mg/cu m. This figure has remained unchanged since. [93] The basis for this reduction to 5 mg ZnO/cu m, according to the ACGIH Documentation of the Threshold Limit Values, [94] was the industrial observation that zinc chills (metal fume fever) occurred in nonferrous foundries where concentrations of zinc fume rarely exceeded 15 mg/cu m. In addition, according to DE Hickish (in a written communication in 1963 to the TLV committee), metal fume fever was observed in an oxyacetylene welder who had been working on galvanized steel where very limited air sampling had subsequently indicated concentrations of 3.0-4.2 mg/cu m of zinc oxide. A question remained, however, as to whether the measurements were representative of the exposure of the welder.

The present federal standard for zinc oxide fume is an 8-hour time-weighted average of 5 mg ZnO/cu m (29 CFR 1910.1000). This standard of 5 mg ZnO/cu m is based on the ACGIH TLV originally established in 1962. [93]

Basis for Recommended Environmental Standard

Industrial exposure to zinc oxide fume by inhalation has been shown to cause metal fume fever. [8,9,12,14,46] Reports in earlier papers of prolonged or intermittent exposure to zinc oxide fume causing gastro-intestinal disturbances and other, chronic effects [35-37] have largely been discounted. [34,41,57] The reported medical data were insufficient and environmental data were either incomplete or of doubtful validity.

A report of skin lesions from frequent and prolonged coverage of the skin with zinc oxide powder [44] concluded that the material was an irritant but nontoxic. The lesions were found to be caused by bacterial infection and daily washing and improved personal cleanliness were sufficient to eliminate the disorder.

Drinker et al [6,29] published data which suggested that metal fume fever may also have been caused by well dispersed clouds of zinc oxide powder. Mogilevskaya [31] described clinical changes in the lungs of 13 of 19 workers engaged for 2-3 years in the manufacture of zinc powder, as well as similar changes in the lungs of experimental rats exposed to zinc oxide powder. The changes included inflammation of the upper respiratory tract (nasopharyngitis and laryngitis) in the workers and peribronchial pneumonia, sclerosis, and abnormal bronchial tissue in the rats. The author [31] concluded that zinc oxide powder and zinc powder caused changes in the upper respiratory tract and in the bronchi and peribronchial tissues. Dzukaev and Kochetkova [32] observed fibrous changes in the lungs of workers in a zinc oxide shop and demonstrated clinical changes in the lungs of rabbits. The data were difficult to interpret since the rabbits were also exposed to lead.

The lack of environmental data on zinc oxide fume could be due to the lack of interest in the metal fume fever syndrome because of its transitory nature. Experienced workers cope with the problem and usually do not bother to report it. [34] Most of the animal studies have been directed toward the elucidation of the mechanism or pathogenesis of metal fume fever. [45,50,51]

In 1944, Hammond [46] reported the incidence of metal fume fever in stone crusher repairmen who, with oxyacetylene torches, cut out the worn linings of steel crushers in which zinc and zinc alloys were used as binders and fillers. These workers were exposed for periods of 1-3 hours to zinc oxide fume (as zinc) at 320-545 mg Zn/cu m. Eventually all these men experienced metal fume fever. There were concomitant exposures to approximately 12.4 mg/cu m of manganese fume and to 1.6 mg/cu m of lead fume. In contrast, men employed in pouring molten zinc into the crushers for unspecified periods of time were exposed at concentrations of zinc oxide fume of 8-12 mg Zn/cu m, and were never recorded as suffering metal fume fever following such work.

Having produced classical metal fume fever in volunteer subjects after 10 1/2-12 minutes' exposure at 600 mg/cu m of high purity, freshly generated zinc oxide fume, [5] and having observed metal fume fever in a colleague who had been exposed at an average of 52 mg/cu m for about 5 hours, Drinker et al [6] conducted an elaborate series of experiments to determine the threshold for zinc oxide fume-induced metal fume fever. Twenty-seven experimental exposures of 10 volunteers, 7 males and 3 females, were conducted at various concentrations, durations of exposure, respiration rates, and minute volumes. A dose-response slope was constructed using a rise in body temperature as the endpoint. A threshold value of 15 mg/cu m was selected by the authors who stated "We use a concentration of 15 mg per cubic meter as the threshold limit, because we have found that men exposed for eight hours to concentrations of that order do not ordinarily acquire fever." The earlier study by Batchelor et al [34] was used in support of this statement. However, the available data fail to support a threshold limit of 15 mg/cu m. Batchelor et al reported that a concentration of 57-70 mg/cu m of very finely divided zinc oxide powder inhaled slowly and deeply for 15 minutes or more was close to the threshold for metal fume fever. [34] The recommendation of Drinker and his colleagues [6] of 15 mg/cu m as a threshold limit value was widely accepted until 1962. [93]

