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FROM: T. G. Grumbles

DATE: February 15, 1991

SUBJ: VENTILATION IN CONFINED SPACES

The attached article reviews the principles involved and makes recommendations on the most efficient way to ventilate confined spaces where oxygen deficiency is a concern. It's a lengthy article but if you go to page 139, the recommendations are summarized.

T. G. Grumbles

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Attachment

Distribution: <u>SAFETY DIRECTORS</u>

Bruce Trego-Aber, Balt, Harry Peirce-Blane, Kathy Perez-Hmd, K. L. Fogg-LCCP, R. V. Gantz-LCLAB, G. M. Shirley-LCVCM, Brent White-Okc, R. B. Martin-Austin, J. R. Drumwright, Rick Quy

Ventilation to Eliminate Oxygen Deficiency in a Confined Space— Part III: Heavier-Than-Air Characteristics

Richard P. Garrison and Muzaffer Erig
School of Public Health, The University of Michigan, Ann Arbor, Michigan 48109

This study investigated characteristics of ventilation to eliminate oxygen deficiency caused by heavier-than-air (HTA) contaminants in confined space (CS) models. The HTA "contaminant" gases were carbon dioxide, halocarbon-22, and sulfur hexafluoride, having specific gravities (SG) of approximately 1.5, 3.0, and 5.0, respectively. Neutrally bouyant nitrogen (SG = 0.98) also was tested, consistent with previous studies. CS models having cubical and vertical noncubical shapes were tested. Other variable design parameters included ventilation mode (exhaust and supply), volume flow rate, inlet/outlet elevation, and sampling elevation inside the CS model. Testing confirmed that HTA contaminants would stratify in the CS models. Regressions of experimental data provide a means to calculate oxygen recovery times from initial deficiencies. Ventilation time was found to increase significantly with increasing contaminant SG. The effect was most pronounced at low CS model elevations. Supply ventilation was more effective than was exhaust. A low ventilation inlet/outlet elevation was considerably more effective than was a high elevation. Geometrically similar cubical models of different size performed in very similar manners. Results for vertical, noncubical CS models emphasized the importance of introducing ventilation near the bottom of the space. Guidelines for CS ventilation from this and previous studies, additional issues, and recommendations are discussed. **Garrison, R.P.; Erig, M.: Ventilation to Eliminate Oxygen Deficiency in a Confined Space—Part III: Heavier-Than-Air Characteristics. Appl. Occup. Environ. Hyg. 6:131–140; 1991.**

Introduction

Oxygen can be displaced and diluted inside confined spaces (CS) to the extent that the atmosphere inside the space is unsafe to breathe. Any air contaminant can cause this if present in sufficient quantities. Of course, toxic contaminants can also pose serious hazards in much smaller quantities, without causing oxygen deficiency.

Relatively nontoxic contaminants, for which oxygen displacement may be the primary potential hazard, and toxic contaminants may include gases having densities quite different from that of air. Gases having greater density than air are described as being "heavier-than-air." The specific gravity (SG) of a gas or vapor is defined as the ratio of the gas/vapor density to that of air. Specific gravity can be calculated by dividing the molecular weight (MW) of a given gas/vapor by 28.9, which is the average "molecular weight" for air as a mixture of oxygen (approximately 21%, MW = 32) and nitrogen (approximately 79%, MW = 28).

If a heavier-than-air (HTA) contaminant is released slowly, in sufficient quantity and without agitation, then it is possible for the contaminant to stratify, causing significantly higher concentrations in lower regions of confined spaces. Failure to recognize this has lead to accidents, including fatalities, during confined space entries.

This study examined characteristics of HTA contaminants in laboratory CS models. The overall objective was to observe and evaluate parameters affecting mechanical ventilation to eliminate oxygen deficiency caused by HTA contaminants. A second objective was to supplement an empirical database for CS model ventilation which could be used in the development of computer-designed models to predict CS ventilation performance.

This study is Part ~~III of~~ a series investigating ventilation characteristics to eliminate oxygen deficiency in confined spaces. Part I examined characteristics of a cubical CS model, using nitrogen (neutrally buoyant, SG = 0.98) with a relatively broad range of design parameters.[1] Part II also used nitrogen and investigated characteristics of noncubical CS models, constituting progressive expansions from the basic cubical configuration.[2] These studies have been part of a research project funded by the National Institute for Occupational Safety and Health.

Experimental Method

The experimental facilities and testing methods for this study were very similar to those of the two previous studies.[1,2] A "contaminant" was used to displace oxygen (O_2) inside a confined space model. Oxygen concentration (%O_2)

was measured at different locations inside the CS model, prior to and following mechanical ventilation of the model with fresh (uncontaminated) air. The primary differences from the experimental procedures followed in the two previous studies were:

- Contaminants other than N_2—specifically, the HTA gases carbon dioxide (CO_2), halocarbon-22 (chlorodifluoromethane, HC22), and sulfur hexafluoride (SF_6) were tested. The test gases were selected on the basis of specific gravity and of having relatively low hazard potential. They were introduced slowly at the bottom of the CS model to minimize dispersion prior to ventilation testing.
- Different sampling locations—with HTA contaminants, it was necessary to place greater emphasis on effects at different elevations inside the CS model. For this study, samples were taken at four elevations on the vertical central axis. In previous studies, the sampling locations were in different vertical quadrants of the CS models.
- Limited CS model configurations—in order to have a manageable number of tests in the final experimental protocol, it was necessary to reduce the number of CS model shapes and sizes and the variations of ventilation design parameters.

Figure 1 illustrates the CS model shapes, ventilation configurations, and sampling locations tested in this study. Three CS models were used: 1) a basic cubical shape (CS Model A); 2) a vertical, noncubical shape (CS Model E2) three times higher and greater (volume) than CS Model A; and 3) a double-sized cubical shape (CS Model B) geometrically similar to CS Model A and having eight times greater volume. The CS model designations A, E2, and B are the same as used in the previous study.[2] Additional designations (lower case letters) were also used to name specific test configurations for each model shape.

Table 1 summarizes the six CS model/ventilation/sampling configurations investigated in this study. These configurations were selected to provide four types of comparisons:

- CS Models Aa versus Ab versus Ac—ventilation flow rate variation for the basic cubical model, with flow rate measured in terms of air changes per hour (ACH), i.e., the 1-hour (60-minute) volume flow divided by the volume of the CS model.
- CS Models Aa versus Ba—doubling all CS Model ventilation and sampling dimensions (i.e., maintaining geometric similarity) and using the same nondimensional ventilation volume flow rate (ACH) for two cubical models of different size.
- CS Models Aa versus E2a—expanding the cubical model to a vertical, noncubical shape, with ventilation inlet/outlet (I/O) and sampling elevations moving proportionately to maintain the same nondimensional heights (%H, percent of CS model height, H) and the same nondimensional flow rate (ACH);
- CS Models Ab versus E2b—adding cubical volumes on top of the original basic cube to form a vertical, noncubical shape, keeping the actual dimensional flow rate (cfm) and the I/O and sampling elevations (inches) the same.

The final test protocol involved 96 test cases (6 × 2 × 2 × 4) consisting of the following: 6 CS model/ventilation configurations; 2 ventilation modes (exhaust and supply); 2 inlet/outlet elevations (25 and 75 %H); and 4 contaminants of different specific gravities (N_2, CO_2, HC22, and SF_6, having SG = 0.98, 1.50, 3.00, and 5.05, respectively). Four sampling elevations were monitored for each test case: at 10, 25, 40, and 70 %H for most cases.

