

PART ONE

THE RECIRCULATION OF EXHAUST AIR

A Seminar

sponsored by

**National Institute for Occupational Safety and Health
Cincinnati, Ohio**

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PREFACE

The National Institute for Occupational Safety and Health sponsored a seminar on "The Recirculation of Exhaust Air" October 23 and 24, 1975 in Cincinnati, Ohio. The objective of this seminar was to critique and review the results of a previous exhaust air recirculation criteria development effort and to provide guidance for future development of criteria. The proceedings are included in Part One.

The previous exhaust air recirculation development was performed by contract by the Southwest Research Institute. The results of this effort are included as Part Two. It is to be noted that the criteria presented is conceptual in nature and is not to be considered as final criteria for the recirculation of exhaust air.

The seminar was coordinated by Mr. Franklin A. Ayer of the Technology and Resource Management Department, Research Triangle Institute. Mr. Robert T. Hughes of the Control Technology Research Branch, Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health was seminar chairman.

The Recirculation of Exhaust Air

ABSTRACT

The recirculation of exhaust air has been considered as a means for reducing industrial energy requirements for over 25 years. Recently the need to conserve energy has become crucial, and specific questions regarding recirculation have arisen.

NIOSH sponsored a study by the Southwest Research Institute to develop technical performance criteria for recirculated exhaust air systems. The purpose of this seminar was to review that study, look for gaps in the state-of-the-art, and, through a convergence of disciplines, form an accurate picture of the feasibility of recirculation.

Topics covered include threshold limit values for toxic substances, cost-effectiveness, performance standards, and reengineering--parameters that scientists and engineers would use in developing recirculation systems. Various techniques for monitoring contaminants were discussed and specific design suggestions were given.

It was concluded that recirculation is both necessary and feasible, although no single ventilation manual will emerge as a panacea. Designing of new systems, where possible, is preferable to remodeling or adding on. Finally, competent maintenance and recordkeeping and a program of regular reevaluation must be included in any recirculation system that is to remain safe and efficient.

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WELCOME

Elliott S. Harris, Ph.D.*

I would like to welcome you here this morning, on behalf of NIOSH. I would like to give you just a little background to NIOSH, why we exist and what we do.

Under the Occupational Safety and Health Act of 1970, Congress set up two groups to provide for the mandate that the worker shall be able to work without injurious effects to his health or reduction of his life span, for his working lifetime.

The two agencies that were set up were the Occupational Safety and Health Administration and NIOSH, which is the National Institute for Occupational Safety and Health. Now in its wisdom Congress set them up in two separate agencies. OSHA is in the Department of Labor; NIOSH is in Health, Education, and Welfare.

OSHA is that agency which promulgates the standards and enforces the standards. NIOSH is that agency which provides research and background to help OSHA develop those standards. We develop standards here; we do not promulgate them. We go through a regular formal and legal promulgation procedure.

NIOSH research covers a wide range. We have several divisions. The Division of Technical Service provides a service to labor and industry to determine whether a hazard exists in the workplace. A request comes in for them to do a hazard evaluation; they go out and determine whether dangerous conditions do exist, the nature of the dangerous conditions if they do exist, and they make recommendations for their alleviation.†

The Division of Field Studies and Clinical Investigation‡ works on a broader scale. It works on an industrywide scale doing epidemiological evaluations and determining whether there is any specific disease entity which is peculiar to a given industry. If such a disease entity exists, then the next step is to determine what the causative agent is and if in any way it can be alleviated.

Interrelated with these two other divisions is the Division of Laboratories and Criteria Development.§ That is the division that we are associated with. We provide both laboratory support to these other divisions, and a laboratory research capability, which is at the present time quite encompassing.

We start out from the biological end with a branch in Toxicology. It does experimental work in animal toxicology, looking at dust, fumes, mist, gases, and what the biological responses to these contaminants are. This branch determines the nature of the response and also it quantitates that response, and eventually this information comes out in the form of one of the aspects of a recommendation for a standard.

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†This effort is now in the Division of Surveillance, Hazards Evaluation and Field Studies.

‡Now the Division of Surveillance, Hazards Evaluation and Field Studies.

§Now the Division of Biomedical and Behavioral Science and the Division of Physical Sciences and Engineering.

