IV. ENVIRONMENTAL DATA

Sampling and Analysis

Many sampling methods have been adapted specifically for measurement of carbon dioxide. However, most of these are not suited to an accurate assessment of hazards in the workplace because of limitations of their applicable ranges.

A procedure for plastic bag sampling was described by Apol et al. [98] The authors evaluated the collection procedure using known concentrations of trichloroethylene. They found that concentrations within the bag remained constant for 20 hours and diminished by 10% after 90 hours. The maximum difference between the known, introduced concentration and that analyzed by gas chromatography was 3 ppm. The authors stated that the percentage of error at the 95% confidence level was within expected precision, although they did not state the exact amount. They concluded that the use of bags was practical, easy, and precise enough to be of value, even for calibration of the sampling apparatus.

Collection of carbon dioxide in bags has also been reported favorably (W Carlson, written communication, August 1975). Five-liter plastic bags made of Saranex were tested with a carbon dioxide concentration of 4.2%. After 26 hours, 98.6% of the gas remained. Bag sampling methods have also been reported by Smith and Pierce, [99] VanderKolk and VanFarowe, [100] and by Conner and Nader. [101] Curtis and Hendricks [102] reported on a method using a self-filling gas-sampling bag for use in industrial plants. Although carbon dioxide was not sampled by these methods, the gases sampled included sulfur dioxide, nitrogen dioxide, ozone, auto exhaust hydrocarbons, benzene, methyl alcohol, dichloromethane, and methyl isobutyl ketone. All of these authors [100-102] reported favorably on the use of bags for air sampling. Appendix I describes the recommended air sampling method using collection bags of this type.

Continuous carbon dioxide monitoring techniques are used in critical environments such as submarines and spacecraft. [103,104] Respiratory gas levels in hospital patients are monitored by other continuous analytical methods. [105-109] Examples of the devices prescribed for use in medical surveillance of respiratory gases are described by Scholander [105] and Andersen and Jorgensen. [109] Future development of these types of devices may make such equipment useful for field applications. The method of Andersen and Jorgensen [109] is a modification of the Orsat (or Hempel) principle, in which the concentration of the carbon dioxide is determined by the volume absorbed in a sodium hydroxide solution. The Scholander method [105] is useful for measuring respiratory gases in very small samples (about 0.5 ml). This analytical method is also based on the absorption properties of carbon dioxide and is used extensively for source monitoring in combustion operations. However, the complexity and size of the equipment used in this method make its application in the field difficult and impractical.

Lodge et al [110] described an atmospheric carbon dioxide analyzer based on the pH of the sampling solution. The apparatus consisted of a diaphragm pump to draw in an atmospheric sample and a suspension of marble chips in distilled water. The pH of this suspension was measured by an electrode attached to a standard pH meter. In field trials, the analyzer was tested against a nondispersive infrared (NDIR) analyzer. The authors reported that, in paired trials, their apparatus yielded concentration values of carbon dioxide essentially equivalent to the NDIR. While this method appears to be simple and fairly accurate, the equipment is not immediately suited to workplace applications. Further, the trials reported were responsive only in the range of 200-800 ppm; the authors did not indicate the performance of the equipment in the range of the proposed standard.

An apparatus described by Joyce and Woods [111] was reported to measure carbon dioxide concentrations at a pressure of 50 atm. Designed primarily for use in diving and other underseas operations, the apparatus was based on fluerics, the technology of no-moving-parts devices. It consisted of a capillary and orifice device (passive resistor bridge) to measure the carbon dioxide concentration by gas viscometry; an amplifying apparatus; a readout device; and an aspirator to move the gas sample through the system. The report offered experimental data in the range of 2-10% carbon dioxide. No information was presented on the usefulness of the apparatus at 1 atm. This device may become useful with further modifications, but at present its applicability to industrial sampling has not been appraised.