The basis for including zinc oxide dust comes from animal [31,32,45] and human [45,95] experimental data which indicated that symptoms of metal fume fever resulted from exposure to zinc oxide dust. Batchelor et al [34] found that an individual unaccustomed to zinc, breathing zinc oxide dust slowly and deeply at concentrations of approximately 57-70 mg/cu m for 15 minutes or more, developed a low grade metal fume fever reaction. Respiratory effects in humans and animals from zinc oxide powder consisted of pneumonia, sclerosis of bronchial tissue, and atrophic mucosal changes of the upper respiratory tract, thus suggesting chronic toxicity from zinc oxide powder. [31,32] However, the reported findings are clouded by a lack of quantitative data and the possibility of simultaneous human occupational exposures to substances other than zinc oxide. Turner and Thompson [45] reported histories of "oxide chills" in 7 out of 9 men employed in a zinc oxide packing room. The symptoms described by the workers consisted of irritation and dryness of the nose and throat and frequent headaches. The incidence of zinc oxide-induced metal fume fever seems strongly dependent on particle size with thresholds having been described for zinc oxide powder in the vicinity of 60 mg/cu m, and for oxidized zinc fumes encountered in welding operations on the order of 15 mg/cu m. Suggestions of cases of metal fume fever in the range of 5 mg/cu m are unsupported by firm data.

Although the effects of zinc fume fever are transitory, the possibility of chronic respiratory effects resulting from zinc oxide inhalation, whether as a fume or in larger particulate form, cannot be dismissed. It is appropriate to retain the current federal standard of 5 mg/cu m, as a time-weighted average, and to recommend a ceiling of 15 mg/cu m, as determined by a sampling time of 15 minutes, to prevent the incidence of metal fume fever associated with zinc oxide inhalation and the possible development of pathological tissue changes in the lungs.

The sampling and analytical methods presented in Appendices I and II are based on Method Number 173 of the NIOSH Manual of Analytical Methods. The analytical method as developed is not specific for zinc oxide but measures total zinc. It is recognized that analysis for total zinc is not the most desirable approach and that additional research is needed to develop a method which is specific for zinc oxide. NIOSH is currently developing a sampling and analytical method to distinguish zinc oxide from total zinc.

From the work of Drinker et al, [6,8,29] the respirable fraction of suspended zinc oxide particles, 1 µm or less in size, seems to be responsible for metal fume fever. However there is not enough justification at this time to warrant a requirement for size-selective sampling.

It is recognized that many workers are exposed to small amounts of zinc oxide or are working in situations where, regardless of the amount generated, there is only negligible contact with the substance. Under these conditions, it should not be necessary to comply with many of the provisions of this recommended standard, which has been prepared primarily to protect worker health under more hazardous circumstances. Concern for worker health requires that protective measures be instituted below the enforceable limit to ensure that exposures stay below that limit. For these reasons, "exposure to zinc oxide" has been defined as exposure above half the TWA environmental limit, thereby delineating those working situations which do not require the expenditure of health resources for environmental and medical monitoring and associated recordkeeping. Half the environmental limit has been chosen on the basis of professional judgment rather than on quantitative data that delineate nonhazardous areas from areas in which a hazard may exist.

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VII. APPENDIX I

METHOD FOR SAMPLING ZINC OXIDE IN AIR

The sampling and analytical methods presented in Appendices I and II are based on those described in Method No. 173 of the Physical and Chemical Analysis Branch of NIOSH. [88]

Atmospheric Sampling

Breathing zone samples representative of the individual worker's exposure are collected. A description of sampling location and conditions, equipment used, time and rate of sampling, and any other pertinent information are recorded at the time of sample collection. Enough samples must be collected to permit calculation of a time-weighted average (TWA) exposure for every operation or location in which there is exposure to zinc oxide.

(a) Equipment

The sampling train consists of a membrane filter and a vacuum pump.

(1) Membrane filter: Samples of zinc oxide are collected in the breathing zone of the worker, using a sampler with a cellulose ester membrane filter. The filter is a 0.8 μm pore size mixed cellulose ester membrane mounted in a closed-face sampling cassette which can be attached to the worker near his breathing zone.

(2) Pump: A battery-operated pump, complete with clip for attachment to the worker's belt, capable of operation at 2 liters/min or less.