On the biological end we also have a branch for Physiology and Ergonomics, where they are concerned with such things as heat standards in the workplace. They are concerned with the handling of materials, biodynamics. They are concerned with the effect of vibration on the worker, whether it be segmental or whole body vibration, and there is a difference between the way the two will affect an individual.

We can go on and say we also have psychologists who are worried about motivation and also the effects of stress on heart disease, on cardiovascular problems. They are also concerned about the psychological aspects of safety.

Supportive to these other branches and also working in parallel with them is the physical end. The physical end consists of our Physical and Analytical Chemistry Branch, which develops methodologies for determining the contaminants.

We go on then to the branch that is sponsoring this particular seminar today. That is the Engineering Branch. The Engineering Branch covers a wide variety of functions. It is concerned with the development of criteria for the certification of respirators and safety devices. They are concerned with such things as the measurement of heat stress. Bob is involved in that. They are concerned with the development of sampling procedures. They are very widely diversified.

The main reason that you are here today is that as a result of the energy crisis or the energy crunch we are finding a new emphasis on our efforts. We are finding that not only must we look for new sources of fuels, but we've got to concern ourselves with the conservation of the fuels that we have.

One of the aspects of conservation is that we must not be so profligate with our air, the air which is already tempered. We are going to have to take the tempered air and recirculate it, and reduce the amount of energy that is put into the air as it comes back through.

But when you recirculate the air, as you discuss it today, the stuff that comes back with it--the dust, the gases--has got to be removed; otherwise you will have a continuous buildup of toxic contaminants.

It is the engineering of this consideration, the handling of that air, how it is going to be purified, how it is going to be kept clean, how it is going to be kept fit for human consumption, which is what you are here to discuss. I want to wish you all the best of luck in discussing it and I'm sure it's going to be a very interesting symposium.

INTRODUCTORY REMARKS

Robert T. Hughes*

As Dr. Harris indicated, all of us here today are very much aware of the escalating energy costs and in many cases the reduction or lack of availability of energy required to either heat or cool the industrial makeup air. Where the air exhausted from the processes can be cleaned and recirculated to the workplace, a significant reduction of energy requirements and a significant energy savings can be realized. For a recirculation system to be an acceptable method of energy conservation, we must have suitable criteria for the system design, performance, and operations, which will assure worker protection from harmful toxic contaminants. Recirculation has been employed very infrequently in the past. Criteria have not been developed which will permit a consistent and safe approach to the design and operation of the systems. We have an urgent need for such criteria, as industry is turning in ever-increasing numbers to recirculation. Improper system installation, design, or operation could result in severe exposure to toxic contaminants.

As a result of this need, NIOSH sponsored a study with the Southwest Research Institute. The study had four primary objectives: To develop a list of recirculable and nonrecirculable contaminants; to develop an analytical recirculation model which could predict system performance as a function of system and work-base parameters; to develop a reliability model which would assure a long system life and fail-safe operation; and fourth, to assess the state-of-the-art of air cleaning and contaminant monitoring devices.

This study has been completed and has provided significant progress toward meeting these objectives; however, it has also resulted in many questions which we must answer to make recirculation a safe and reliable procedure. I think some of the questions that came up are a lot more interesting than the answers that developed.

The objective of this symposium is to review the results of the study and to discuss recirculation in general, with special attention to the needs of industry and the system designer, for it is the system designer and industrial user who need the final criteria so they can put recirculation into operation to save energy and to maintain a healthful working environment.

The speakers we have represent a wide cross section of industry and government, and all are intimately concerned with the successful application of recirculation.

I might add here that many symposia are set up to disseminate information; somebody has done some work and wants to disseminate the information. This is true here too, but I also want you to consider this as sort of a reverse dissemination procedure. As I said, we have many questions which have come up and we at NIOSH need to know what your thoughts and your needs

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are so that we can continue this effort. Hopefully in the end we can provide criteria which will meet everybody's needs and be adequate. We have allowed question and answer periods for each of the presentations, and as I said, I urge active participation from each of you in these periods.

I guess as a format we would like to open the floor to any questions at the conclusion of each of the presentations, and I urge you to be informal and ask any question. You can challenge any statement you want. I mean don't hesitate, because we are here to share ideas and to learn.