Figure 2 shows the experimental facilities. A test run for

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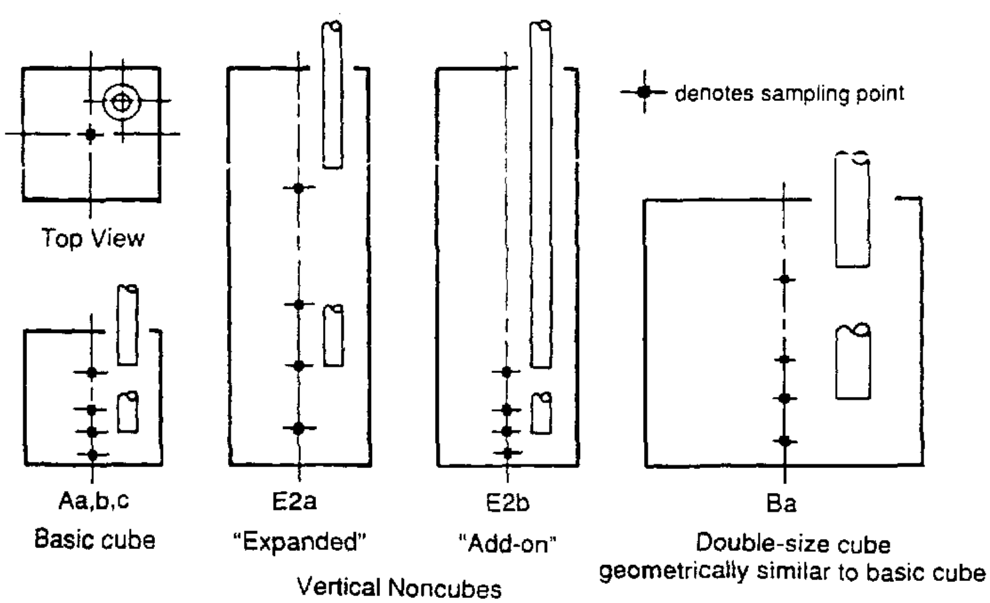

FIGURE 1. CS model configurations, with ventilation inlet/outlet and sampling elevations, for testing HTA contaminants.

TABLE I. Characteristics of CS Models Tested with Heavier-Than-Air Contaminants

Configuration	Description	CS Volume (cf)	Ventilation Flow Rate ACH	Ventilation Flow Rate cfm	Inlet/Outlet Elevations %H	Inlet/Outlet Elevations inches	Sampling Elevations %H	Sampling Elevations inches	Contaminant Volume (cf)
Aa	Basic cube and flow rate	8	20	2.7	25 75	6 18	10 25 40 70	2.4 6.0 9.6 16.8	4
Ab	Basic cube, high flow rate	8	60	8	25 75	6 18	10 25 40 70	2.4 6.0 9.6 16.8	4
Ac	Basic cube, higher flow rate	8	120	16	—	—	same as Aa & Ab	—	—
E2a	Vertical noncube, nondimensional expansion, sampling and I/O elevations moved upward	24	20	8	same as Aa	18 54	same as Aa	7.2 18.0 28.8 50.4	12
E2b	Vertical noncube, add-on volume expansion, sampling and I/O elevations in bottom cube	24	20	8	8.3 25	same as Ab	3.3 8.3 13.3 23.3	same as Ab	same as Ab
Ba	Double-sized cube, geometrically similar to basic cube	64	20	64	same as Aa	12 36	same as Aa	4.8 12.0 19.2	32

each case involved checking and adjusting all four sampling locations to read a nominal ambient concentration of 21.0 $\%O_2$; introducing the desired volume of a particular contaminant gas into the CS model; turning ventilation ON; and recording $\%O_2$ versus time (minutes) using a computer with analog/digital data conversion from the four-channel O_2 monitor. Data were collected continuously, with one measurement approximately every second for each sampling location until oxygen recovery was very nearly complete (within 0.1 $\%O_2$ of ambient).

The CS models were constructed of wood (four sides) and clear plexiglas (two sides). The overall dimensions (width × depth × height) of the CS models were as follows: Model A was 0.61 × 0.61 × 0.61 m (2 × 2 × 2 ft); Model E2 was 0.61 × 0.61 × 1.83 m (2 × 2 × 6 ft); and Model B was 1.22 × 1.22 × 1.22 m (4 × 4 × 4 ft). The circular CS top opening, located in the center of a quadrant, had a diameter of 15.2 cm (6 in.) for CS Models A and E2, and 30.4 cm (12 in.) for CS Model B. The inside diameter of the ventilation pipe was 5.1 cm (2 in.) for CS Models A and E2, and 10.2 cm (4 in.) for CS Model B.

A contaminant volume equal to 50 percent of the CS model volume was used for most test cases, consistent with previous studies using nitrogen. Each sampling location was connected to one sensor of a four-channel, electrochemical oxygen monitor (ENMET Corp). The same flow rate (approximately 0.25 L/min) was drawn through each sample line, connected to a manifold at the inlet of a small diaphragm pump. Ventilation flow rate was measured with a calibrated orifice plate and manometer.

Previous studies[1,2] have shown that oxygen recovery could be described reasonably well with a simple exponential relationship, specifically,

$$\%O_2 = 21-(21-B)e^{-Ct}$$

In this model, the coefficients (21 − B) and C represent the initial oxygen concentration and an oxygen recovery time constant, respectively. The time constant (C) describes the rate of oxygen recovery from an initial deficiency. This parameter can be used to calculate the ventilation time required for the oxygen level to change from an initial value to some final value.

$$\text{Ventilation time (min) for oxygen recovery} = \frac{\ln[(21-\%O_2\ \text{initial})/(21-\%O_2\ \text{final})]}{C}$$

Using this model, regressions were performed on the experimental data to obtain values for C. For the 96 test cases, and four sampling locations for each case, the av-

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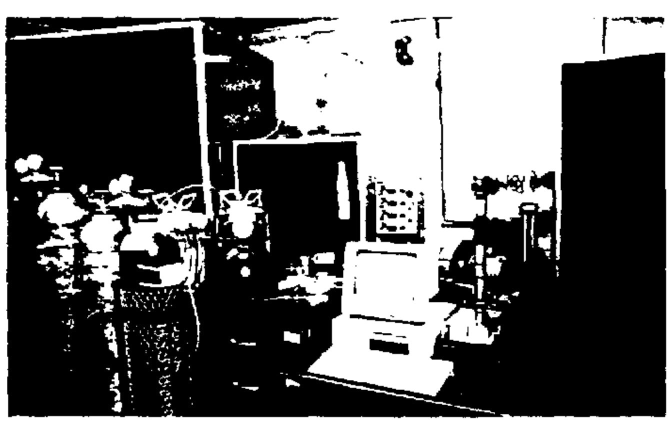

FIGURE 2. Experimental facilities showing CS models, with contaminant delivery, ventilation, sampling, and oxygen monitoring systems.