(b) Calibration

Since the accuracy of an analysis can be no greater than the accuracy of the volume of air which is measured, the accurate calibration of a sampling pump is essential to the correct interpretation of the volume indicated. The frequency of calibration is dependent on the use, care, and handling to which the pump is subjected. Pumps should also be recalibrated if they have been misused or if they have just been repaired or received from a manufacturer. If the pump receives hard usage, more frequent calibration may be necessary. Regardless of use, maintenance and calibration should be performed on a regular schedule and records of these kept.

Ordinarily, pumps should be calibrated in the laboratory both before they are used in the field and after they have been used to collect a large number of field samples. The accuracy of calibration is dependent on the type of instrument used as a reference. The choice of calibration instrument will depend largely upon where the calibration is to be performed. For laboratory testing, primary standards such as a spirometer or soapbubble meter are recommended, although other standard calibrating instruments such as a wet test meter or dry gas meter can be used. The actual setups will be similar for all instruments.

Instructions for calibration with the soapbubble meter follow. If another calibration device is selected, equivalent procedures should be used. The calibration setup for personal sampling pumps with a membrane filter is shown in Figure X-1. Since the flowrate given by a pump is dependent on the pressure drop of the sampling device, in this case a membrane filter, the pump must be calibrated while operating with a representative filter in line.

(1) The voltage of the pump battery is checked with a voltmeter to assure adequate voltage for calibration. The battery is charged if necessary.

(2) The sampling train is assembled as shown in Figure X-1.

(3) The pump is turned on and the inside of the soapbubble meter is moistened by immersing the buret in the soap solution and drawing bubbles up the inside until they are able to travel the entire buret length without bursting.

(4) The pump rotameter is adjusted to provide the desired flowrate.

(5) The water manometer is checked to ensure that the pressure drop across the sampling train does not exceed 13 inches of water at 1 liter/min or 2.5 inches of water at 200 ml/min.

(6) A soapbubble is started up the buret and the time it takes the bubble to move from one calibration mark to another is measured with a stopwatch.

(7) The procedure in (6) above is repeated at least twice, the results averaged, and the flowrate calculated by dividing the volume between the preselected marks by the time required for the soapbubble to traverse the distance.

(8) Corrections to the flowrate may be necessary if the pressure or temperature, when samples are collected, differs significantly from that when the calibration was performed. Flow rates may be calculated by using the following formula:

$$q \text{ actual} = q \text{ indicated} \cdot \sqrt{\frac{P(\text{calibrated})}{P(\text{actual})} \cdot \frac{T(\text{actual})}{T(\text{calibrated})}}$$

where = q = volumetric flowrate

T = absolute temperature (Kelvin or Rankine)

P = atmospheric pressure

(9) Use graph papers to record the air flow corrected to 25 C and 760 torr as the ordinate and the rotameter readings as the abscissa.

(10) Data for the calibration include the volume measured, elapsed time or number of strokes, pressure drop, air temperature, atmospheric pressure, serial number of the pump, date, and name of the person performing the calibration.

(c) Sampling Procedure

(1) Sampling is performed using a closed-face membrane filter cassette.

(2) The sampler shall be operated at a flowrate of 1 liter/min and samples taken for 15 minutes.

(3) The temperature and pressure of the atmosphere being sampled are measured and recorded.

(4) One membrane filter is treated in the same manner as the sample filters with the exception that no air is drawn through it. This filter serves as a blank.

(5) Immediately after sampling, personal filter samples should be sealed in individual plastic filter holders for shipment. The filters must not be loaded to the point where portions of the sample might be dislodged from the collecting filter during handling.

VIII. APPENDIX II

METHOD FOR ANALYSIS OF ZINC OXIDE IN AIR

The procedure is based on Method No. 173 of the NIOSH Manual of Analytical Methods. [88]

Principle of the Method

The sample, collected on a cellulose membrane filter, is ashed using nitric acid to destroy the organic matrix. The zinc is solubilized in an acidic solution maintaining a pH of 1. Samples, blanks, and standards are aspirated into the atomic absorption flame. A hollow cathode lamp for zinc provides the characteristic line. The absorption of this line by the ground state atoms in the flame is proportional to the Zn in the aspirated sample.

Range and Sensitivity

The optimum working range is 0.025-2 μg Zn/ml. This value can be extended to higher concentrations by dilution of the sample. The sensitivity is 0.025 μg Zn/ml. This value will vary somewhat depending upon the instrument used.

Interferences

None have been reported.