RECIRCULATION OF EXHAUST AIR--AN OVERVIEW

William J. Astleford*

Abstract

This paper describes a study to develop technical performance criteria for recirculated exhaust air systems. These criteria reflect contaminant toxicity, the requirements for air monitoring and air cleaning equipment, reliability analyses of fail-safe systems, and theoretical modeling of system performance.

Based on contaminant toxicity, 356 of the 514 compounds that are listed in the body of the ACGIH-TLV table are potentially recirculatable. Carcinogenic compounds and compounds with ceiling concentrations are to be excluded from recirculation systems. Air monitoring equipment should be online, automatic, and specific for individual contaminants. Reliability analyses indicate that recirculation systems that incorporate backup or redundant air cleaning equipment have a lower probability of failure for all operating times than systems without backup. Systems without backup air cleaners should contain provision for exhaust bypass to the atmosphere in the event of an air cleaner or monitor failure.

Analytical recirculation models were developed to predict the transient response of workroom concentration as a function of contaminant generation rate, room volume, general and recirculated air flows, and the air cleaner and local exhaust hood capture efficiencies. The effect of air cleaner failure and bypass of exhaust air to the atmosphere were also modeled.

The goals of this symposium as I see them are not only to review and discuss a specific piece of research, but more importantly, through our dialogue, to formulate a definitive statement on (1) the future direction of recirculation as a tool for energy conservation, which will continue to maintain the current high standards of air quality in the industrial workplace, (2) the technical areas that impede implementation of recirculation, and (3) the economic realities that accompany a decision to install and maintain a recirculation system. This seminar provides a rather unique vehicle for achieving these goals. Many agencies periodically conduct in-house evaluations of their technical programs. However, to my knowledge, NIOSH is one of the few agencies that includes in its closed-loop evaluations those additional elements of private industry and State and Federal Government that have an input to the direction and implementation of the research topic that is being considered. This approach is especially important when the end result can have an impact on a large portion of the industrial labor force.

The energy crisis, or preferably, the energy shortage, is an accepted fact, and energy conservation is now the key phrase. Energy conservation by industry is motivated by both the increasing cost of conventional fossil fuel energy sources, and, in many cases, the unavailability of energy for process and environmental control.

One of the most attractive methods of reducing energy consumption is to recirculate exhaust air, thus reducing the energy requirements of the physical

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plant that supplies tempered air to the workspace. However, the first consideration in any decision to recirculate must be the health and safety of the employees. The thrust of the project that Southwest Research Institute (SwRI) conducted for NIOSH was to investigate the requirements for recirculation systems that would provide adequate worker protection. With respect to worker protection, the overriding requirement is that, as a result of recirculation, the contaminant concentrations anywhere in the workroom must not exceed the Threshold Limit Values (TLV) that are published by the ACGIH (ref. 1). To meet this requirement, the system must incorporate many fail-safe features. That is, it must be engineered to clean the air to the required level prior to recirculation and to monitor the quality of the air cleaner effluent. The system must be sufficiently instrumented to detect incipient failure of critical system components and take corrective action.

Maintaining an adequate workroom air quality is a complex problem. Existing ambient air quality and stationary source emission standards deal with a relatively small number of compounds, whereas in an industrial recirculation system we are concerned with approximately 500 compounds in the TLV list which may be present individually or in various combinations, depending on the industrial process. Even though our study included only the compounds on the TLV list, we must recognize the fact that there are several thousand additional compounds in the Toxic Substances List as well as several hundred new compounds that are created each year. The potential for recirculating these substances must be determined on an individual basis.

Recirculation of exhaust air, per se, is not a totally new subject, but unfortunately it is very difficult to find historical literature citations. One of the earliest papers on this subject was written in 1950 by Arthur Stern and Donald O'Neil of the New York State Department of Labor (ref. 2). Their article was prefaced by a statement that I wish to quote.

The most common reason for wanting to recirculate to a workroom the air discharged from industrial process exhaust systems is to effect savings by eliminating the heating of outdoor make-up air during the heating season, and by reducing the heating plant capacity required to heat this air. It is generally agreed that these savings are never a valid reason for recirculating any process effluent which could be detrimental to the health and well being of the persons employed in the workroom. All such detrimental effluents must, therefore, be discharged completely to the outer air and replaced in the workroom by an equivalent amount of outdoor make-up air.

