IV. ENVIRONMENTAL DATA

Environmental Concentrations

Concentrations of airborne cadmium fume or dust in workplaces, as cited in the literature, are related mainly to reports of toxicity of cadmium. Ideally, such reports would give concentrations at worker breathing zones, averaged over the period of exposure. Size distribution, temporal variation, and chemical composition would be stated. In none of the reports are such ideal data presented. Samples obtained from fixed-position air sampling devices are more common than breathing zone samples. Many of the reports antedate the development of reliable personal samplers.

Particle sizes of freshly formed fume are ordinarily in the tenth-to hundredth-micrometer range. The workroom studies in which particle size has been estimated confirm this for cadmium fume. Neumann[238] reported that concentrations determined by electrostatic precipitator sampling were 65 times those determined by impinger sampling, typical of a particle size well under 0.5 μm. King[128] reported 91% by weight of a cadmium fume to be less than 0.5 μm.

Table XIV-2 shows some toxic effects in association with ranges of airborne cadmium concentrations. As the table shows, cadmium concentrations have ranged to very high levels.

Air Sampling

The most popular current method for taking air samples for cadmium is the use of cellulose ester membrane filters. Such filters having a nominal pore size of 0.8 μm will provide essentially complete collection for particulates in the size range of fume, less than 0.5 μm, or the larger particle sizes of dust.[239,240] If lower resistance to airflow is necessary, membrane filters with nominal pore sizes up to 5.0 μm may be used but possibly with some loss in efficiency. Other ashless filter papers may be used, but analytical filter papers such as Whatman 41 have efficiencies which vary greatly with face velocity, and microsorban is not as convenient or as readily available. Nuclepore filters are not sufficiently efficient at fume particle sizes,[241] and glass fiber filters, though otherwise useful,[242] cannot be digested by the recommended analytical procedure. Electrostatic precipitator samples are satisfactory for general air sampling, but inconvenient for breathing zone samples.

Size-frequency determinations of airborne cadmium may be useful in evaluating the degree of potential absorption. Several cascade impactors are available for air sampling which could be suitable for particle-size frequency determination if followed by a membrane filter.[243] Heavy stage deposits should be avoided to prevent reentrainment of deposited particles. An alternative for determination of particle size frequency over longer time periods is the multiple cyclone sampler.[244] Optical or electron microscope size-frequency determination is probably of little value at hygienic concentrations, because the cadmium dust or fume cannot be readily distinguished from other dust in polluted air. Light-scattering electronic particle counters are similarly nondiscriminatory.

Air sampling for worker exposure should be performed by personal sampling whenever possible. A personal sample can be taken for up to 8 hours on a worker by using a battery-operated, belt-worn pump connected by rubber or plastic tubing to a membrane filter holder. Any known flow rate between 0.5 and 3 liters/minute is satisfactory. To obtain TWA exposures, personal samples should be taken for a minimum of 2 hours. If sampling is conducted for less than a full work shift, all operations likely to generate cadmium dust, fume, or mist must be included within the sample period.

As an often less desirable alternative to personal sampling, "breathing zone" samples may be taken through a filter or precipitator tube held near the worker's face. If TWA concentrations are to be estimated, there should be at least 3 samples at the site of each task performed by the worker. The average concentration of airborne cadmium for each task is then multiplied by the number of hours the worker engages in that task; the concentration-time (Ct) products are added up and divided by the number of hours in the working day.[245] Alternatively, Ct products can be added and divided by total sampling time.

General air samples are often desirable to monitor effectiveness of control procedures. Such samples should be taken at specified locations so that control procedure effectiveness may be determined by before-and-after comparisons.

Chemical Analysis

Cadmium level is readily determined in an aqueous matrix by a variety of techniques. Analytical procedures include electrochemical,[246,247] spectrographic,[246] colorimetric,[246,248,249] and atomic absorption[110,242,250,251] techniques. These methods have been compared by Cholak and Hubbard[246] and by Matson et al.[252]

All of the methods noted above require that the sample be dissolved in an aqueous medium. This can be accomplished by a variety of techniques. Oxidizing acids, such as nitric acid,[246,248,249] perchloric acid,[252] or mixtures of acids,[250] have been used. Ashing in a muffle furnace may give variable results because of the volatility of cadmium and certain of its salts. Low temperature ashing has also been used.[242]

The colorimetric method using diphenylthiocarbazone (dithizone) has been employed.[246,248,249] The procedure described by Saltzman[249] uses a buffer system at high pH. This matrix maintains a homogeneous aqueous system prior to the extraction step. The reagents also mask the reaction between certain metals and dithizone.

Spectrographic techniques have been used extensively.[248] Air quality data have been compiled using this method of analysis.[13,242,253] This method has desirable attributes, particularly for analysis of several elements in a sample.

Electrochemical analysis using stripping techniques[252] provides greater sensitivity than some of the earlier techniques.

Atomic absorption spectroscopy has received wide acceptance. Homogeneous solutions with aspiration rates which can be matched with those of standards are readily analyzed at low concentrations. Interferences by both phosphate[110] and sodium chloride[1 (p 5),254] have been reported. It does not seem likely that these interferences will be significant in analyzing most samples of airborne cadmium, but, if they are significant, the samples can be treated as described in the discussion (see below) of analysis of blood and urine, where such interferences can be significant. The cadmium can be chelated and the chelate complex extracted in an organic solvent for analysis. The flexibility which atomic absorption analysis has for the analysis of a number of metals is a considerable advantage, because the preparation steps are similar. Trace metal analysis requires a highly skilled technician, regardless of the specific technique used. Meticulous cleanliness and attention to detail are needed to prevent loss or contamination.