Precision and Accuracy

In general, this analytical method will provide a coefficient of variation of approximately 2% depending upon the instrument used. Data on accuracy of the method are not yet available.

Advantages and Disadvantages

The method is rapid because there is little sample preparation. It does not require a high degree of technical skill. It is not affected by the presence of other common metallic elements. However, since it measures total zinc, it is not capable of distinguishing various zinc compounds from each other.

Apparatus

Hollow cathode lamp for zinc.

Atomic absorption spectrophotometer, having a monochromator with a reciprocal linear dispersion of about 6.5 Angstroms/mm in the ultraviolet region, and equipped with a burner head for air-acetylene flame.

Oxidant: Air which has been filtered to remove water, oil, and other foreign substances.

Fuel: Acetylene, commercially available for atomic absorption use.

Pressure-reducing valves: A 2-gauge, 2-stage pressure reducing valve and appropriate hose connections are needed for each compressed gas tank used.

Glassware, borosilicate:

- 125-ml Phillips beakers with watchglass covers
- 15-ml graduated centrifuge tubes
- 10-ml and 100-ml volumetric flasks
- 125-ml polyethylene bottles
- Hotplates capable of reaching 400 C

Reagents

Doubly distilled or deionized water

Redistilled concentrated nitric acid

Distilled 1:1 hydrochloric acid

Aqueous stock standard containing 1000 μg zinc/ml (commercially available).

Procedure

(a) Cleaning of Equipment

Before use, glassware should be washed with a laboratory glassware detergent, rinsed with tap water, then 10% nitric acid, and finally rinsed with distilled water.

(b) Analysis of Samples

Samples are transferred to clean 125-ml Phillips beakers and several milliliters of concentrated nitric acid are added to each. Each beaker is covered with a watchglass and heated on a hotplate (140 C) in a fume hood until the sample chars or until a slightly yellow solution remains. Several additions of nitric acid may be needed to completely ash and destroy the organic material.

Once the ashing is complete as indicated by a whitish residue in the beaker and following several minutes on the high temperature hotplate (400 C), the residue is converted to the chloride form by 3 successive evaporations with 1:1 hydrochloric acid. The ash is then dissolved with 1:1 hydrochloric acid and quantitatively transferred to a 15-ml graduated centrifuge tube and brought up to volume with deionized water. Aliquots of this can be diluted if necessary or the volume can be reduced by evaporation to get the zinc concentration within the working range of the method.

The sample is then aspirated into an oxidizing air-acetylene flame. The analytical wavelength is 2139 Angstroms. The other operating parameters are set according to the instrument instructions from the manufacturer. When very low zinc concentrations are found in the sample, scale expansion can be used to increase instrument response.

Calibration and Standards

From the 1000 μg zinc/ml stock standard solution, prepare working standards to cover the range between 0.025 and 2 μg/ml. The standard solutions are made 0.3 N in hydrochloric acid and are stored in polyethylene bottles. The low concentration standards may deteriorate and should be made on the day to be used.

Aspirate the series of standards and record the percentage of absorption.

Prepare a calibration curve by plotting on linear graph paper the absorbance versus the concentration of each standard in μg/ml. It is advisable to run a set of standards both before and after a sample run to ensure that conditions have not changed.

Calculations

From the calibration curve, read the concentration in µg/ml in the analysis sample.

Blank values, if any, are subtracted from each sample.

The concentration of zinc in the original sample in µg/ml equals the µg/ml in the analysis sample times the dilution factor.

To obtain the concentration of zinc oxide in the original sample, multiply the concentration of zinc by 1.245.

IX. APPENDIX III

MATERIAL SAFETY DATA SHEET

The following items of information which are applicable to a specific product or material shall be provided in the appropriate block of the Material Safety Data Sheet (MSDS).

The product designation is inserted in the block in the upper left corner of the first page to facilitate filing and retrieval. Print in upper case letters in as large a type size as possible. It should be printed to read upright with the sheet turned sideways. The product designation is that name or code designation which appears on the label, or by which the product is sold or known by employees. The relative numerical hazard ratings and key statements are those given in Chapter V, Part B, of the NIOSH publication, An Identification System for Occupationally Hazardous Materials. The company identification may be printed in the upper right corner if desired.

(a) Section I. Product Identification

The manufacturer's name, address, and regular and emergency telephone numbers (including area code), are inserted in the appropriate blocks of Section I. The company listed should be a source of detailed backup information on the hazards of the material(s) covered by the MSDS. The listing of suppliers or wholesale distributors is discouraged. The trade names should be the product designation or common name associated with the material. The synonyms are those commonly used for the product, especially formal chemical nomenclature. Every known chemical designation or competitor's trade name need not be listed.