This philosophy prevailed for nearly a quarter of a century because, as Dr. Caplan stated a year and half ago at an EPA-sponsored symposium (ref. 3),

With an abundant and cheap supply of energy, the easy way out was to forbid the recirculation of exhaust system air regardless of the cleaning system used if the contaminant was toxic.

It was also considered cheaper to exhaust to the atmosphere than cope with the problems that result from incorrect operation or poor maintenance of the air cleaners and system components, both of which are solvable problems.

I would now like to briefly discuss the occupational health considerations that comprised our study. The research effort consisted of four basic task elements.

The initial task effort was entitled, "Determination and Categorization of Recirculatable Contaminants." The emphasis on this task was to screen

the ACGIH-TLV list to determine which contaminants could be recirculated based on the chemical, physical, and toxicological properties of each individual compound. The screening was process-independent in the sense that it precluded the additive or synergistic effects of exposure to multiple process compounds.

Beginning with the ACGIH-TLV list, those compounds that are identified as human or experimental carcinogens as well as those that bear a ceiling concentration or MAC were placed immediately in the unrecirculatable category. Of the remaining compounds, a review of the open literature led to the conclusion that an additional 64 contaminants were unrecirculatable for one or more of the following reasons:

1. The compound was an experimental carcinogen that was not identified as such in the TLV table;
2. The compound had an indicated ceiling concentration that was not reflected in the TLV table;
3. Neoplastic effects had been observed experimentally;
4. The compound was capable of inducing systemic effects within the permissible excursion of concentration above the TLV.

On the basis of toxicity, the remaining 356 compounds are potentially recirculatable. To obtain a better understanding of a compound's suitability for recirculation, the five toxicological criteria that are shown in figure 1 were devised and applied to each of the remaining contaminants. We asked the questions:

1. Does the compound have an odor or irritant threshold, and, if so, is the concentration at or below the published TLV?
2. Do systemic effects occur above the odor, irritant, and TLV levels?

Of the 356 contaminants that were subjected to these criteria, 128 satisfied all five inequalities. As shown in table 1, these compounds were placed in Group 1, which we believe is most suitable for recirculation, because they exhibit desirable early warning properties with respect to odor and irritation as well as manageable systemic effects. Group 1 is almost exclusively composed of gases and vapors. The remaining 228 compounds were then categorized according to their normal physical states. Group 2 is composed of gases and vapors, Group 3 contains true particulates, and in Group 4 are those compounds that can exist either as vapors or particulates. The compounds in Groups 2, 3, and 4 are still potentially recirculatable, but there is a degree of uncertainty because they did not satisfy all five toxicity criteria. In those cases where odor, irritant, or systemic concentration data were not available in the literature, the inequalities could not be evaluated and the compound was relegated to Groups 2, 3, or 4.

$$C_o < \text{TLV}$$

$$C_s > C_o$$

$$C_i \leq \text{TLV}$$

$$C_s > C_i$$

$$C_s > \text{TLV}$$

Note.— C = concentration; TLV = Threshold Limit Value; o = odor; i = irritant; s = systemic effects.

Figure 1. Toxicity criteria.

Table 1. Air cleaner and contaminant monitor summary

	Group 1	Group 2	Group 3	Group 4
Total number of contaminants, N	128	116	103	9
Cleaners ^a	45	27	37	2
Monitors ^a	127	91	0	3
Cleaners ^b and Monitors	45	22	0	1
Percent ^c	35	19	0	11

^aNumber of contaminants for which either cleaning or monitoring equipment was indicated.

^bNumber of contaminants for which both cleaning and monitoring equipment were indicated.

^cPercentage of N with cleaners and monitors by contaminant group.

At this point, we felt that the toxicity screening had provided a relatively thorough assessment of which contaminants could or could not be recirculated and to some extent the degree of desirability of those that could be recirculated. The next step was to identify requirements for (1) air cleaning equipment to remove the contaminant from the carrier gas stream prior to discharge into the workroom and (2) instrumentation to monitor the quality of the discharged air. The basic requirement for the air cleaner is that the device should be capable of cleaning the process airstream to a level such that the discharge from the air cleaner does not result in concentrations that exceed the TLV anywhere in the room. Quantitation of this level involves theoretical predictions that are derived from an analytical model of the recirculation system.