A method is presented in Appendix II for the analysis of air samples. Atomic absorption spectroscopy is recommended because of the precision, accuracy, and sensitivity attainable; an additional advantage is the flexibility of analysis which this technique provides. This technique is used in several laboratories for the analysis of air samples.[242,251,255]

A similar procedure for the determination of cadmium in air was developed by the Physical and Chemical Analysis Branch of the National Institute for Occupational Safety and Health (NIOSH). The test of the NIOSH procedure included studies of the variation of hot-plate temperature, quantity and quality of nitric acid (57% increase in acid volume, acid not redistilled), loss of cadmium by prolonged heating or heating to dryness, the use of hydrochloric acid for achieving final working solutions, the use of a water blank, and the variation in band pass of the spectrophotometer. The standard deviation of 7 replicates was less than 3%. Two spectrophotometers gave similar results.

Lehnert et al[256] have described a method of analysis of blood and urine for cadmium by atomic absorption spectrophotometry after extraction by methyl isobutyl ketone of a chelate of cadmium and ammonium pyrrolidine dithiocarbamate. Wet ashing of 10 ml of serum or 50 ml of urine was accomplished with a solution of 10 ml of 65% nitric acid, 5 ml of 96% sulfuric acid, and 5 ml of 70% perchloric acid. Residues were dissolved in dilute hydrochloric acid and adjusted to pH 2.5. The chelate was formed by adding 2 ml of 5% aqueous ammonium pyrrolidine dithiocarbamate solution, and was extracted into 2 ml methyl isobutyl ketone. This organic phase was then analyzed by atomic absorption spectrophotometry. Under their conditions, they found detection limits of 12 ng Cd/100 ml of urine or 60 ng Cd/100 ml of serum, with a precision of 10% and mean recoveries of 96%. Using this method, Lehnert et al[120] found mean blood and urine concentrations of cadmium in 15 adults not exposed to cadmium in their work to be 0.33 μg Cd/100 ml of serum and 84 ng Cd/100 ml of urine, based on 24-hour urine samples. Berman [110] described a similar procedure for atomic absorption spectrophotometric analysis of blood and urine, except that blood proteins were first precipitated with trichloroacetic acid before the chelation and extraction. Imbus et al[121] used a modification of the spectrographic method of Cholak and Hubbard[246] to analyze blood and urine of about 150 workers, mostly from Cincinnati but also from other cities in the US, apparently not exposed in their work to cadmium or the other metals examined. Cadmium was removed from blood or urine samples by dithizone, then removed from the dithizone solution by 0.2 N hydrochloric acid. After evaporation to dryness, the material was dissolved in buffer and analyzed spectrographically. Mean blood concentrations were 0.85 μg/100 g, with 95% of the samples being less than 1.68 μg/100 g. Mean urine concentrations were 1.59 μg/liter, and 95% of the determinations were less than 4.13 μg/liter. The ranges were 0.34-5.35 μg Cd/100 g of blood and from less than 0.5 to 10.8 μg Cd/liter of urine. These concentrations are in the general range of those found by Lehnert et al[120] on German adults, viz, means of 0.33 μg/100 ml of blood and 0.84 μg/liter of urine.

Pulido et al[254] corrected for the absorbance of chloride ion at the cadmium 2,288 Angstrom line by using a uniformly shaped flame such as that produced by a ring burner and by a reduction in slit width. They also found they could correct for chloride interference by comparing absorbances from a continuous source such as a hydrogen lamp with that of the cadmium hollow cathode tube.

Matson et al[252] have reported that use of anodic stripping voltammetry gives results and precision similar to those of atomic absorption spectrophotometry, neutron activation, dithizone colorimetry, and emission spectrography for analysis of 1-500 ng quantities of blood, hair, or urine.

Recent developments in analysis of cadmium in food, urine, blood, tissues, water, and air have been reviewed by Friberg et al.[2 (pp 2-1 to 2-17)]

Procedures for the determination of urinary proteins are discussed in Appendix III.

Engineering Controls

In a striking instance of control, airborne cadmium concentrations were reduced by a factor of over 1,000 in vacuum metalizing.[257] Less striking reductions were observed in operations between metalizing cycles. A reduction by a factor of 10 in cadmium dust during battery manufacture was noted.[55] In both the examples cited above, conventional ventilation techniques were used for control. Control measures for powder-handling operations with both moderately toxic and very toxic materials, applicable as criteria in designing engineering controls for a number of cadmium- generating operations, are given in *Industrial Ventilation*.[258] Local exhaust ventilation should be provided at all operations as shown in this manual. Inasmuch as cadmium is more toxic than most of the other materials handled, enclosure should be maximized and the upper parts of ranges of air turnover rates should be used.

Air volumes tabulated for welding[258,259] are calculated for a control velocity of 100 feet/minute (fpm). For cadmium fume, control velocities of 150 fpm should be used, so that volumes 50% greater than the tabulated volumes should be used.

Local exhaust systems should be designed and operated in conformance with the American National Standard *Fundamentals Governing the Design and Operation of Local Exhaust Systems*, Z9.2-1971.[260]

Published designs for ventilation control[258] are illustrative of approaches which have been successful in certain applications. It should be emphasized that the recommendations on environmental limits are for performance. Any method of meeting these recommendations consistent with the health and safety of workers may be acceptable. In each case, success of control measures must be demonstrated by appropriate air sampling.