(b) Section II. Hazardous Ingredients

The "materials" listed in Section II shall be those substances which are part of the hazardous product covered by the MSDS and individually meet any of the criteria defining a hazardous material. Thus, one component of a multicomponent product might be listed because of its toxicity, another component because of its flammability, while a third component could be included both for its toxicity and its reactivity. Note that a MSDS for a single component product must have the name of the material repeated in this section to avoid giving the impression that there are no hazardous ingredients.

Chemical substances should be listed according to their complete name derived from a recognized system of nomenclature. Where possible, avoid using common names and general class names such as "aromatic amine," "safety solvent," or "aliphatic hydrocarbon" when the specific name is known.

The "%" may be 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 or maximum amount, ie, "10-40% vol" or "10% max wt" to avoid disclosure of trade secrets.

Toxic hazard data shall be stated in terms of concentration, mode of exposure or test, and animal used, ie, "100 mg/kg LD50-oral-rat," "25 mg/kg LD50-skin-rabbit," "75 ppm LC man," or "permissible exposure from 29 CFR 1910.1000," or if not available, from other sources of publications such as the American Conference of Governmental Industrial Hygienists or the American National Standards Institute, Inc. Flammable or reactive data could be flash point, shock sensitivity, or other brief data indicating nature of the hazard.

(c) Section III. Physical Data

The data in Section III should be for the total mixture and should include the boiling point and melting point in degrees Fahrenheit (Celsius in parentheses); vapor pressure, in millimeters of mercury (mm Hg); vapor density of gas or vapor (air = 1); solubility in water, in parts/hundred parts of water by weight; specific gravity (water = 1); percent volatiles (indicated if by weight or volume) at 70 degrees Fahrenheit (21.1 degrees Celsius); evaporation rate for liquids or sublimable solids, relative to butyl acetate; and appearance and odor. These data are useful for the control of toxic substances. Boiling point, vapor density, percent volatiles, vapor pressure, and evaporation are useful for designing proper ventilation equipment. This information is also useful for design and deployment of adequate fire and spill containment equipment. The appearance and odor may facilitate identification of substances stored in improperly marked containers, or when spilled.

(d) Section IV. Fire and Explosion Data

Section IV should contain complete fire and explosion data for the product, including flash point and autoignition temperature in degrees Fahrenheit (Celsius in parentheses); flammable limits, in percent by volume in air; suitable extinguishing media or materials; special firefighting procedures; and unusual fire and explosion hazard information. If the product presents no fire hazard, insert "NO FIRE HAZARD" on the line labeled "Extinguishing Media."

(e) Section V. Health Hazard Information

The "Health Hazard Data" should be a combined estimate of the hazard of the total product. This can be expressed as a TWA concentration, as a permissible exposure, or by some other indication of an acceptable standard. Other data are acceptable, such as lowest LD50 if multiple components are involved.

Under "Routes of Exposure," comments in each category should reflect the potential hazard from absorption by the route in question. Comments should indicate the severity of the effect and the basis for the statement if possible. The basis might be animal studies, analogy with similar products, or human experiences. Comments such as "yes" or "possible" are not helpful. Typical comments might be:

> Skin Contact--single short contact, no adverse effects likely; prolonged or repeated contact, mild irritation and possibly some blistering.
>
> Eye Contact--some pain and mild transient irritation; no corneal scarring.

"Emergency and First Aid Procedures" should be written in lay language and should primarily represent first aid treatment that could be provided by paramedical personnel or individuals trained in first aid.

Information in the "Notes to Physician" section should include any special medical information which would be of assistance to an attending physician including required or recommended preplacement and periodic medical examinations, diagnostic procedures, and medical management of overexposed workers.

(f) Section VI. Reactivity Data

The comments in Section VI relate to safe storage and handling of hazardous, unstable substances. It is particularly important to highlight instability or incompatibility to common substances or circumstances such as water, direct sunlight, steel or copper piping, acids, alkalies, etc. "Hazardous Decomposition Products" shall include those products released under fire conditions. It must also include dangerous products produced by aging, such as peroxides in the case of some ethers. Where applicable, shelf life should also be indicated.