One of the most practical industrial analytical methods appears to be the use of detector tubes. A 1973 report by the Working Party of the Technology Committee of the British Occupational Hygiene Society [112] described the Draeger detector tubes for carbon dioxide. In this report, the tubes were classed as having met the Committee's major criteria for performance. The reported accuracy of the tubes was + 30%, -20% at 5,000 ppm with a 95% confidence limit. The current performance criteria, as stated in 42 CFR 84.20 (e), are $\pm$ 25% at 1, 2, and 5 times the test standard, and $\pm$ 35% of the actual value at one-half the standard. The Draeger detector tubes were also rated at +50%, -20% at 10,000 ppm and 2,500 ppm. The required apparatus included a standard sampling pump which drew a monitored volume of air through the tube. The principle of the carbon dioxide tube involves the length of stain, according to the reaction:

Carbon dioxide + hydrazine ⟶ carbonic acid monohydrazide.

The indicative color is a bluish violet. Tubes are available in the ranges 0.01-0.3%, 0.01-1.2%, 0.5-6%, 0.5-10%, 1-20%, and 5-60% for carbon dioxide in air. No interfering gases have been reported in the reaction. [113] At present, five types of detector tubes have met the NIOSH performance criteria: Bacharach 19-0359, MSA 85976, Kitagawa 126A and 126SA, Gas Tec CO2 2L, and Draeger CO2 CH23501. [114,115] As reported by Kusnetz et al, [116] the acceptability of detector tubes is limited by their semi-quantitative nature, variability, storage and calibration problems, the subjectivity in the reading of the tubes, and the problem of pump calibration. These limitations seriously detract from the usefulness of detector tubes for precise workplace monitoring. Detector tubes do appear to be adequate devices for screening or preliminary determinations and for immediate determinations in emergency situations, but industrial applications should be based on more quantitative determinations. Further, detector tubes are not suited to the calculation of TWA concentrations.

Other methods easily adapted to use in the workplace are the direct-reading devices based on thermoconductivity [117-119] and spectrophotometers, both dispersive and nondispersive infrared. [120] Several manufacturers market devices which detect carbon dioxide concentrations on these bases. Any of these methods which are equivalent in accuracy, precision, and sensitivity to the method recommended may be used for determination of the environmental limits.

Perhaps the most accurate analytical method for determining carbon dioxide concentrations in industrial applications is gas chromatographic analysis. With this technique, it is possible to analyze the carbon dioxide concentration directly in an air sample without further manipulation; before analysis, however, adequate representative samples must be collected.

The problems encountered in the use of an analytical gas chromatographic method center on the separation of carbon dioxide from other atmospheric gases. Several column types have been described which seek to overcome this problem: molecular sieves; liquid-coated Teflon and liquid-coated Chromosorb [104]; a 17-column system [103]; a single Porapak Q column with cryogenic temperature modifications [121]; a Carbosieve-B column [122]; a 2-column molecular sieve [123]; and a 3-column chromatographic method. [124] A simple silica gel column has also been reported which is [125] less complex and less expensive than those previously listed. This column was reported to have resulted in a maximum sensitivity of 13 ppm carbon dioxide with the standard deviation in peak height of $\pm$ 2% and in peak area of $\pm$ 5% when running at a 500-ppm maximum peak height. The column is reliable, inexpensive, and commonly available;

therefore, an analytical method using the silica-gel packed gas chromatography column is recommended. The method is described in Appendix II.

Environmental Levels

Very little information is available on actual levels of carbon dioxide found in common industrial settings. Most of these data are from submarines, aircraft, silos, and similar closed environments.

A careful study of gas concentrations in silos was reported by Commins et al. [126] They undertook an investigation to identify the concentrations of toxic gas evolved from natural fermentation in silos and to evaluate the hazard to workers under these conditions. Daily measurements were made 1 and 5 feet above the surface of the silage. Carbon dioxide concentrations were determined with an Orsat apparatus after collection of the gas in rubber bags. Results indicated that, on the sixth day after filling, a maximum concentration of 78% carbon dioxide was detected 1 foot above the surface of the silage. At 5 feet above the surface, the level was as low as 3% on the same day. The difference at the levels measured was due to the weight of carbon dioxide and its tendency to fall to surface level. Subsequent measurements made during operation of a powerful air blower (air stream rate of 5,000 cu ft/min) showed a decrease from 78 to 17% carbon dioxide 1 foot above the silage after 13 minutes with the air blower working.

Another study of gas concentrations in silos was reported by Chrostek and Baier. [127] The danger of toxic gas evolution in silos is caused by the natural fermentation of the forage stored. As fermentation occurs, oxygen is consumed, and carbon dioxide and oxides of nitrogen are generated. Measurements indicated that within 2 days after filling of the silo, the carbon dioxide concentration ranged from 30 to 40%.