V. DEVELOPMENT OF STANDARD

Basis for Previous Standards

In 1941, the American Standards Association (now known as American National Standards Institute, Inc., or ANSI) recommended as an American Defense Emergency Standard an allowable concentration of 1 mg Cd/10 cu m (0.1 mg Cd/cu m) for cadmium and its compounds.[248] This was superseded in 1970 by ANSI Z37.5-1970,[261] which recommended a TWA concentration of 0.1 mg/cu m and a ceiling concentration of 0.3 mg/cu m for cadmium fume and a TWA concentration of 0.2 and a ceiling concentration of 0.6 mg/cu m for cadmium dusts as acceptable concentrations during an 8-hour workday. In the case of workdays longer than normal, the standard recommended that exposures not exceed Ct values (the product of concentration and time) of 50 mg-min/cu m for fume and 100 mg-min/cu m for dusts; this is approximately equivalent to maintaining the same TWA concentrations calculated for workdays greater than 8 hours. Although the report briefly reviewed cadmium toxicity, the specific basis for the acceptable concentrations was not stated.

This ANSI standard[261] is the basis for the present federal standard (29 CFR 1910.1000) of 0.1 (TWA) and 0.3 (ceiling) mg Cd/cu m for fume and of 0.2 (TWA) and 0.6 (ceiling) mg Cd/cu m for dust, published in the *Federal Register* 39:23543 (Table G-2), June 27, 1974 (with an erroneous listing of 3 instead of 0.3 mg/cu m as the ceiling for fume).

In 1946, the ACGIH recommended an MAC Value of 0.1 mg/cu m for cadmium, continuing it for several subsequent years but changing the name MAC Values to Threshold Limit Values (TLV's) in 1948 (these 1946-1949 MAC or TLV lists were unpublished but privately circulated). In 1956,[262] the TLV of 0.1 mg/cu m was assigned to CdO fume, rather than Cd. In 1965,[263] a tentative value of 0.2 mg/cu m for cadmium (metal dusts and soluble salts) was added, and changed to a recommended value in 1967.[264] More recently, the ACGIH recommended several changes in the TLV's of cadmium dusts and fumes. In 1970, the TLV of cadmium dusts and salts was continued at 0.2 mg/cu m as a TWA concentration but the TLV of fume was changed to 0.1 mg/cu m as a ceiling.[265] In 1973, the ACGIH announced its intent to change the TLV of fume to 0.05 mg/cu m, also as a ceiling.[266] In 1974, the intention to change the TLV of cadmium dusts and salts to 0.05 mg/cu m as a TWA concentration was announced. [267] In 1975, a note was added indicating that cadmium oxide production involved a carcinogenic or cocarcinogenic potential.[268] In a supplement[269] to the 1971 TLV documentation,[270] a review by Bonnell[271] and the report of Tsuchiya[63] were cited as reasons for a lowering of the TLV of cadmium fume to a ceiling concentration of 0.05 mg Cd/cu m. The basis for indicating that there is a carcinogenic or cocarcinogenic potential in cadmium oxide production was not stated.

According to Riihimaki,[3] the occupational health environmental limit of Finland was changed several years ago to 20 μg/cu m for cadmium dusts and 10 μg/cu m for cadmium fumes. He did not give the basis for these limits.

Sweden[272] has promulgated limit values of 0.05 mg Cd/cu m (total) and 0.02 mg Cd/cu m (respirable), as TWA concentrations for cadmium and its inorganic compounds. The basis was not stated, but a discussion by Friberg et al[1 (p 200)] suggests that these limits are based in part on the mathematical model discussed in Chapter III, *Correlation of Exposure and Effect.*

In a comparison of USSR and US hygienic standards, Roschin and Timofeevskaya[273] reported in 1975 that the USSR maximum permissible concentration (a ceiling value) for cadmium oxide was 0.1 mg/cu m, but they did not describe the basis for this limit value.

Many other countries have also adopted 0.1 mg/cu m as the permissible limit of cadmium or cadmium oxide. According to a 1970 report of the ILO/WHO,[274] these include Bulgaria, Czechoslovakia, Hungary, Japan, Poland, and Rumania.

Basis for the Recommended Environmental Standard

(a) Workplace Environmental Limits

In Chapter III (see *Correlation of Exposure and Effect*), various chronic effects of exposure to cadmium were discussed. Clearly demonstrated effects include anemia, kidney malfunction, and pulmonary changes including emphysema; less clearly demonstrated effects or effects with less evidence of relevance to a workplace environmental standard include effects on gonads, adrenals, pancreas, thyroid, and liver. Conflicting evidence of changes in liver function may be accounted for by differences in examination of liver function in the various studies or by the likelihood that liver function is adversely affected only at high exposure concentrations. Both possible explanations may be correct, so that effects on the liver may occur after sufficient exposure to cadmium.

Except for the study of Tsuchiya,[63] anemia has not been observed in workers except from exposure at high concentrations. Tsuchiya observed anemia in workers exposed at an average concentration of 125 μg/cu m. However, in a later study of workers in this same plant,[130] he commented that the anemia might have been due in part to nutritional deficiencies; in any case, it did not occur in workers whose exposure levels were reduced, eventually reaching 16-29 μg/cu m after engineering controls had been improved.

While it seems likely that the threshold for development of adverse effects on pulmonary function is higher than the threshold for adverse effects on kidney function, available data do not clearly establish this. Lauwerys et al[133] found reduced pulmonary function and proteinura in workers, all smokers, exposed to cadmium at concentrations of 66 μg/cu m, thought to represent past exposure also, for up to 40 years; some of these workers were also occasionally exposed to cadmium fume (most likely cadmium oxide fume). Only proteinuria was seen in workers exposed 1-12 years at 134 μg/cu m.