(g) Section VII. Spill or Leak Procedures

Detailed procedures for cleanup and disposal should be listed with emphasis on precautions to be taken to protect workers assigned to cleanup detail. Specific neutralizing chemicals or procedures should be described in detail. Disposal methods should be explicit including proper labeling of containers holding residues and ultimate disposal methods such as "sanitary landfill," or "incineration." Warnings to comply with local, state, and federal anti-pollution ordinances are proper but not sufficient. Specific procedures shall be identified.

(h) Section VIII. Special Protection Information

Section VIII requires specific information. Statements such as "yes," "no," or "if necessary" are not informative. Ventilation requirements should be specific as to type and preferred methods. Respirators shall be specified as to type and NIOSH or US Bureau of Mines approval class, ie, "Supplied air," "Organic vapor canister," "Suitable for dusts not more toxic than lead," etc. Protective equipment must be specified as to type and materials of construction.

(i) Section IX. Special Precautions

"Precautionary Statements" shall consist of the label statements selected for use on the container or placard. Additional information on any aspect of safety or health not covered in other sections should be inserted in Section IX. The lower block can contain references to published guides or in-house procedures for handling and storage. Department of Transportation markings and classifications and other freight, handling, or storage requirements and environmental controls can be noted.

(j) Signature and Filing

Finally, the name and address of the responsible person who completed the MSDS and the date of completion are entered. This will facilitate correction of errors and identify a source of additional information.

The MSDS shall be filed in a location readily accessible to workers potentially exposed to the hazardous material. The MSDS can be used as a training aid and basis for discussion during safety meetings and training of new employees. It should assist management by directing attention to the need for specific control engineering, work practices, and protective measures to ensure safe handling and use of the material. It will aid the safety and health staff in planning a safe and healthful work environment and suggesting appropriate emergency procedures and sources of help in the event of harmful exposure of employees.

MATERIAL SAFETY DATA SHEET

I PRODUCT IDENTIFICATION

MANUFACTURER'S NAME	REGULAR TELEPHONE NO. EMERGENCY TELEPHONE NO.

ADDRESS

TRADE NAME

SYNONYMS

II HAZARDOUS INGREDIENTS

MATERIAL OR COMPONENT	%	HAZARD DATA

III PHYSICAL DATA

BOILING POINT, 760 MM HG		MELTING POINT
SPECIFIC GRAVITY (H_2O=1)		VAPOR PRESSURE
VAPOR DENSITY (AIR=1)		SOLUBILITY IN H_2O, % BY WT.
% VOLATILES BY VOL.		EVAPORATION RATE (BUTYL ACETATE=1)
APPEARANCE AND ODOR		

IV FIRE AND EXPLOSION DATA

FLASH POINT (TEST METHOD)		AUTOIGNITION TEMPERATURE	

FLAMMABLE LIMITS IN AIR, % BY VOL.	LOWER		UPPER	

EXTINGUISHING MEDIA	
SPECIAL FIRE FIGHTING PROCEDURES	
UNUSUAL FIRE AND EXPLOSION HAZARD	

V HEALTH HAZARD INFORMATION

HEALTH HAZARD DATA

ROUTES OF EXPOSURE

INHALATION

SKIN CONTACT

SKIN ABSORPTION

EYE CONTACT

INGESTION

EFFECTS OF OVEREXPOSURE

ACUTE OVEREXPOSURE

CHRONIC OVEREXPOSURE

EMERGENCY AND FIRST AID PROCEDURES

EYES:

SKIN:

INHALATION:

INGESTION:

NOTES TO PHYSICIAN

VI REACTIVITY DATA

CONDITIONS CONTRIBUTING TO INSTABILITY

INCOMPATIBILITY

HAZARDOUS DECOMPOSITION PRODUCTS

CONDITIONS CONTRIBUTING TO HAZARDOUS POLYMERIZATION

VII SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED

NEUTRALIZING CHEMICALS

WASTE DISPOSAL METHOD

VIII SPECIAL PROTECTION INFORMATION

VENTILATION REQUIREMENTS

SPECIFIC PERSONAL PROTECTIVE EQUIPMENT

RESPIRATORY (SPECIFY IN DETAIL)

EYE

GLOVES

OTHER CLOTHING AND EQUIPMENT

IX SPECIAL PRECAUTIONS

PRECAUTIONARY STATEMENTS

OTHER HANDLING AND STORAGE REQUIREMENTS

PREPARED BY:

ADDRESS:

DATE:

X. APPENDIX IV

TABLES AND FIGURE

TABLE X-1

CHEMICAL AND PHYSICAL PROPERTIES

Formula	ZnO
Formula weight	81.37
Specific gravity	5.606
Melting point	1975 C
Solubility	0.00016 g/100 ml water at 29 C; soluble in mineral acids, dilute acetic acid and ammonium chloride