As a result of the fatalities and serious illnesses described by Dalgaard et al, [70] the same authors also inquired into the levels of carbon dioxide and other gases present in the holds of ships carrying trash fish. They collected air samples in glass pipets and analyzed them by gas chromatography. The measurements were made immediately upon opening the hatches when the ships were in port. Analyses on 13 industrial fishing vessels indicated carbon dioxide levels of from 1 to 40%.

A survey of theaters and cinemas by Clark [128] indicated that carbon dioxide concentrations ranged from 320 ppm (0.032%) to a maximum of 2,500 ppm (0.25%) in a full theater while the exhaust fan was operating.

A June 1976 study [77] on carbon dioxide exposure levels at a beer brewery disclosed a mean 8-hour TWA concentration of 1.08% carbon dioxide in samples from breathing zones of cellar workers analyzed by infrared spectrophotometry. This TWA was the mean for 15 shifts representing 5 days (3 shifts/day) of monitoring. The highest 8-hour shift TWA was 1.95% carbon dioxide with excursions as high as 8% for 3 minutes and 6.5% for 6 minutes. This is the only report found which specified environmental levels in a typical high-potential-exposure occupational setting and therefore reflects extremely pertinent worker exposure data.

Engineering Controls

The objective of engineering control of carbon dioxide should be to minimize concentrations of the gas in workplace air. Respiratory protective equipment is not an acceptable substitute for proper engineering controls, although such equipment should be available for use in emergencies and during maintenance and repair procedures.

Since operations using the liquid phase of carbon dioxide must be pressurized and therefore closed, control of the liquid should present no problem under normal working conditions. Where the gaseous phase is introduced into the atmosphere, adequate exhaust ventilation must be provided. Pertinent information on both general dilution and local exhaust ventilation can be found in Industrial Ventilation--A Manual of Recommended Practice, [129] ANSI Z9.2-1971, [130] and the American Society of Heating, Refrigerating, and Air Conditioning Engineers Handbook and Product Directory. [131] The most recent edition of each should be consulted. Since carbon dioxide gas is about 1.5 times heavier than air, local exhaust ventilation should be applied as close as possible to the source of generation.

V. DEVELOPMENT OF STANDARD

Basis for Previous Standards

In 1931, Flury and Zernick [132] summarized the toxic effects of carbon dioxide and reported that at concentrations of up to 2.5% it produced no harmful effects in 1-hour inhalations. They also reported that effects on respiration appeared only after 3% carbon dioxide was reached and these included increases in the rate and depth of respiration. Based on the information provided by Lehmann-Hess, Flury and Zernick [132] identified a level of 5,550 ppm (0.55%) as causing no real symptoms after 6 hours. Further, they quoted Lehmann-Hess as reporting that exposure to carbon dioxide at 33,500-39,000 ppm (3.35-3.9%) for 1/2-1 hour had no immediate or delayed effects.

In 1943, the USPHS listed 5,000 ppm (0.5%) as the Maximum Allowable Concentration (MAC) for carbon dioxide. [133] A compilation of MAC's prepared by Cook [134] in 1945 also recorded 5,000 ppm (0.5%) as the limit established by California, New York, and Oregon. At the same time, Utah set a limit of 5,550 ppm (0.5%). In 1950, Elkins [135] also proposed 5,000 ppm (0.5%) as the MAC for carbon dioxide. His recommendation was based primarily on the asphyxiation hazards of the gas, although he cautioned that carbon dioxide could not be considered physiologically inert. As late as 1956, Smyth [136] reported (in his summarization of "Hygienic Standards for Daily Inhalation") that asphyxia was the most important effect of carbon dioxide. He further stated that the 5,000-ppm (0.5%) level was low enough to cause no noticeable effects.