While these findings could reflect the longer period of time required for the development of emphysema, it was noted that there were decreases in pulmonary function measurements that were not statistically significant in the workers exposed at 134 μg/cu m. It seems that if emphysema were going to develop in these workers a reduction in pulmonary function should have become more evident. Tsuchiya[63] did not study pulmonary function (but he did not find abnormal chest X-rays), so his finding of proteinuria without emphysema may not support the argument that renal dysfunction occurs at lower concentrations than does pulmonary dysfunction. In view of the less than positive support for this inference on relative thresholds for renal and pulmonary dysfunction, medical examinations of cadmium workers should include studies of both kidney and lung functions (see later discussion of medical surveillance).

Workplace environmental limits of 40 μg Cd/cu m as a time-weighted average concentration and 200 μg Cd/cu m as a 15-minute ceiling concentration are recommended as part of the environmental standard.

Tsuchiya recommended a TWA limit of 50 μg/cu m in his 1967 report[63] but qualified his recommendation with the comment that this limit applied to Japanese workers and not necessarily to others. The nutritional status of these workers may have been a consideration in his qualification of the recommended limit. Lauwerys and coworkers[133] also recommended a workplace limit of 50 μg Cd/cu m, based on findings of no toxic effects in groups of workers exposed at 31 μg/cu m and of toxic effects in workers exposed at 66 μg/cu m or more. Their findings of proteinuria and reduced pulmonary function in workers exposed up to 40 years at 66 μg/cu m suggest that the recommended limit of 50 μg/cu m does not have a large margin of safety. Some of this work force was intermittently exposed to fume, presumably at higher concentrations, but this does not completely explain the effects at 66. Prior exposure concentrations may have been higher, but there is no direct evidence to support such a speculation. The authors commented that they were unsure of concentrations in prior years but had assumed that they were the same because no important process modifications had occurred; however, they considered lack of data on previous exposures to constitute a major uncertainty in their survey. It should be noted that Lauwerys and coworkers,[133] mindful of these considerations, recommended a limit of 50 μg/cu m.

Additional support for this TWA limit of 50 μg/cu m comes from another work population, in this same study of Lauwerys et al,[133] which had experienced no toxic effects at 31 μg/cu m, and from the report of Piscator et al[131] on workers exposed at below 100 μg/cu m, mostly at about 40 μg/cu m. One elderly woman in this latter group of workers had proteinuria, but she had also been found to have proteinuria some years earlier, when exposures were apparently higher. Other significant effects attributable to exposure to cadmium were not found; however, one control had renal disease resembling that induced by cadmium, probably the result of a bacterial infection. The entire population in this study was female, and, as was discussed in *Correlation of Exposure and Effect*, men and women appear not to differ in their susceptibility to cadmium.

However, because of the low margin of safety afforded by a limit of 50 μg/cu m suggested by the proteinuria in men exposed many years at a concentration believed to be about 66 μg/cu m, a more conservative limit of 40 μg/cu m is recommended. This limit offers a greater, and probably sufficient, margin of safety.

An important demonstration of the validity of a limit in the range of 30-60 μg/cu m comes from the two sets of findings of Tsuchiya.[63,130] Workers who had developed anemia and proteinuria at 125 μg/cu m improved when exposure concentrations were gradually reduced to 16-29 μg/cu m and new workers did not develop toxic effects (although, as mentioned earlier, improved nutrition may have obscured the pertinence of the observation of anemia).

Data on which to base a recommended ceiling concentration limit are more contradictory. Evidence of acute pulmonary disease at 2,500-2,900 mg-min/cu m, or about 5 mg/cu m for 8-hours' exposure, seems an appropriate basis for recommending limitation on excursions above the TWA concentration limit. However, other investigations have reported exposure levels up to 25 mg/cu m,[95] up to 24,[116] up to 19,[62] and up to 15,[55] without acute pulmonary disease. While it may be that workers were not exposed at such high concentrations more than briefly or that much of the airborne cadmium was nonrespirable dust, the apparent contradictions cannot be readily dismissed. On the other hand, one study[47,48] indicated the occurrence of acute intoxication from cadmium oxide fume at concentrations estimated to be in the range 10-140 μg Cd/cu m, for a cumulative exposure of almost 10 hours. The great range of concentrations found in this simulation of the accidental exposure makes interpretation of the exposure Ct (product of concentration and exposure time) difficult. In addition, the authors[47] suggested that other fumes (copper and zinc, probably as oxides) and fluoride gases (hydrogen fluoride and carbonyl fluoride) contributed to this poisoning, as well as to another fatal poisoning case they described. Until better and less contradictory information is developed, a ceiling concentration limit is proposed that is based in part on good practice, ie, realistic limitations on excursions, and in part on the belief that acute pulmonary disease, possibly with fatal consequences, can develop at around 2,500 mg-min/cu m.

A ceiling concentration limit of 200 μg Cd/cu m, based on sampling periods of 15 minutes, is recommended. Adherence to this limit would prevent excursions, as averaged over a 15-minute period, more than 5 times the recommended TWA concentration limit. Furthermore, it would limit brief exposures to about 1/100th of that Ct likely to cause serious acute disease, ie, 2,500 mg-min/cu m. If a ceiling limit of 200 μg/cu m on 15-minute sampling were enforced, it would be possible to expose workers for up to 2 hours/day, for 8 15-minute periods, at 200 μg/cu m if there were no exposure for the rest of the day (a concentration of 200 μg/cu m for 120 minutes would give a Ct of 24,000 μg-min/cu m, the same as the TWA concentration of 40 μg/cu m for 600 minutes). This Ct of 24,000 μg-min/cu m is almost 1/100th that of 2,500 mg-min/cu m or 2,500,000 μg-min/cu m.