Adapted from McMahon [1] and Weast [96]

TABLE X-2

POTENTIAL OCCUPATIONAL EXPOSURES TO ZINC AND ITS COMPOUNDS

Alloy makers
Arc welders, electric
Brass foundry workers
Braziers
Bronze foundry workers
Electric fuse makers
Electroplaters
Galvanizers
Gas welders
Junk metal refiners
Metal cutters
Metalizers
Metal sprayers
Paint manufacturers
Printing plate makers
Roofing makers
Shipyard workers
Zinc founders
Zinc smelters
Zinc workers

Derived from Gafafer [7]

TABLE X-3

SAMPLING IN AREAS OF POOR VENTILATION

Coating	Type Weld	Sampling Location	Concentration ZnO, mg/cu m
Zinc-silicate	Electric arc	2' directly above welding	159.9
"	"	2' above and 2 1/2' back	107.2
"	"	3' " " 2' "	68.9
"	"	3' " " 2' "	64.0
"	"	Welder's shoulder	199.44
			Mean 119.9
Zinc-silicate	Oxy-acetylene	1' above and 1' back	45.9
"	"	3' " " 2 1/2' "	22.8
"	"	3' " " 2 1/2' "	21.4
"	"	3' " " 2' "	18.0
"	"	3' " " 2' "	42.6
"	"	3' " " 2' "	19.9
"	"	3' " " 2' "	17.1
			Mean 26.81
Galv. Steel	Electric arc	2' above and 1' back	65.5
"	"	2' " welders' face	152.0
"	"	6' " floor and 5' in front of welder	31.5
"	"	Welder's shoulder	185.0
			Mean 108.5
Galv. Steel	Oxy-acetylene	2' above and 2' back	106.6
"	"	3' " " 2 1/2' "	33.0
"	"	2' " " 1' "	64.0
"	"	6' " " 5' "	30.0
"	"	3' " " 1' "	85.0
			Mean 63.72

From Pegues [58]

TABLE X-3 (continued)

SAMPLING IN AREAS OF POOR VENTILATION

Coating	Type Weld	Sampling Location	Concentration ZnO, mg/cu m
Clean Steel	Electric arc	2' above and 1' back (control sample)	14.9
"	"	20' from enclosure (Room air-control sample)	0
"	Oxy-acetylene	20' from enclosure (Room air-control sample)	1.3

From Pegues [58]

TABLE X-4

SAMPLING IN AREAS OF "GOOD" VENTILATION*

Coating	Type Weld	Sampling Location	Concentration ZnO, mg/cu m
Zinc silicate	Electric arc beading	Welder's hood	9.84
Zinc silicate	Electric arc welding	Welder's hood	19.81
Galv. steel	Electric arc welding	Near nose	6.63
Galv. steel	Oxyacetylene cutting	Welder's hood	12.28

*As qualified by Pegues

From Pegues [58]

TABLE X-5

ROOM AIR SAMPLES
ELECTRIC ARC WELDING ON ZINC-SILICATE COATING

Sampling Location		Concentration ZnO, mg/cu m	Average
3' downwind from welder	3' from floor	15.4	14.15
3' downwind from welder	3' from floor	12.9	
20' downwind from welder	3' from floor	4.9	5.86
20' downwind from welder	3' from floor	6.8	
20' downwind from welder	6' from floor	30.5	22.3
20' downwind from welder	6' from floor	14.1	

From Pegues [58]

TABLE X-6

OUTDOOR SAMPLES (10-MPH WIND)

Coating	Type Weld	Sampling Location	Concentration ZnO, mg/cu m
Zinc silicate	Electric Arc	Inserted in hood	4.22
Galv. steel	Electric Arc	Inserted in hood	13.24
Galv. steel	Oxyacetylene cutting	3" from welder's nose	2.40

From Pegues [58]

TABLE X-7

SAMPLES TAKEN IN TANKS VENTILATED BY FLEXIBLE EXHAUST TUBES TERMINATING NEAR CLOUD OF WELDING FUME

Sampling Conditions	Concentration ZnO, mg/cu m
Wing tank. Two welders. Bottom of tank near nose of welder	11
Blank determination in wing tank.* No welding	1
Ditto at height of 4m	3
Ditto at height of 9m	1
Ditto under deck head. Two welders. Near nose of welder	10
Duplicate of last condition	11

---

*Volume of wing tank was 1450 cu m

From Boekholt [59]