In 1946, the American Conference of Governmental Industrial

Hygienists (ACGIH) recommended a Threshold Limit Value (TLV) of 5,000 ppm (0.5%) for carbon dioxide although the basis for this level was not offered. [137] The 1971 Documentation of the Threshold Limit Values [138] listed the same 5,000-ppm (0.5%) value and this was based on Schaefer's report [139] that 3% carbon dioxide produced little or no effect on submariners, even throughout continuous exposure, so long as the oxygen content was maintained at normal concentrations. The TLV was also supported by Schulte [140] who stated that exposure to carbon dioxide at a concentration of 2% resulted in headache and dyspnea on mild exertion after several hours. This review article offered no experimental data, nor did it specify a source of data to support this statement. Also cited in the ACGIH Documentation of TLV's [138] was the previously reported study by Borum et al [141] and a review by Schaefer. [142] Schaefer [142] reviewed much of his previously reported work on acid-base and electrolyte balance as affected by carbon dioxide in relation to space-cabin confinement. The findings were the same as those reported earlier. [53,54,57,58] Although the Documentation of TLV's attributed a report of acidosis and adrenal cortical exhaustion to a study by Borum et al, [141] there is no such mention in the article. The study was another report of the "Operation Hideout" experiment originally presented by Faucett and Newman. [35] In 1947, Consolazio et al [143] reported that the US Naval Medical Research Institute had set a level of 3% (30,000 ppm) in 17% oxygen as an MAC in the American Submarine Service.

The 1969 Documentation of MAC in Czechoslovakia [144] listed levels adopted in several countries. In East and West Germany and in the United States, the recommended level was listed at 5,000 ppm (0.5%). In Great

Britain and Yugoslavia, a level of 5,086 ppm (0.5%) was recorded. A peak level of 20,000 ppm (2%) also was listed for the United States, but source documentation was not provided.

A listing of suggested Soviet spacecraft air standards [145] gave 0.2-0.3% (2,000-3,000 ppm) as the carbon dioxide standard for continuous exposures of greater than 4 months' duration. No supporting data were listed.

In 1974, the ACGIH offered an addendum to the Documentation of TLV's [138] which recommended a level of 15,000 ppm (1.5%) for healthy people engaged in special environments including submarines, spacecraft, and breweries. Also recommended was a specific medical classification for workers permitted to be exposed at this concentration. Additional information on which the standard was based included the report by Ebersole [146] on "Operation Hideout," the submarine study which has been reported many times in the literature. [30,35,36,54,55] While this level (15,000 ppm, 1.5%) has not yet been incorporated into the TLV Documentation, the ACGIH reported it as the most recent standard recommendation and represented it as a safe, practicable limit which would provide an adequate margin of safety for the worker.

The present federal standard (29 CFR 1910.1000) for carbon dioxide is an 8-hour TWA level of 5,000 ppm based on the ACGIH TLV for 1968.

Basis for the Recommended Standard

Inhalation of carbon dioxide at concentrations greater than 17% is life threatening and the effects appear rapidly. Loss of consciousness has been reported in less than 50 seconds during inhalation of between 17 and

30% carbon dioxide in all subjects exposed. [28,29,44] At concentrations of 10.4% for 3.8 minutes and 7.6% for 7.4 minutes, loss of consciousness was observed in 3 of 31 and in 1 of 42 test subjects, respectively. [27] Symptoms reported at 10% carbon dioxide included eye flickering, psychomotor excitation, myoclonic twitching, headache, dizziness, dyspnea, sweating, restlessness, and "fullness in head." [22,27] Schaefer [30] noted similar symptoms in humans exposed to the gas at 7.5% for 15 minutes. The information provided by the aforementioned investigators [22,27,30] indicated that dyspnea, dizziness, and headache were the predominant symptoms at or above 7.5% carbon dioxide. The only reported effect of brief exposure at lower concentrations was that of respiratory stimulation. [27] A subjective awareness of increased ventilation with slight-to-moderate dyspnea on acute exposure to carbon dioxide has been reported at an average maximal respiratory minute volume of 62.7 liters/minute (range 29-110 liters/minute) with marked dyspnea reported at 86.8 liters/minute (range 50-130 liters/minute). [27] Subjects reporting no dyspnea had maximal minute volumes ranging from 24-114 liters/minute (average 60 liters/minute). [27] Upon inhalation at 7.6%, respiratory minute volumes averaged 51.5 liters/minute (range 24-102 liters/minute); at 5% carbon dioxide, the average minute volume was 26 liters/minute, at 4% it was 14 liters/minute, and at 3% it was only 11 liters/minute. Although the reported data indicated a broad range of sensitivity to the respiratory stimulant effects of carbon dioxide, the 3% level appears to be well below the lower limit of sensitivity and would provide adequate protection against possible respiratory discomfort for even the most susceptible individuals. NIOSH therefore recommends a ceiling limit of 3% (30,000 ppm) for up to 10 minutes. This ceiling value is regarded as necessary to safeguard the working population potentially exposed to briefly elevated concentrations of carbon dioxide and to provide an adequate margin of protection against the effects of acute exposures to the gas.