In addition to these kidney and lung effects of cadmium exposure, there is reason for concern about teratogenic and carcinogenic effects. Experimental evidence of teratogenic effects of cadmium[95,170-178] was developed in rodents given high doses of cadmium compounds, but there is limited confirmation in a USSR study of children of female cadmium workers. Unfortunately, this report gives too few details to allow critical examination. These human fetal abnormalities were probably the result of retention of zinc by the mother from cadmium absorption, with the consequence that too little zinc was available for fetal development. This is supported by experimental evidence that injection of zinc salt into rodent dams at the time of or soon after injection of cadmium salt prevented the development of abnormalities.[177,178] Thus, reduction of cadmium exposure to a level that does not result in abnormal zinc requirements should allow sufficient zinc to the fetus for normal development. This point involves some unproved assumptions but has some additional support from an analogy with the role of zinc in renal injury (see *Correlation of Exposure and Effect*). Clearly, research on this point is needed.

Evidence of cadmium's ability to cause malignant or other tumors is contradictory. A small number of cases of prostatic cancer have been found among men working with cadmium,[65,96,97] mostly in men in their 7th and 8th decades. Although these few cases do not establish cadmium's ability to cause prostate cancer, some investigators[97] have found statistically significant evidence of an increased incidence of this type of cancer among men who have lived for 20 or more years since their first exposure to cadmium and who were exposed during at least 4 years. Evidence that cadmium does not cause prostate cancer comes from an epidemiologic study[101,102] and from experimental work with rodents.[105-107] However, neither type of investigation has been free of significant flaws. The epidemiologic study[101,102] did not obtain good evidence that the subjects were exposed to cadmium, so it is not appropriate to cite the results as positive evidence that cadmium does not induce prostate cancer or that it does induce kidney cancer, as was discussed in *Effects on Humans*. The rodent studies[105-107] did not use doses of Cd(II) sufficient to cause significant toxicity and, thus, are not helpful.

Evidence of an excess of total neoplasms and of lung cancer among cadmium smelter workers developed in a NIOSH study[97] is difficult to interpret because there was also exposure to arsenic; NIOSH has previously concluded that inorganic arsenic compounds are carcinogenic[237] (although concentrations of arsenic known to have caused a high incidence of lung cancer were higher than those found in 1973 in the NIOSH study). In addition, the study of Kipling and Waterhouse[96] did not find an excess of lung cancer, although lack of detail makes comparison of the studies uncertain. Priority should be given to mortality studies of cadmium workers without concomitant exposure to other toxic materials and to long-term animal studies at doses up to maximally tolerated ones.

In view of the present uncertainties in the evidence on teratogenicity and carcinogenicity of cadmium in occupational exposure, a standard based on these effects is not now recommended. This recommendation should be reconsidered if additional data on these points that warrant such reconsideration are developed.

The recommended limits of 40 μg/cu m (TWA) and 200 μg/cu m (ceiling) are for total particulate cadmium. Thus, limits based only on small, so-called respirable, particles, are not recommended. Cadmium oxide and many other forms of cadmium are not inert, varying in their solubilities in water and probably in body fluids, so that large particles not reaching the alveoli may still be toxicologically active because they can be removed from the upper respiratory tract by ciliary action and transferred to the gastrointestinal tract. Thus, some of these large particles would probably be swallowed and become systemically toxic through gastrointestinal absorption (though gastrointestinal absorption would be expected to be less than absorption from the respiratory tract).

It has been implicit in the environmental limits, such as TLV's that have prevailed for many years (see discussion of previous standards in the section above), that cadmium oxide fume is more toxic than cadmium oxide dust. It seems probable that the basis for this is the assumption that fumes, being usually of smaller particle sizes than dusts, will penetrate more efficiently into the lungs and thus be more efficiently absorbed by the blood. For compliance purposes, it is not evident how to distinguish fume and dust except by particle size, even if there were some more fundamental difference in toxicities of fume and dust. A detailed comparison of results from various epidemiologic investigations is inappropriate because of differences in methods of investigation, in characteristics of the populations studied, including differences in work history, and, perhaps most importantly, in ability to describe exposure levels because of variations in methods and frequencies of estimating concentrations over the years of exposure usually required to cause toxic effects.

Nevertheless, allowing for these difficulties, it seems that a comparison of the results of the studies of Tsuchiya, [63, 130] of Kjellstrom et al,[132] and of Lauwerys et al[133] exemplifies the problem. Workers studied by Tsuchiya[63,130] who were exposed to fume at about 125 μg/cu m developed toxicity, but new workers exposed in the same plant at gradually decreasing concentrations (to under 50 μg/cu m) did not develop toxicity, and the clinical conditions of some of the first group of workers improved. One of the groups investigated by Lauwerys et al[133] at 66 μg/cu m (total) or 21 μg/cu m (respirable) of dust contained proteinuric individuals; it is conceivable that these exposure concentrations had been higher in previous years, as discussed earlier. Kjellstrom et al[132] described a population exposed to cadmium oxide dust that was almost entirely respirable, ie, below 5 μm in particle size; exposure levels of this population had been about 50 μg/cu m recently but had been higher in prior years. Considering the incidence of proteinuria in these populations and making some judgments about differences in overall exposure levels, it seems that the effects found are comparable at similar concentrations of either total dust or fume. While this argument is not a rigorous justification for basing the recommended environmental limit on total particulate, it seems at least to add some support to a limit expressed as total particulate. Perhaps a more important point is that, since data are not available to demonstrate unequivocally that a given amount of cadmium is more toxic as small than as large particles, a workplace environmental limit in terms of total particulate is more conservative, ie, effectively lower, in many situations than the same limit in terms of respirable particulate.