TABLE II. Regression Values of Oxygen Recovery Time Constant (C) for Exhaust Ventilation with Different Specific Gravity Contaminants and CS Model Configurations

CS Model Parameters				Oxygen Recovery Time Constant, C — Contaminants (Specific Gravity)			
Configuration	Volume Flow Rate (ACH)	Inlet Elevation (%H)	Sampling Elevation (%H)	N_2 (0.98)	CO_2 (1.50)	HC22 (3.00)	SF_6 (5.05)
Aa	20	25	10	0.27	0.10	0.07	0.05
			25	0.50	0.41	0.41	0.30
			40	0.62	0.61	0.61	0.44
			70	1.00	1.20	1.23	1.00
		75	10	0.32	0.02	0.013	0.012
			25	0.30	0.021	0.017	0.016
			40	0.32	0.043	0.036	0.035
			70	0.32	1.00	0.82	1.30
Ab	60	25	10	0.90	0.25	0.13	0.09
			25	0.80	1.10	1.00	0.73
			40	0.82	1.50	1.30	1.00
			70	0.82	2.40	2.20	1.70
		75	10	0.70	0.04	0.021	0.01
			25	0.61	0.045	0.027	0.011
			40	0.67	0.10	0.05	0.021
			70	0.67	1.20	0.80	0.50
Ac	120	25	10	1.20	0.50	0.20	0.14
			25	1.00	1.50	1.70	2.00
			40	1.00	2.10	2.30	2.50
			70	1.10	2.40	3.00	2.50
		75	10	0.95	0.055	0.04	0.014
			25	0.88	0.10	0.05	0.015
			40	0.80	0.24	0.22	0.04
			70	0.85	1.50	0.20	1.40
E2a	20	25	10	0.35	0.03	0.026	0.02
			25	0.33	1.00	0.60	0.50
			40	0.33	1.30	0.80	0.70
			70	0.33	1.50	1.40	1.10
		75	10	0.32	0.017	0.016	0.012
			25	0.32	0.02	0.045	0.035
			40	0.31	0.05	0.11	0.10
			70	0.33	2.00	2.00	2.40
E2b	20	8.3	3.3	0.90	0.17	0.11	0.09
			3.3	0.80	0.80	1.00	0.79
			13.3	0.80	1.00	1.50	1.00
			23.3	0.80	1.50	2.40	2.30
		25	3.3	0.70	0.022	0.018	0.014
			8.3	0.60	0.029	0.026	0.015
			13.3	0.70	0.06	0.06	0.022
			23.3	0.70	0.08	0.85	0.60

TABLE III. Regression Values of Oxygen Recovery Time Constant (C) for Supply Ventilation with Different Specific Gravity Contaminants and CS Model Configurations

CS Model Parameters				Oxygen Recovery Time Constants, C — Contaminants (Specific Gravity)			
Configuration	Volume Flow Rate (ACH)	Outlet Elevation (%H)	Sampling Elevation (%H)	N_2 (0.98)	CO_2 (1.50)	HC22 (3.00)	SF_6 (5.05)
Aa	20	25	10	0.84	0.30	0.16	0.11
			25	0.83	0.30	0.30	0.20
			40	0.80	0.31	0.30	0.30
			70	0.51	0.31	0.30	0.40
		75	10	0.41	0.10	0.04	0.027
			25	0.38	0.11	0.05	0.032
			40	0.41	0.20	0.11	0.087
			70	0.40	0.44	0.60	0.50
Ab	60	25	10	0.89	0.83	0.81	0.69
			25	0.86	0.84	0.81	0.69
			40	0.92	0.88	0.82	0.69
			70	0.92	0.89	0.81	0.68
		75	10	0.92	0.75	0.48	0.20
			25	0.88	0.74	0.49	0.30
			40	0.94	0.82	0.69	0.53
			70	0.92	0.83	0.70	0.60
Ac	120	25	10	1.40	1.50	1.20	0.65
			25	1.40	1.50	1.30	0.80
			40	1.40	1.00	1.30	0.80
			70	1.48	1.40	1.20	0.65
		75	10	1.50	1.50	0.70	0.60
			25	1.60	1.40	0.80	0.65
			40	1.55	1.40	0.70	0.70
			70	1.60	1.30	0.50	0.70
E2a	20	25	10	0.61	0.30	0.28	0.20
			25	0.61	0.30	0.37	0.30
			40	0.61	0.30	0.37	0.35
			70	0.59	0.31	0.37	0.30
		75	10	0.41	0.14	0.14	0.07
			25	0.42	0.20	0.20	0.12
			40	0.42	0.39	0.43	0.30
			70	0.42	0.43	0.42	0.25
E2b	20	8.3	3.3	0.90	0.70	1.00	0.68
			8.3	0.86	0.50	0.87	0.69
			13.3	0.92	0.53	0.77	0.69
			23.3	0.92	0.54	0.80	0.60
		25	3.3	0.90	0.45	0.40	0.20
			8.3	0.90	0.42	0.55	0.33
			13.3	0.92	0.44	0.67	0.55
			23.3	0.92	0.43	0.70	0.63

erage coefficient of determination (R^2) was 92 percent, ranging from 80 to 99 percent. The standard errors of the regression estimates of C were within 1–5 percent. These results were considered acceptable, although previous studies involving only N_2 were found to have somewhat higher R^2 and lower standard errors.

Results

Tables II and III provide the regression values of C for all of the test cases except those involving CS Model Ba, which are adequately represented by the data for CS Model Aa (discussed subsequently). Values of C are given for each sampling elevation, for the test configurations, and for exhaust (Table II) and supply (Table III) ventilation. These tables supplement the database of C values established in the previous two studies.[1,2] The regression database can be used to compare ventilation effectiveness for different CS model situations. A one hundredfold difference in C values represents a one hundredfold difference in ventilation time, e.g., 3.9 minutes when C = 1.2 and 390 minutes when C = 0.012 for oxygen recovery from 10 to 20.9 $\%O_2$.

Figures 3 and 4 present oxygen recovery characteristics ($\%O_2$ versus minutes) of HTA contaminants for the basic cubical CS Model Aa at a flow rate of 20 ACH. Figure 3 compares results for the lightest (N_2, SG = 0.98) and heaviest (SF_6, SG = 5.05) gases at three sampling elevations (10, 25, and 40 %H) for exhaust and supply ventilation

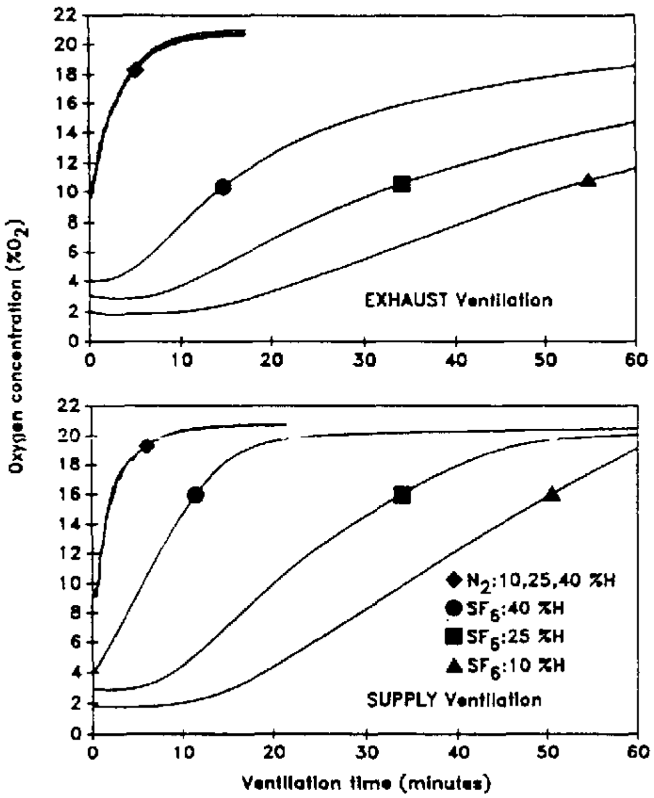

FIGURE 3. Oxygen recovery for the cubical CS Model Aa for N_2 and SF_6 at three sampling elevations (10, 25, 40 %H), with high (75 %H) I/O elevation at 20 ACH.

at high (75 %H) I/O elevation. Figure 4 shows O_2 recovery for the same CS Model Aa at 20 ACH, with high (75 %H) and low (25 %H) I/O elevations for all four contaminants (N_2, CO_2, HC22, and SF_6) at the lowest (10 %H) sampling elevation.