Animal studies have suggested that reproductive abnormalities including antifertility effects occurred at concentrations ranging from 2.5 to 35% carbon dioxide. [92,93] One report [93] indicated that the degenerative changes in rat testicular tissue as a result of exposure at from 2.5 to 10% carbon dioxide were limited to reversible structural abnormalities. A single study [92] with mice exposed to 35% carbon dioxide suggested the possibility of antifertility effects. However, the extremely high concentration of carbon dioxide used limits the relevance of these data to possible effects in humans. The teratogenic effects suggested by rat and rabbit studies [94,96] involved cardiac and spinal abnormalities in the offspring of dams exposed to carbon dioxide. Pregnant rats were exposed at a concentration of 6% for one 24-hour period between days 5 and 21 of gestation [94]; rabbits were exposed at a concentration of 10-13% for 4-10 hours on each of 2 or 3 days between days 7 and 12 of gestation. [96] The value of these results in predicting the effects of carbon dioxide on human fetal development is limited by the short gestation periods (21 days for rats, 30 days for rabbits) in the species exposed. Furthermore, comparable exposures of humans at these concentrations would result in rapid and pronounced respiratory and central nervous system effects and would not be tolerated.

One investigator [97] alluded to the carcinogenic properties of solid carbon dioxide; however, dry ice was used for these studies solely because it is a cold irritant. It would be expected that any cryogenic substance that destroys tissue would have similar dermal effects if it were applied over a comparable time period. No reports of carcinogenicity due to inhalation of gaseous carbon dioxide have been found in the literature.

A few investigators have indicated that cardiac abnormalities were observed during and after exposure to carbon dioxide. [28,44,47,61,62] The irregularities were minor and not necessarily predictive of the development of more serious complications. None of these abnormalities in cardiac function have been causally related to the carbon dioxide exposures.

No significant behavioral changes have been demonstrated during continuous exposure at concentrations below 4% carbon dioxide, [48] although a single report [50] concerning chronic exposure to 3% carbon dioxide described stimulatory and depressant behavioral effects on the first 2 days of exposure at this concentration. These results are contradictory to the more recently published studies [33,34,48] which gave no similar indications of behavioral alterations at the same concentration.

Numerous studies [33,47,54,55,57-59] have shown that continuous exposures to 1.5-3% carbon dioxide do not result in serious challenges to body function. An early Schaefer [139] article, cited as a basis for the present ACGIH standard, also indicated no significant symptomatic effects of 3% carbon dioxide, although physiologic alterations, such as changes in pH and bicarbonate ion concentration, were apparent from chronic exposure. However, the decreased pH, increased bicarbonate ion concentration, and changes in other electrolyte levels represented evidence of normal physiologic response mechanisms. The same conclusions may be drawn from the studies on respiratory function. Experiments conducted at carbon dioxide concentrations of 1.5% for 42 days [35,36,38] have demonstrated a propensity for tolerance, physiologic adaptation, and an absence of adverse effects. Respiration appears to be the first mechanism to respond to an increased carbon dioxide exposure, and increased ventilatory rates are a direct result of increased carbon dioxide concentrations. Respiratory stimulation is indicative of a sensitive response mechanism and is apparent at all levels of carbon dioxide tension above 1%. The adaptation to the respiration-stimulating effects of carbon dioxide during continuous exposure is dramatically represented by a decreased response to a subsequent challenge with the gas at a higher concentration. This apparent tolerance has been reported often. [35,38,41] The respiratory adaptation upon prolonged exposure to carbon dioxide is also characterized by improved oxygen utilization, more efficient carbon dioxide elimination, and an increased alkali reserve. These adjustments are related to similar changes in alveolar pCO_2 and to blood buffering activity. Evidence obtained in some studies suggests, although indirectly, that as homeostatic mechanisms achieve stability, the signs and symptoms of bodily reactions, such as pulse rate and headache, begin to fade. [33] These adaptive changes indicate that there is no irreparable damage or extreme challenge to the body. Continuous exposure at concentrations of 1.5-3% carbon dioxide can be tolerated by healthy workers even for prolonged periods without untoward effects.