The recommended limits are also proposed to apply to all forms of cadmium. There is limited information that some compounds of cadmium are less toxic than others, but lack of good data on these differences makes difficult a recommendation of several limits for different compounds of cadmium. If exposure to alkyl forms of cadmium is encountered, one could speculate by analogy with alkyl versus inorganic forms of lead or of mercury that the recommended standard will not offer sufficient protection. More research on relative toxicities of various forms of cadmium is needed before different standards for each form can be derived.

(b) Medical Monitoring

It is proposed that mandatory medical surveillance include preplacement and periodic examinations of lungs, kidneys, and blood pressure. In addition, blood counts, studies of liver function, and, in male workers, palpation of the prostate are recommended. Pulmonary function tests should be performed periodically, and chest X-rays should be taken if indicated from results of periodic examinations. For comparison, preplacement examinations and examinations at termination of employment involving cadmium exposure should include X-rays as well as pulmonary function tests. Quantitative analysis of urine protein should be conducted frequently, since this should give early and probably the first indication of adverse effects of cadmium. Proteinuria with its implications of renal dysfunction is less likely to be reversible as it continues, so early detection of low molecular weight proteins in the urine, with the expected result of steps to improve hygiene and work practices, should prevent serious and irreversible effects of cadmium. Therefore, it is proposed that analysis of urine be conducted every 4 months as well as before placement and at termination. Procedures for estimations of proteins in urine are described in Appendix III; the conventional boiling test is not adequate for cadmium-induced proteinuria. If a worker is found to begin to excrete significant amounts of protein in his urine during exposure to cadmium, electrophoretic examination of the urine for the presence of various proteins, especially for peaks in the β-globulin region, will be helpful in deciding whether exposure to cadmium is involved in the genesis of the proteinuria. Alternatively, specific analysis for β_2-microglobulin can be performed. It can be performed by radioimmunoassay or radial immunodiffusion, which give comparable results[275]; semi-automatic procedures allowing simultaneous processing of 24 samples have been described.[276] Piscator[277] has pointed out that an increase in total protein excretion in cadmium workers of 2-3 fold is accompanied by an increase in excretion of β_2-microglobulin of about 50-fold. Analysis of urine for glucose and amino acids is also recommended since in some cases it may give early evidence of renal changes. In this connection, Piscator[74] found that quantitative determination of glucose in urines of cadmium workers showed slight increases in excretion of glucose that were not revealed by test tapes of the type intended for detection of diabetes mellitus.

While the evidence of hypertension from cadmium absorption is contradictory, blood pressure measurements are simple, inexpensive, and harmless and should be part of the required examination.

The uncertain nature of the evidence of liver dysfunction makes a requirement for liver function tests difficult to justify. Similarly, anemia is unlikely at exposure concentrations near the recommended limits. However, both liver function and blood tests are recommended for their possible relationship to cadmium exposure as well as their relevance to an evaluation of general health. A digital prostate examination is also recommended, at least in workers over 40 years old, and can include a rectal examination as part of an evaluation of health status.

Smokers should be counseled on their possibly increased risk of chronic pulmonary disease during exposure to cadmium.

(c) Record Retention

Because of the possible development of chronic obstructive pulmonary disease or chronic renal disease as a result of cadmium exposure, retention of medical and environmental records for 20 years after cessation of work involving exposure to cadmium is recommended.

(d) Biologic Monitoring

Monitoring of blood or urine for cadmium is not proposed as a requirement because blood or urine cadmium concentrations do not adequately correlate with absorption of cadmium or with the state of health of the individual worker. However, group means may correlate better, so such determinations may be useful in assessing plant hygiene and work practices. In addition, gradually increasing levels of cadmium in urine may indicate undue absorption of cadmium that may eventually lead to toxic injury. Thus, periodic monitoring of urine for cadmium is recommended. If the concentration of cadmium in urine of an individual worker rises above the upper part of the range of normal concentrations of urine cadmium, probably about 10 μg/liter,[121] an investigation of such a worker's personal habits and hygiene as well as of his or her occupational exposure to cadmium is suggested. Blood or urine can be analyzed by the method of Lehnert et al,[120,256] described in Chapter IV, *Chemical Analysis*. This and similar methods such as that described by Berman[110] utilize atomic absorption spectrophotometry, so that chloride and other interfering substances must be eliminated, for example by chelation of the cadmium and extraction of the chelate by an organic solvent.[110,120,256]

(e) Environmental Monitoring

Sampling and analysis methods were reviewed in Chapter IV. Cadmium aerosols should be collected on 0.8 μm cellulose filters. While filters of smaller pore size, for example 0.45 μm, will be just as efficient, they place a greater load, possibly too great a load, on the sampling pump. Much larger pore sizes, for example 5 μm, may collect the particulate less efficiently. Atomic absorption spectrophotometry was selected for analysis of cadmium because it is reliable, sensitive, and quick; in addition, it is probably more accurate than other methods, but relative accuracies of various methods have not been adequately studied. Other analytical methods, such as polarographic or colorimetric methods, may be more suitable in specific applications, and they can also be reliable. Recommended procedures for sampling and analysis are given in Appendices I and II.