Figure 5 provides a general comparison of the two cubical models of different size (CS Models Aa and Ba) which were geometrically similar and were ventilated at the same nondimensional volume flow rate of 20 ACH. Data were taken from O_2 recovery curves of all 32 test cases for these models. The purpose of this comparison was to evaluate whether findings for small-scale laboratory models could be applied reasonably to larger models, perhaps ultimately to actual confined spaces.

Estimating the length of time needed to ventilate a confined space is a fundamental design objective. For O_2 deficiency, it is obviously a function of the rate of recovery, which can be represented empirically by an O_2 recovery time constant (C). Previous studies[1,2] have compared different CS models using ventilation times calculated using regression values of C; specifically, "delta T," the time for nearly (99%) complete recovery from a 10 $\%O_2$ initial level to 20.9 $\%O_2$. For consistency, this same time parameter was used for comparisons in this study. However, it should be kept in mind that recovery often required more time, sometimes considerably more, for HTA conditions involving initial oxygen levels below 10 $\%O_2$ and, therefore, requiring additional time to reach 10 $\%O_2$.

Figure 6 illustrates effects of changing ventilation volume flow rate on ventilation time, delta T, for oxygen recovery from 10 to 20.9 $\%O_2$, calculated from time constants in Tables II and III. These data are for the basic cubical shape (CS Models Aa, Ab, and Ac) for all four contaminants under exhaust and supply ventilation with low (25 %H) I/O elevation.

Figure 7 provides comparisons of ventilation time characteristics for cubical (CS Models Aa, Ab) and larger, vertical, noncubical (CS Models E2a, E2b) configurations. These comparisons present data for the lowest sampling elevation, for which oxygen recovery times were greatest. Consequently, the HTA characteristics illustrated are more pronounced than they were at higher sampling elevations.

The comparisons of Figure 7 include significant differences in ventilation design. CS Models Aa and E2a utilized the same *nondimensional* design parameters: ventilation flow rate of 20 ACH (2.7 cfm for Aa; 8.0 cfm for E2a); I/O elevations of 25 and 75%H; and sampling elevation at 10 %H. CS Models Ab and E2b had the same *dimensional* design parameters: ventilation flow rate of 8 cfm (60 ACH for Ab; 20 ACH for E2b); I/O elevations of 6 and 18 inches; and a sampling elevation of 2.4 inches. Figure 7 can be described as involving comparisons between the basic cubical CS model and a proportional, threefold, vertical "expansion" of the cube and the ventilation design parameters (Aa versus E2a) and comparisons between the basic cube and a vertical noncube made by "adding on" two cubic volumes on top of the basic cube, leaving the ventilation design in the bottom cube unchanged (Ab versus E2b).

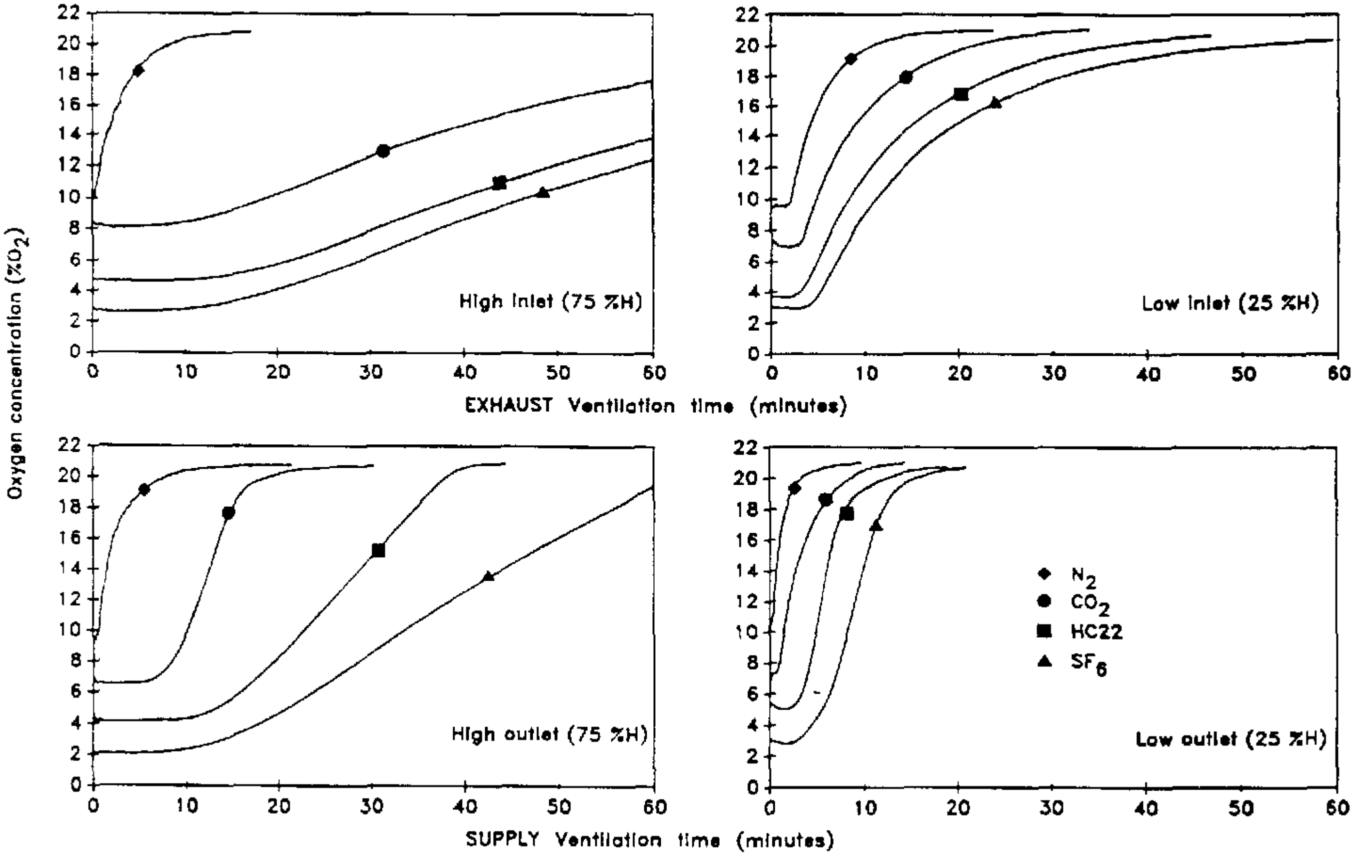

FIGURE 4. Oxygen recovery for the cubical CS Model Aa at the lowest sampling elevation (10 %H) for exhaust and supply ventilation at 20 ACH.