In the industrial setting, a worker might be required to perform at several levels of work intensity (eg, muscular exertion) throughout the day. These levels might cover a range between 0.5 kcal/minute and 6.0 kcal/minute (during exceedingly strenuous or exhausting exercise for very short time periods). The effects of carbon dioxide on metabolism and ventilatory responses, although enhanced in these cases, begin to manifest themselves subjectively only when a concentration of at least 2.8% carbon dioxide is reached. [61,62] Several studies [33,48,63,64] have indicated that all grades of exercise, including exhaustive stress (250 W, 3.58 kcal/minute), can be tolerated for at least 30 minutes at carbon dioxide concentrations of up to 4%. During inhalation of carbon dioxide at concentrations ranging from 2.8 to 5.2% at maximum exercise levels (180-250 W, 2.58-3.58 kcal/minute, attained on a bicycle ergometer or at treadmill speeds of 6 mph), healthy, trained subjects experienced respiratory difficulty, impaired vision, severe headache, and mental confusion; three subjects collapsed. [65] At or below 2.8% carbon dioxide concomitant with lower, but still strenuous, levels of exercise (130-180 W, 1.86-2.58 kcal/minute), no ill effects other than awareness of increased ventilation (no dyspnea reported) were experienced by the subjects. [61,62] Prolonged exposure at elevated concentrations of the gas could result in attenuation of the effects enhanced by both exercise and simultaneous exposure to carbon dioxide, [58] although even an individual previously unexposed to carbon dioxide can normally tolerate simultaneous 2.8% carbon dioxide inhalation and heavy exercise stress. In fact, it has been observed that training (as in the case of divers) or continuous exposure results in a lessened severity of signs and symptoms during both normal activity and moderate exercise. [38]

All the studies dealing with the effects of prolonged exposure to carbon dioxide have utilized continuous exposures. The occupational situation, however, represents an intermittent exposure with the nonwork phase being a normal-air-breathing period. The results of a study based on the responses of one subject suggested that an intermittent exposure of 15 hours in carbon dioxide and 9 hours in normal air does not approximate a chronic exposure situation in terms of ventilatory, acid-base, or other major physiologic response mechanisms. [41,53] One study in brewery workers [77] tends to support these observations but no additional information has been found. The studies showing a decreased ventilatory response to carbon dioxide upon rechallenge after continuous exposure would suggest that intermittent exposure which may, in fact, represent a periodic rechallenge situation, could result in a progressive diminution of response with each repeated daily exposure. However, evidence to support this hypothesis is lacking.

Evidence regarding the effects of chronic exposure to carbon dioxide at concentrations below 1% has been limited. The effects discussed include increases in alveolar dead space at concentrations of 0.8 and 0.9% carbon dioxide [37] and cyclic calcium tides corresponding to alternate bone storage and release of carbon dioxide during exposure to 0.8-1.2% carbon dioxide. [60] The significance, if any, of these changes remains to be determined. The majority of the available human data deals with continuous exposures at levels of 1.5 and 3%, at both of which it has been adequately demonstrated that observed changes are limited to normal renal and respiratory compensatory mechanisms without any apparent adverse symptoms. Adaptive mechanisms involving reduced responses to the respiratory, and possibly to the cardiovascular, effects of carbon dioxide provide an additional safety index during prolonged exposure. Although the absence of specific data relating to intermittent exposures may limit the reliability of the data obtained from continuous-exposure studies, the available evidence indicates that even a prolonged continuous exposure to 3% carbon dioxide presents no apparent problem during normal activity in specially conditioned and physically fit subjects. However, it is important to consider that the entire range of workload demands maintained in the exercise studies previously described is similarly and repeatedly encountered for varying time periods throughout the average workday. Furthermore, the worker population encompasses a broad spectrum of physical well-being and susceptibility to the respiratory and metabolic effects of carbon dioxide. Therefore, since work-related exercise could exaggerate these effects, and mindful of the need to protect all workers, NIOSH recommends a TWA concentration of 1% (10,000 ppm) for a 10-hour work shift and a 40-hour workweek.