(f) Work Practices

Work practices are discussed in Chapter VI. Brazing with alloys containing cadmium (often referred to as silver soldering) is especially hazardous because of the high concentration of cadmium oxide fume produced, so good local ventilation and, often, respiratory protection are needed. Storage, handling, and eating of food in cadmium exposure areas should be prohibited to prevent food contamination and subsequent ingestion of cadmium. While cadmium does not pose a fire hazard, its deposition on smoking materials may result in generation and inhalation of cadmium oxide fume at a later time, so that smoking as well as the carrying of uncovered smoking materials in the workplace should be prohibited. There isn't good evidence that cadmium aerosols will penetrate the skin, but their deposition on clothes may result in aerosol generation (eg, blowing of dust) away from work, which may increase the workers' exposure as well as cause his family to be exposed. For this reason, it is proposed that workers be required to change work clothing before leaving work.

(g) Informing Workers of Cadmium Hazards

A continuing education program is an important part of a preventive hygiene program for employees exposed to hazardous materials such as cadmium. Workers should be periodically apprised by properly trained persons about the possible sources of cadmium exposure, the adverse health effects associated with excessive exposure to cadmium, the engineering and work practice controls in use and being planned to limit exposure to acceptable levels, and on environmental and medical monitoring procedures used to check on control procedures and on health status of employees. The types and functions of monitoring equipment, such as personal samplers, should be explained so that each employee understands his or her part in environmental monitoring. Medical monitoring procedures should be explained, especially the pulmonary function and urine protein studies, and their importance in detecting possible adverse health effects from cadmium exposure discussed. The suggestive evidence of prostate cancer from cadmium exposure should be mentioned so that male workers will understand the reasons for periodic rectal examinations. The benefits to workers of participating in these environmental and medical monitoring procedures should be stressed.

(h) Action Level

It is recognized that many workers are exposed to small amounts of cadmium compounds or are working in situations where, regardless of amounts used, there is only negligible contact with the material. 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 workers' health under more hazardous circumstances. Concern for workers' health requires that protective measures be instituted below the enforceable limit to ensure that exposures stay below that limit. For these reasons, an action level of cadmium has been defined as occupational exposure above half the recommended TWA environmental limit, thereby delineating those work situations which do not require the expenditure of health resources for environmental and medical monitoring and associated recordkeeping. This level 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. However, brazing, welding, or thermal cutting with cadmium alloys presents a significant hazard regardless of the TWA concentration, and such operations should be performed only in accordance with the recommended standard. Similarly, food storage, handling, and eating should be prohibited in cadmium work areas regardless of TWA concentrations.

VI. WORK PRACTICES

Chapter III discussed the acute toxicity of cadmium oxide fume at high concentrations, sometimes causing fatal pulmonary edema. Overexposures to freshly formed cadmium fume can develop especially from three types of processes:

Burning or welding of cadmium-plated metals.

Silver brazing with cadmium-containing alloys, rods, solders, or wires.

Heating or burning of other cadmium-containing substances.

These procedures involve temperatures ranging from above that of cadmium's melting point (321 C, 610 F) to beyond its boiling point (765 C, 1409 F). The closer the temperature to the boiling point of cadmium the more freely and profusely its fresh fume is evolved into the worker's breathing zone to cause a great risk of overexposure with acute poisoning. (Cadmium metal vapor or fume would be expected to oxidize rapidly to form cadmium oxide fume.)

(a) Recognition

Even at lethal concentrations, cadmium fume or dust has no specific warning odor or immediately irritating effects, so far as is known. Thus, any operation involving cadmium-containing or cadmium-plated substance and any form of heating, such as welding, brazing, soldering, or grinding, is likely to be highly hazardous. Moreover, cadmium-plated metals are often mistaken for galvanized or zinc-plated metals. Consequently, specific determination of the presence or absence of cadmium in products to be subjected to processes involving heat is essential. Chemical analyses of suspect metals should be conducted to confirm the presence or absence of cadmium. If this is not possible, a spot test can be used. One spot test that can be used with welding rods involves a very gentle heating of a small spot of metal, about the size of a nickel (be sure not to burn off the metal). After this gentle heating, cadmium will form a gold-yellow film, whereas zinc will turn a smoky-gray color. Another spot test involves the application of one drop of a 10% *fresh* solution of ammonium nitrate to the clean metal surface. Let the nitrate solution dissolve some of the metal for a few seconds. Blot the wet area with a filter or similar paper. Apply one or two drops of a 5% *fresh* solution of sodium sulfide to the wetted portion of the filter paper. If a yellow color develops on the wet paper area, the metal tested contains cadmium. If the paper remains colorless, no cadmium is present.[47]

(b) Silver Brazing

Silver brazing, commonly called silver soldering, is the process of joining metals by heat with a silver alloy filler metal. Many filler metal alloys contain cadmium, which can produce cadmium oxide aerosol when overheated, so care must be taken to control the temperature of silver brazing operations if the alloy contains cadmium. Under no circumstances should a torch flame be applied directly to such an alloy. The heat of the base metal should be used to melt the filler metal and cause it to flow. Silver brazing with cadmium-containing alloys should be performed only with satisfactory local exhaust or with appropriate respiratory protection.

(c) Welding, Cutting, and Heating

Welding and thermal cutting of material containing cadmium must be performed only with local exhaust ventilation demonstrated by sampling and analysis of breathing zone atmospheres to be sufficient to maintain airborne cadmium at or below recommended limits. For single operations, where local exhaust ventilation is not available or where air sampling and analysis has not demonstrated acceptable air concentrations, suitable respirators (listed in Chapter I) must be provided and worn.