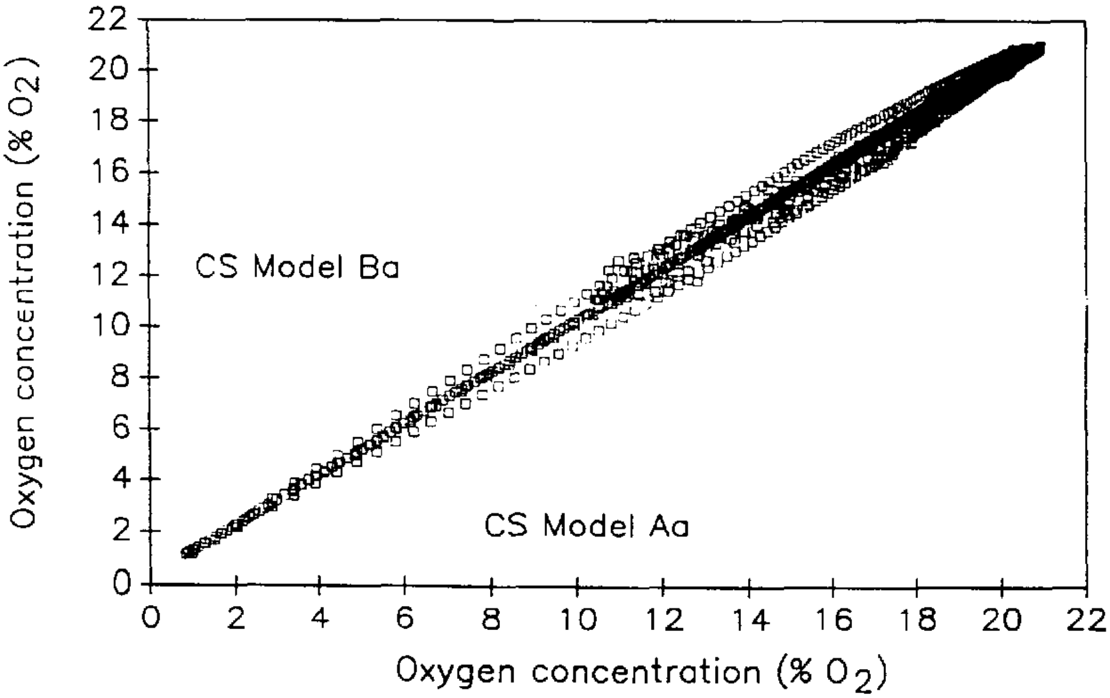

FIGURE 5. Comparison of oxygen recovery data for two geometrically similar cubical CS models (Ba vs. Aa) of different size for all test cases, with ventilation at 20 ACH.

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Discussion

In all of the test cases, mechanical ventilation caused more rapid air mixing and contaminant dilution than would have occurred without it. Figures 3–7 show that recovery from HTA contaminant stratification and oxygen deficiency occurred within periods of time ranging from minutes with effective ventilation design to hours for heavy contaminants with poor ventilation design. Preliminary testing indicated that O_2 recovery by diffusion alone would take much longer—roughly 24–36 hours for the basic cubical CS model containing SF_6.

Contaminant density had a significant effect upon ventilation effectiveness. Figures 3, 4, 6, and 7 show that ventilation time generally increased with increasing contaminant density. This effect was most pronounced for the lowest (10 %H) elevation in the CS models, as shown in Figure 3. Differences between contaminants were least evident for effective air mixing, such as caused by low (25 %H) outlet supply ventilation in Figures 4, 6, and 7.

Supply ventilation was generally more effective than exhaust ventilation. Figures 3, 4, 6, and 7 show supply ventilation causing oxygen recovery in less time than for exhaust under otherwise identical conditions for all of the CS models. This advantage tended to improve with increasing contaminant density (Figures 3, 4, 6, and 7), was greatest at low elevations (Figure 3), and was not affected significantly by CS shape variations (Figure 7). The magnitudes of the differences between supply and exhaust ventilation can be dramatic, e.g., from several minutes for complete recovery under supply ventilation to an hour or more for HTA contaminants under exhaust ventilation. The reason for more rapid contaminant dilution under supply ventilation is the increased dynamic mixing caused by the airflow jet discharged from the ventilation outlet.

I/O elevation was found to have very significant effects upon ventilation characteristics. Figures 4 and 7 show that ventilation time was less for low (25 %H) I/O elevations compared to higher (75 %H) elevations. This advantage of low I/O over high I/O was most pronounced for high contaminant densities and low CS model sampling elevations (Figure 4).

Ventilation volume flow rate can significantly affect ventilation time for oxygen recovery. Figure 5 shows ventilation time, delta T, dropping substantially for increasing volume flow rate (ACH) for both supply and exhaust ventilation. This increase was not in proportion to change in flow rate. A three-times change from 20 to 60 ACH reduced ventilation time for HTA contaminants by less than 50 percent for exhaust ventilation and by variable amounts with different contaminants for supply ventilation at the lowest (10 %H) sampling elevation, with different characteristics at higher elevations. Reductions in ventilation time were observed over the full range (20–120 ACH) tested for exhaust, but there was little improvement above 60 ACH for supply ventilation for the cubical CS Model A.

Geometric similarity is necessary for two CS models of different size to experience similar ventilation perfor-

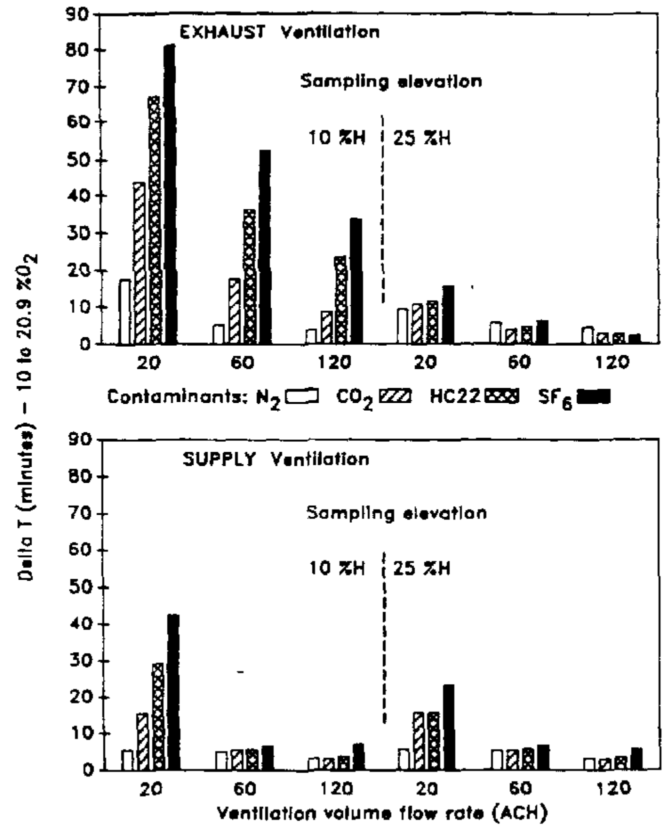

FIGURE 6. Oxygen recovery times, delta T(10–20.9 %O_2), for different ventilation volume flow rates (cubical CS Models Aa, b, c) for different contaminants, with low (25 %H) I/O elevation.