The recommended standard provides for safeguarding employees from the hazards of carbon dioxide by the incorporation of a TWA concentration of 1% (10,000 ppm) carbon dioxide, a ceiling limit of 3% (30,000 ppm) carbon dioxide for up to 10 minutes, and other requirements prescribed to maintain the health and safety of potentially exposed persons. However, respiratory stimulation due to inhalation of carbon dioxide resulting in an increased intake of other airborne chemicals must be considered when carbon dioxide exposure is complicated by the presence of other chemicals. It is felt that exposure at or below the recommended TWA concentration of 1% carbon dioxide will produce an insufficient alteration in respiratory rate (from a normal of 7 liters/minute to 9 liters/minute or less) to appreciably increase the intake of other chemicals. Other requirements in the recommended standard include appropriate labeling of carbon dioxide containers and posting of exposure work areas, recordkeeping, emergency procedures, and precautions for entry into confined spaces. In addition, environmental sampling and analytical methods are recommended with a sampling schedule designed to assure compliance with the prescribed limits. There are also requirements for personal protective equipment, including clothing to protect against skin contact with dry ice and respirators for protection against the acute symptoms of carbon dioxide inhalation. Compliance with the recommended standard also requires that employees be informed of the hazards to which they may be exposed in the work area.

Compatibility with Other Standards

Whenever people are confined in sealed environments, exhaled carbon dioxide accumulates and, if uncontrolled, will reach a concentration level in excess of acceptable tolerance. Persons concerned with sealed environments, such as spacecraft and submarines, are particularly cautious about the concentration of carbon dioxide in these spaces and about methods of preventing the buildup from becoming excessive. A recent publication [145] listed the National Aeronautics and Space Administration (NASA) limits (which were published in 1972) for manned spacecraft air contaminants for several lengths of exposure. The highest allowable level of carbon dioxide was 40,000 ppm (4%) carbon dioxide for a 10-minute exposure. Also listed were 30,000 ppm (3%) for 60 minutes, and 10,000 ppm (1%) for both 90-day and 6-month exposures. NASA, in its Skylab Flight Mission Rules (published in 1973), [147] specified the maximum sustained carbon dioxide partial pressure for mission continuation as 7.6 mmHg (1%), and the maximum emergency excursion allowable for a maximum of 3 hours as

15 mmHg (1.9%). These limits were based in part on experiments of continuous exposure [33] and on some of the previously cited submarine studies, [35,36] as well as on a compendium [148] of many such related studies. [20,24,27,33,35,36,42,50,51,56,57,83,149,150] The level was specified for continuous exposure in what must be considered a critical situation. It was also ascertained to be a level that would not cause significant deterioration of mental or psychomotor activity, as this would be most serious in manned space flight situations.

Schaefer's review [149] of literature on human tolerance to chronic exposure to carbon dioxide suggests a triple tolerance approach. The author based his conclusions partly on previous submarine experiments [35,36] in which responses to various concentrations of carbon dioxide were identified. The resultant triple tolerance limit indicated that, at a level of 0.5-0.8% carbon dioxide, no significant physiologic, psychologic, or adaptive changes occurred. No data were offered to indicate that there were effects over this range. At a 1.5% exposure, performance and psychologic functioning were not adversely affected, although acid-base and electrolyte adaptation occurred as a result of continuous exposure. At levels above 3% carbon dioxide, deterioration in performance may be expected, as may alterations in basic physiologic functions, such as blood pressure, pulse rate, and metabolism. Schaefer [149] further stated that, although early regulations held that a level of 3% carbon dioxide was permissible for submarine exposures, physiologic alterations identified at a 1.5% concentration led the US Navy to propose an allowable level "in the neighborhood of 1% and preferably below 1% carbon dioxide for conditions of continuous prolonged exposure." More recent (1975) Navy standards for nuclear submarines [145] offered three exposure-level limits. The 1-hour emergency level was 19 mmHg (2.5%), the 24-hour continuous exposure level was 7.6 mmHg (1%), and that for a 90-day continuous exposure was 3.8 mmHg (0.5%).