Where molten cadmium is used or formed, temperatures should be kept as low as possible consistent with the requirements of the work operation to prevent generation of excess fume. Wherever possible, this should be accomplished by automatic controls, with recording of temperatures and use of alarms or other indicators of excessive temperatures. If possible, avoid using cadmium-containing alloys for brazing. In any case, cadmium-containing metals must be appropriately segregated and labeled, so that workers will not unknowingly apply heat to cadmium.

(d) Engineering Controls

Control design criteria for a number of cadmium fume-generating operations are given in *Industrial Ventilation—A Manual of Recommended Practice*.[258] Local exhaust ventilation should be provided at all operations as shown in this manual. Inasmuch as cadmium is more toxic than most of the other materials handled, enclosure should be maximized and the high end of any range of control velocities should be used.

Air volumes tabulated for welding[258,260] are calculated for a control velocity of 100 feet/min. For cadmium fume, control velocities of 150 feet/min should be used, so that volumes 50% greater than the tabulated volumes should be used.

Local exhaust systems should be designed and operated in conformance with ANSI Z9.2-1971, *Fundamentals Governing the Design and Operation of Local Exhaust Systems*.[260] It should be emphasized that the aim of these control procedures is adequate performance, ie, achievement of airborne concentrations at or below environmental limits and prevention of other forms of absorption such as ingestion. Published designs for ventilation control illustrate approaches which have been successful in certain applications. Any method for meeting these recommendations consistent with the health and safety of workers may be acceptable. In each case, success of control measures must be demonstrated by appropriate air sampling.

Enclosures, exhaust hoods, and duct work must be kept in good repair so that design air flows are maintained. Air flow should be measured at each hood at least twice a year, and preferably monthly. Continuous air flow indicators are recommended, such as water or oil manometers properly mounted at the juncture of fume hood and duct throat; these should be marked to indicate acceptable air flow. A log showing design air flow and results of periodic inspection should be kept.

Effluent air should be cleaned, if necessary, to meet any emission standards that may be promulgated (there are now no EPA emissions standards for cadmium). Air from the exhaust ventilation system must not be recirculated into the workplace.

(e) Respiratory Protection

For adequate respiratory protection against the many conditions that may be encountered in individual operations, many types of respirators have been developed and approved. Each has particular applications and limitations from the standpoint of protection, and each has its advantages and disadvantages from the standpoint of operation and maintenance. Detailed information on the selection and use of respirators can be obtained from *Respiratory Protective Devices Manual*.[278] ANSI Z88.2-1969[259] also classifies, describes, and gives limitations of respirators.

Respirators fall into several classifications, according to their mode of operation: (1) atmosphere-supplying respirators, which include those to which suitable air is supplied by tanks carried by the wearer or by a hose carrying air from a remote source (self-contained masks, hose masks, airline masks, and combination self-contained and airline masks); (2) air-purifying respirators which filter or absorb the contaminant (gas mask with chemical cartridge, particulate masks, and combination masks for gas, vapor, and particulate); and (3) combination atmosphere-supplying and air-purifying respirators. The factors that affect the overall performance of air-purifying respirators are the reliability of the face seal, the efficiency of the filters, and other variables such as leakage from exhalation valves.

The applicable regulation on certification and approval of respirators is 29 CFR 11. This requires, among other things, that all air-purifying respirators approved for dusts and fumes with an environmental limit less than 0.05 mg/cu m be equipped with a high efficiency filter.

(f) Protective Clothing

Protective clothing is not normally required for cadmium operations. It is possible that cadmium dust collected on clothing could be released into the air to cause a secondary exposure so that, if such clothing were worn to the worker's home, the worker and others might be exposed to cadmium dust. The better solution is to improve workplace housekeeping to prevent clothing contamination, but it seems a wise precaution that work clothing be changed at the end of the workshift and not carried home. Thus, there should be change rooms with separate storage areas, such as lockers, and shower and hand washing facilities should be provided.

(g) General Housekeeping

Where cadmium-containing dust may exist, cleaning should be performed by vacuum pickup or wet mopping to minimize generation of airborne dust; no dry sweeping or blowing should be permitted. Prompt cleanup of spills, repair of equipment and leaks, proper storage of materials, and collection of cadmium-containing dust must be emphasized to workers and supervisors.

(h) Personal hygiene

Cadmium is toxic by ingestion, so sanitary provisions to prevent food contamination are essential. As a minimum, such precautions should include the prohibition of eating, food handling, or food storage in the workplace areas where cadmium contamination can occur. Hands should be washed before eating or before using tobacco products. Smoking in the work area can increase exposure by contamination of the smoking materials, so smoking or carrying of tobacco or tobacco products open to the air should be prohibited.

While there isn't good reason to believe that cadmium compounds penetrate the skin to a significant extent, it is good practice to avoid skin contact and if contact has occurred to wash the affected areas promptly.

(i) Storage

Cadmium-containing, including cadmium-plated, metal parts should be kept separate from parts not containing cadmium so that accidental exposures resulting from welding and cutting will not occur.

(j) Emergency Procedures

Emergency procedures should be established for any event that might result in substantial release of airborne cadmium. Such procedures should include provisions to notify the attending physician that exposure to high concentrations of cadmium fume may cause lung edema. This edema may not become evident until 8-24 hours after the exposure.

Emergency procedures should also include provision for appropriate respirators specified in Chapter I.

It is important to design specific emergency procedures to be followed in the event of a fire, to protect both workers and firefighters.