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mance. Similarity must apply for both the CS configuration and the ventilation design. Figure 6 shows that geometric similarity was sufficient for the two cubical CS models (Aa and Ba) of this study to exhibit nearly the same oxygen recovery. Empirical results such as found by this study (Tables II and III) are limited to the CS model and ventilation design parameters which were tested. Geometric similarity may make it possible to extend application of the data to larger field CS situations. However, it may be unlikely that any field spaces will conform closely enough to the test data to allow highly accurate predictions of ventilation time.

This study allows limited consideration of CS shape effects; specifically, Figure 7 provides comparisons of cubical and vertical, noncubical CS models. The effects of differences between cubical CS Model Aa and the "expanded," noncubical Model E2a include a three times greater ventilation rate and amount of contaminant. Higher flow rates (cfm) for CS Model E2a resulted in increased vertical air flow velocities through the unchanged horizontal cross-sectional areas of the CS model and the ventilation pipe. Higher velocities caused increased air mixing within CS Model E2a. Low (25 %H) elevation supply ventilation was most effective for eliminating O_2 deficiency in both the cubical and noncubical CS models. Findings for the "expanded," vertical, noncubical CS model indicate a signif-

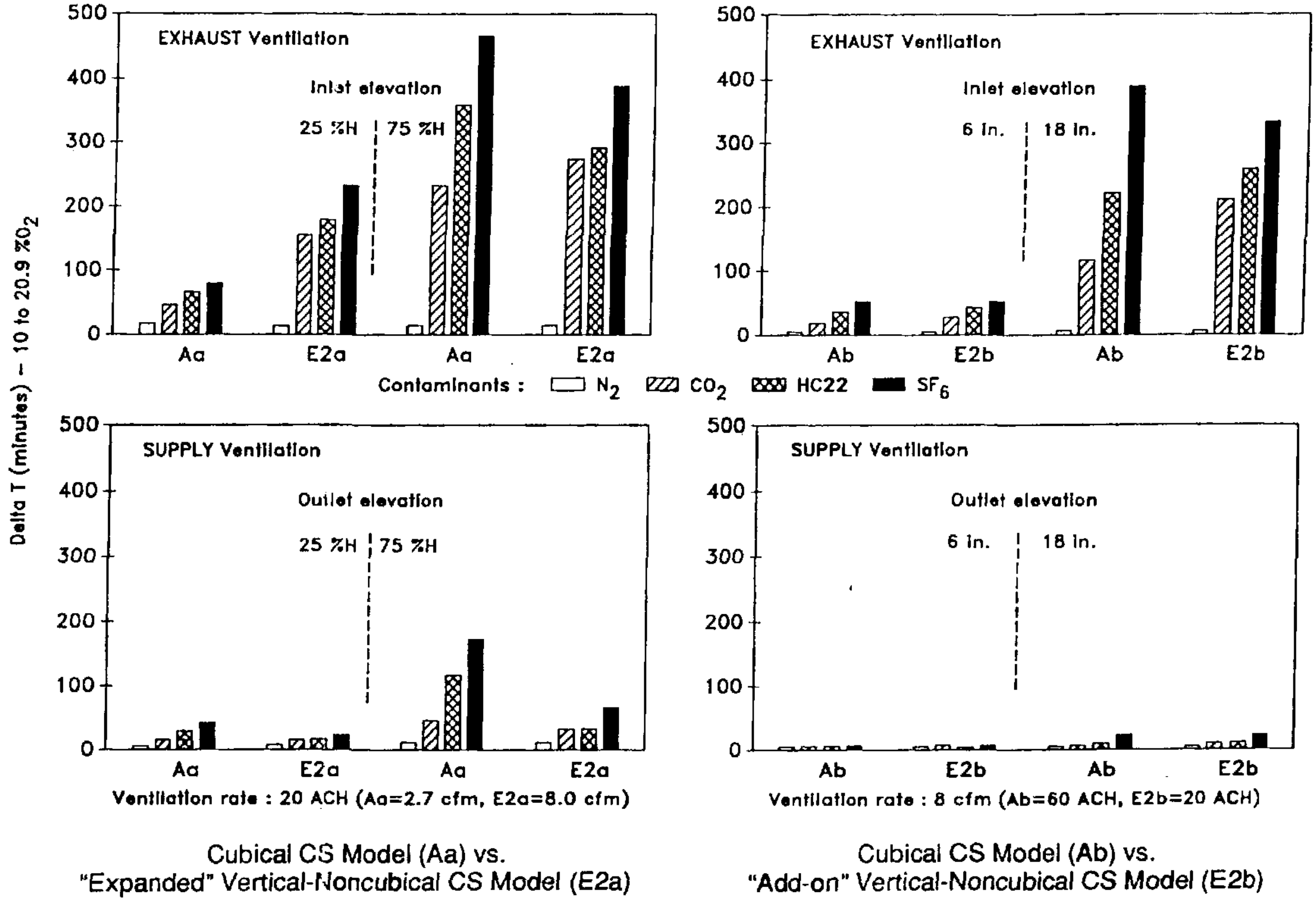

FIGURE 7. Oxygen recovery times, delta T (10 to 20.9%O_2), for the cubical and the vertical, noncubical CS models. Aa and E2a had the same nondimensional ventilation design parameters (ACH,I/O-%H). Ab and E2b had the same dimensional parameters (cfm, I/O-inches).

icant advantage in reducing ventilation time when using low I/O elevation for HTA contaminants.

Findings for the "add-on," vertical, noncubical CS model also show the importance of providing ventilation near the bottom of a CS containing HTA contaminants. Ventilation characteristics for the cube and vertical noncube were similar, suggesting that ventilation design for the "cubical" bottom of a vertical noncube may be predicted reasonably well using cubical CS model data, with relatively little shape (depth) effects.

Data in Figures 3, 4, 6, and 7 show that N_2 was not a good predictor for HTA contaminant effects. Nitrogen was the only contaminant used in the previous studies of cubical and noncubical CS models.[1,2] Findings for nitrogen may be more useful for dilution ventilation to control toxic contaminants in low concentrations for which the mixture density is nearly the same as that of air.

The relationships between CS ventilation design parameters (e.g., CS shape, contaminant SG, ventilation I/O, ACH, and location/elevation in CS) are very complex. Combining these with other relevant parameters (many not yet studied) would result in an empirical database so complicated as to defy almost any effort to establish a rational, accurate, and comprehensive computer design model based solely on empirical findings. A truly comprehensive design model for confined space ventilation probably must come from an analytical basis. This requires developing user-friendly computer programs to solve difficult mathematical models.

Research should continue towards development of practical guidelines for effective CS ventilation. More field testing is needed. This will enhance working experience and improve the predictive capability of laboratory experiments, particularly when done in conjunction with scale model testing. The development of analytical models should be encouraged. Such models could be tested and evaluated against the empirical database obtained in these studies for oxygen deficiency. There are many additional and untested design parameters, such as different CS model shapes (e.g., cylindrical), internal CS surfaces, more than one CS opening, and CS opening size variation, to list a few.