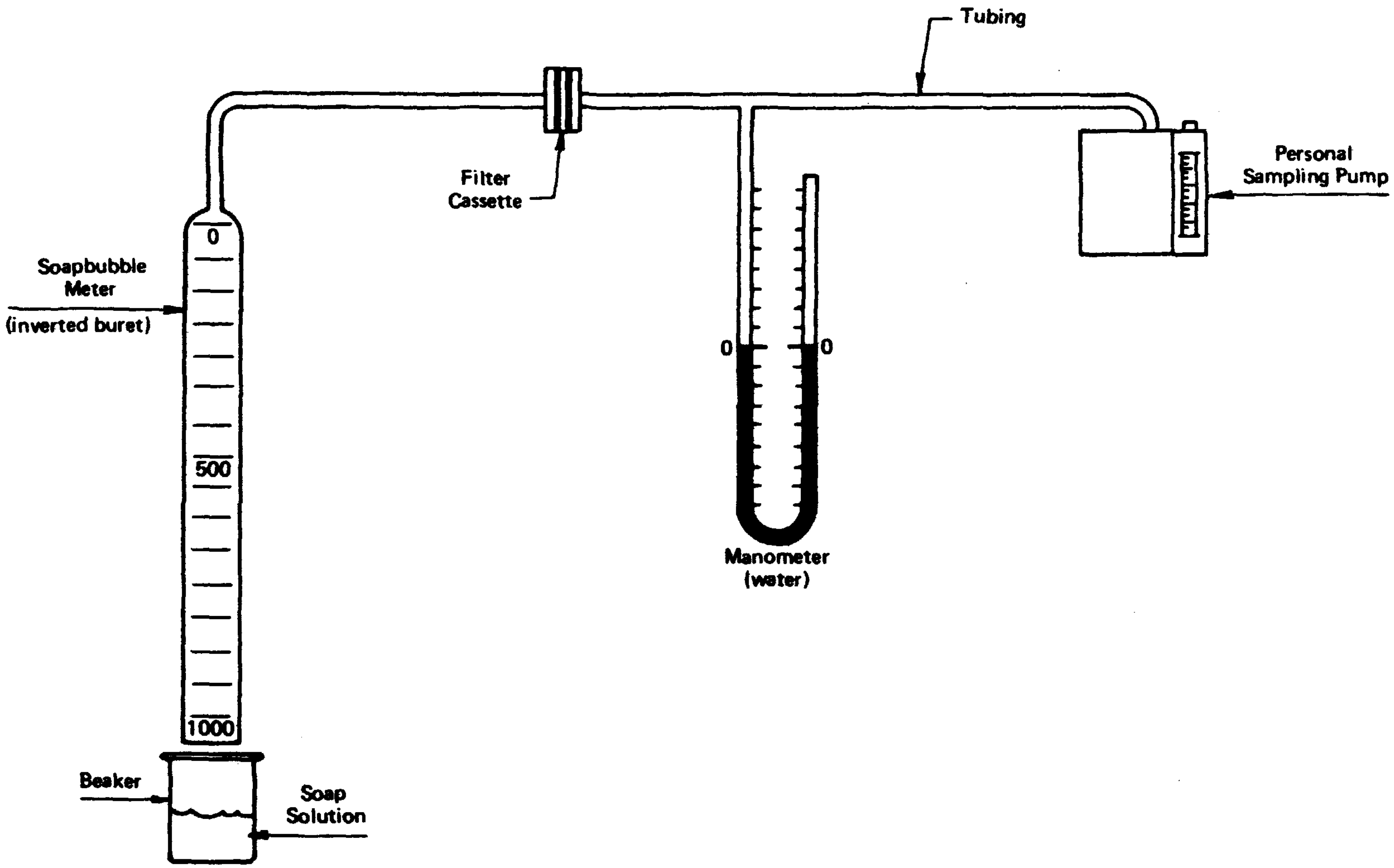
TABLE X-8

SAMPLES TAKEN FROM STEEL PLATES AND SECTION SHOPS WITH ZINC DUST PAINT 20 μm THICK

Sampling Conditions		Concentration ZnO, mg/cu m
Near welder's nose during manual welding		11
In cloud of welding fume		13
Near worker's nose during gas cutting at various locations,		
	automatic	5-10
	by hand	13
In workshop between units at man's height, blue smoke visible		2-4

From Boekholt [59]

FIGURE X - 1. CALIBRATION SETUP FOR PERSONAL SAMPLING PUMP WITH FILTER CASSETTE



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