Guidelines and Recommendations

The conclusions from this study, and those from the two previous studies,[1,2] help to establish a framework of design guidelines for CS ventilation which can be summarized as follows:

- Air movement caused by mechanical ventilation will greatly enhance contaminant dilution inside a CS. Contaminant dilution by diffusion and/or natural ventilation can be much slower than with mechanical ventilation.
- Heavier-than-air contaminants can stratify inside confined spaces. Rates of contaminant dilution tend to decrease as contaminant density increases, especially near the bottom of a confined space.
- Supply ventilation is generally more effective than exhaust in reducing the length of time required for dilution of atmospheric contaminants because air mixing is enhanced by the supply jet. Decisions to ventilate by either supply or exhaust methods should also include considerations of other advantages and disadvantages (discussed subsequently).
- A directed supply jet of fresh air can provide very effective air mixing and dilution, such as rapid oxygen recovery, at locations aligned with the jet. It is highly advisable in many CS ventilation situations to direct fresh air to the breathing zones of workers.
- Low ventilation I/O elevations (e.g., less than 25 %H) are generally more effective than higher I/O elevations (e.g., above 75 %H). This characteristic can be pronounced for HTA contaminants, increasing with contaminant density.
- Ventilation volume flow rate can have significant effects upon ventilation time. Reductions in ventilation time typically are not proportional to increases in volume flow rate. Benefits from exceeding 60 ACH may be minimal for supply ventilation. Flow rates below 20 ACH are not recommended for most CS situations.
- If geometric and air flow similarity are maintained between two confined spaces of different size (i.e., same CS and ventilation geometry and same ACH), then they will probably have similar ventilation characteristics. If geometric similarity is not maintained, then ventilation characteristics may be very different.
- The shape of a CS can have significant effects upon ventilation characteristics. HTA contaminants may cause substantial differences between characteristics of cubical versus noncubical shapes in vertical and horizontal orientations. A cubical CS model may be able to predict ventilation effects in the "cubical end" of a noncubical CS.
- Variations in ventilation effects with CS shape (e.g., cubical versus noncubical) are less pronounced when contaminant density is not significantly different from air, such as for neutrally buoyant nitrogen and for toxic contaminants in relatively low concentrations.

Findings from these studies do not address all important issues of ventilation control for confined spaces. Consideration should be given to other important engineering and administrative control measures, to advantages and disadvantages of different ventilation alternatives, and to ventilation equipment, testing, and training.

Mechanical ventilation of a confined space does not preclude the importance of strict administrative control measures for safe CS entry. Both engineering and administrative controls are needed unless either can be confirmed to be unnecessary (and this can be difficult to do). Entries should be avoided whenever possible. Confined spaces should always be opened as much as possible prior to entry.

Advantages of supply ventilation for a CS can include: rapid and moveable localized dilution directly to worker breathing zones; it can cause more effective air mixing throughout the CS; and it can accomplish mancooling. Disadvantages include: enhanced dispersion/evaporation of

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dusts/liquids; contaminant discharge from CS openings; contaminant buildup if supply air is not fresh; and possibly hazardous mancooling with cold ambient temperatures.

Advantages of exhaust ventilation include: the tendency to be nondispersive of contaminants; contaminants can be discharged away from CS openings; localized control is possible if inlets are positioned close to localized sources; and lower general air flow velocities can reduce mancooling effects. Disadvantages of exhaust ventilation include: less effective general air mixing and dilution; the possibility of drawing contaminants through breathing zones; and the possibility of high localized contaminant concentrations.

Local exhaust ventilation (LEV) can be used effectively in confined spaces provided the inlets (hoods) can be kept close enough to localized contaminant sources. LEV offers the possibility of air cleaning to remove contaminants. LEV may not have sufficient volume flow rate to satisfy needs for dilution ventilation if contaminants are not captured at the hood(s).

Natural ventilation, typically caused by wind and/or thermal convection, can have significant effects upon contaminant concentrations in confined spaces. Natural ventilation has the advantage of not being subject to mechanical failure. However, it can also be changeable without warning and should be used only with strict administrative controls. Natural ventilation should be utilized to whatever extent it may exist. However, mechanical ventilation should be required whenever highly toxic contaminants are present.

Equipment limitations can be significant factors in ventilation design for a particular CS entry. Ventilation time is a function of the fan volume flow rate. Planning and designing for CS ventilation should be made well before an entry is needed in order to be certain that proper equipment will be available. Ventilation equipment can cause problems for egress, visibility, communication, undesired mancooling, and other aspects of CS entry safety.

Testing before and during CS entries should always emphasize monitoring for atmospheric contaminants, even when effective ventilation is in place. Testing during CS entries should also include observations and measurements of ventilation parameters to help evaluate ventilation effectiveness.

Training for CS entries should include setup and operation of all ventilation equipment for all persons involved in routine entries and emergency rescues. Training should address ventilation testing and the calibration and operation of gas/vapor/oxygen monitoring instruments. It should emphasize "hands-on" experience. Training drills at actual confined spaces, with potentially hazardous contaminants present, are highly recommended in addition to classroom instruction.

There will be some CS entries for which ventilation is impossible, such as when air must be excluded from the CS (e.g., pyroforic catalysts) or when space size and geometry prevent effective ventilation (e.g., long, complex utility tunnels). It is advisable to provide ventilation as close as possible to work areas that cannot be ventilated directly. It is necessary in such situations to place special emphasis on administrative controls to offset the loss of safety resulting from poor or nonexistent ventilation.

Poor ventilation is a defining characteristic of a confined space. There is great need to improve the awareness of potential atmospheric hazards in CS and of ventilation as a primary means of control. More specific information is needed on methods for implementing effective CS ventilation.

Mechanical ventilation, even lacking solid comprehensive quantitative design criteria, should be used for most confined space entires. Mechanical ventilation does what no administrative control can do (e.g., entry attendant, permit, atmospheric testing, or personal protective equipment)—it will directly reduce concentrations of potentially hazardous air contaminants in confined spaces.

References

1. Garrison, R.P.; Nabar, N.; Erig, M.: Ventilation to Eliminate Oxygen Deficiency in a Confined Space—Part I: A Cubical Model. Appl. Ind. Hyg. 4:1–11 (1989).
2. Garrison, R.P.; Erig, M.: Ventilation to Eliminate Oxygen Deficiency in a Confined Space—Part II: Noncubical Models. Appl. Ind. Hyg. 4:260–268 (1989).

Received 12/26/89; review decision 2/23/90; revision 8/3/90; accepted 9/4/90

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Interoffice Communication

TO: Distribution

FROM: T. G. Grumbles
DATE: February 15, 1991

SUBJ: CMA CAER WORKSHOP

XF: none

VISTA

Attached is information regarding regional CAER implementation workshops. It appears this workshop is focusing on employee and community outreach.

T. G. Grumbles

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Attachment

Distribution: SAFETY DIRECTORS

Bruce Trego-Aber, Balt, Harry Peirce-Blane, K. L. Fogg-LCCP, R. V. Gantz-LCLAB, G. M. Shirley-LCVCM, Brent White-Okc, R. B. Martin-Austin, J. R. Drumwright, Rick Quy

cc: PLANT MANAGERS

R. W. Seymour-Aber, L. R. Bauer-Balt, G. D. Williams-Blane, J. Pavao-Hmd, J. Friend-LCCP, J. W. Ware-LCLAB, R. A. Conrad-LCVCM, H. D. Garrison-Okc, P. L. Foote-Prem, V. W. Weiss-Austin

ENVIRONMENTAL COORDINATORS

F. G. Jeanson-Aber, D. L. Mahler-Balt, G. D. Williams-Blane, Matt Tonkovich-Hmd, M. G. Hayes, G. L. Foshee, J. L. Johnson, Julie Bozich, Diane Johnson-LCCP, Tony Salah-LCLAB, D. R. Booth-LCVCM, Joyce Callen-Okc, G. C. Lipps-Prem, R. B. Martin, J. R. Roheim-Austin, R. B. Quy

M. S. Reynolds, C. Bozman, M. A. Stephenson

Registration Form

Please register the following person(s) for the **CAER Code of Management Practices Workshop**. A check in the amount of $________ ($175 per person) is enclosed.

Mail registration form and check or money order, payable to the Chemical Manufacturers Association, to: Heather Feltmate, Chemical Manufacturers Association, 2501 M Street, N.W., Washington, DC 20037. Refunds will be made if cancellations are received at least two weeks before the date of the workshop.

Workshop Location:		Register by:
______4/10/91	New Orleans, LA	4/1/91
______4/24/91	Chicago, IL	4/9/91
______5/14/91	Sacramento, CA	5/6/91

So we can better identify you on your meeting badge, please register using your name as you wish it to appear on the badge.

Name ____________________

Title ____________________

Name ____________________

Title ____________________

Company ____________________

Address ____________________

City ____________________

State ____________ Zip ____________

Phone ( ) ____________________

Workshop Agenda

8:00-8:30 a.m.	**Registration and Continental Breakfast**
8:30-8:45	**Welcome and Opening Remarks** James Hinton, *Chairman* *CAER Task Group* *Dow Chemical U.S.A.—Texas Operations*
8:45-9:00	**Welcome from the Chemical Industry Council**
9:00-10:15	**Community Outreach Overview** Members of the Responsible Care Public Advisory Panel • History and overview of the code • The need for community outreach • The benefits of community outreach
10:15-10:30	**Break**
10:30-12:00 noon	**Three Concurrent Break-Out Sessions:**
SESSION 1:	Community Advisory panels • Who is involved • Function of the panel • How it works • Types of panels
SESSION 2:	Employee Participation and Communications • Stimulating interest • Methods of communication • Employees' role in outreach activities
SESSION 3:	Outreach to Target Audiences • Educators and students • Local, state and federal officials • Medical community
12:00-1:00	**Lunch**
1:00-2:30	**Repeat Three Concurrent Workshops**
2:30-2:45	**Break**
2:45-4:15	**Repeat Three Concurrent Workshops**

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Hotel

A block of rooms has been reserved at the following hotels for the CMA workshops. This block of rooms will be held until two weeks prior to the workshop.

After that date, room reservations will be subject to availability. Please refer to the CAER Code Workshop when making reservations.

New Orleans, LA April 10, 1991	Royal Sonesta Hotel 300 Bourbon Street New Orleans, LA 70140 (504) 586-0300 Room Rate: $115/Single
Chicago, IL April 24, 1991	The Westin Chicago 909 N. Michigan Ave. Chicago, IL 60611 (312) 943-7200 Room Rate: $130/Single
Sacramento, CA May 14, 1991	Sacramento Hilton Inn 2200 Harvard Street Sacramento, CA 95815 (916) 922-4700 Room Rate: $78/Single $85/Double

CMA IS NOT RESPONSIBLE FOR MAKING HOTEL RESERVATIONS.

The Responsible Care CAER Code of Management Practices Workshop

Public outreach programs are becoming an increasingly important part of the chemical industry. The ability to deal with the public and its specific segments is becoming a more valuable skill for plant managers to have in the 1990s.

The chemical industry bears greater scrutiny from environmental groups and their growing membership, the media and a more skeptical public. Title III and its reporting requirements have raised the profiles of chemical facilities in the community.

CMA and its member companies have long emphasized community outreach. The public has to become aware of industry operations and the industry has to be sensitive to community concerns. Under Responsible Care, the Community Awareness and Emergency Response, or CAER, process is the vehicle for communicating the industry's commitment to improving its operations. CAER participation is an obligation for CMA members. They have to get into the community. But they also should want to for the benefits it brings.

At the three CAER workshops planned this spring, participants will learn how to meet the community awareness elements of the CAER Code of Management Practices. Speakers and panelists will discuss their experiences in communicating with a number of specific audiences. Each speaker will discuss strategy and methods of outreach.

Panelists for this workshop will be industry representatives and members of the public.

This workshop will be beneficial for plant managers, CAER coordinators and others involved in communication with the community.

Registration

Registration for the **CAER Code Workshop** is $175 per person, which includes breakfast, lunch and beverage breaks.

Telephone registration and cancellations will be considered binding. To register, please notify CMA by close of business April 1 (New Orleans), April 9 (Chicago), May 6 (Sacramento). If you have registered and are unable to attend, please call (202) 887-1273 by dates listed. CMA cannot make a refund for cancellations received after those dates. To register, detach and mail the registration form along with a check or money order payable to the Chemical Manufacturers Association to:

Heather Feltmate
Chemical Manufacturers Association
2501 M Street, N.W.
Washington, D.C. 20037
(202) 887-1273

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The Responsible Care CAER Code of Management Practices Workshop

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CHEMICAL MANUFACTURERS ASSOCIATION

Responsible Care
A Public Commitment

TO: R. D. Gamblin

FROM: T. G. Grumbles
DATE: February 15, 1991

SUBJECT: PROGRESS REPORT

VISTA

Interoffice Communication

1. The draft Responsible Care Employee Safety and Health Code is out for review by CMA Member Companies. It has been distributed internally and comments are due back prior to April 1.

2. The initial Responsible Care Distribution Code is out for self-evaluation. This code is difficult to review because multiple departments and locations are involved in the code element areas. S&T, Manufacturing and Environmental all have ownership of the code elements.

3. A visit was made to Sun Polymers in Baton Rouge to assess their capability to process Aberdeen No. 2 Pond Resin. Sun Polymers already handles off-grade PVC materials for Vista. Sun also processes PVC from BFG, Oxy, Certainteed, Georgia-Gulf and Formosa. The plant is not run the way Vista would operate, but considering the low hazard of the PVC, is a reasonable risk.

4. JCL and Aberdeen Plant personnel met with MS DEQ to discuss renewal of the Aberdeen Air Emission Operating Permit. The MS Air Toxics Policy was discussed in detail and our consultant, Peter Voytek of Clement International, presented information on the appropriate vinyl chloride unit risk factor. DEQ will contact EPA regarding the unit risk factor and get back to us.

5. JCL and Dave Penney of R&D met with EPA Office of Toxic Substances regarding a potential SARA 313 delisting petition for di-n-octylphthalate. Our alcohol customer, Aristech, also attended the meeting. The intent of the meeting was to get an indication from EPA of our chances of successfully delisting DNOP. At this time, chances seem slim, due to potential objections from the EPA Office of Water. A meeting with OW is being arranged by our outside counsel.

T. G. Grumbles
/ljw