The requirements for the air quality monitor include the following:

- (1) The monitor should be online and automatic;
- (2) Sampling and analysis should be performed continuously with a sampling, analysis, and display cycle not to exceed 15 minutes;
- (3) The monitor should be specific for a given contaminant, i.e., interference-free;
- (4) The minimum detectable concentration should be less than that which is predicted by the theoretical recirculation model;
- (5) There should be a digital display of concentration for comparison with a redundant manual sampling of the air cleaner effluent;

- (6) There should be an analog output proportional to concentration for input to a fail-safe control system.

In an attempt to assess the availability of air cleaning and monitoring equipment that meets the performance requirements, a limited number of manufacturers were contacted for detailed information, and a rather large number of manufacturers were contacted by letter to obtain normally distributed product information. The essential result of this inquiry was that the level and completeness of the responses did not permit a fair assessment of availability versus requirements.

The information that was received did have value. The responses were scanned to determine the number of contaminants that could be monitored or removed by existing equipment regardless of the application. The results are summarized in table 1. For Group 1, which contains gases and vapors, 45 of 128 compounds have been controlled in various industrial applications by existing air cleaning equipment. Similarly, 127 of the 128 compounds have been monitored in the industrial environment. In only 45 cases was there evidence that both cleaning and monitoring equipment had been applied to a specific compound. The most interesting statistic in this table is the indicated absence of monitoring equipment for the particulates in Group 3. This observation was corroborated in an article by John Nader which appeared in the August 1975 issue of the APCA Journal under the title, "Current Technology for Continuous Monitoring of Particulate Emissions" (ref. 4). The essential result of that paper is that at the present time there are no commercial monitors available which can provide an elemental breakdown of total mass in a process effluent.

As applied to recirculation of exhaust air, continuous monitoring of gases and particulates can be a benefit to a plant owner. In this same issue of the APCA Journal, there are two articles dealing with the positive aspects or advantages of continuous monitoring, (ref. 5, 6). Monitoring can provide information that may be useful in designing new plant facilities, improving process control, and identifying process effluents that have economic recovery value.

The second task effort on this program included a review of the experience that had been gained by users or purchasers of various types of air cleaning devices. Nine purchasers of gas, vapor, and mist collectors were contacted to obtain performance, maintenance, and failure-rate data for subsequent input to a system reliability analysis. The results of this limited survey were uniformly consistent and indicated that:

- (1) Failure rate data (type and frequency) on major system components are not readily available;
- (2) Periodic maintenance schedules are very informal and are frequently not governed by documented procedures; and
- (3) Users have a limited knowledge of the actual performance of the air cleaner in terms of flow rates, temperatures, pressures, and collection efficiencies.

These results are significant because we are talking about generating high-quality respirable air from contaminant-laden process air, and the lack of this type of data is a major problem area in assembling a highly reliable, fail-safe recirculation system.

The third task effort involved a reliability analysis of two conceptual, fail-safe recirculation configurations. The first physical model, which is

shown in figure 2, employs a redundant or backup air cleaner in parallel with the primary cleaner. Under normal operating conditions, the contaminated inlet air from either a local exhaust hood or a ceiling vent enters the primary blower duct, where it is processed by the primary air cleaner and then returned to the workroom. If the primary cleaner fails, the airflow is diverted by a butterfly valve or damper to the backup air cleaner, thus isolating the primary cleaner. A contaminant monitor probe is located in the common exhaust duct.

In order to sense a component failure and initial corrective action, the system must be instrumented with transducers so that specified failure parameters can be monitored continuously. The electrical output for each transducer is input to a separate failure-control module or comparator. If the input signal is within specified limits, normal operation continues. If the input signal is out of tolerance, an error signal is generated internally indicating a subsystem failure. The appropriate meter relay automatically takes corrective action, and simultaneously, an audiovisual alarm is displayed and will remain activated until it is manually disarmed by maintenance personnel.

The second system, which is shown in figure 3, was designed to exhaust the process effluent to the atmosphere in the event of an air cleaner failure. This configuration is especially suited to recirculation systems where redundant air cleaners are impractical because of economic considerations or space limitations. The electronic instrumentation for detecting and correcting component failures is essentially identical to that which was shown in the previous figure. In the reliability analysis which follows, we considered three air cleaner variations of this configuration. The first case assumed a single air cleaner operating at 100 percent capacity during peak loading. The second variation assumed that the cleaner has excess cleaning capacity, and that the excess is represented by cleaner sections in parallel, e.g., a multicyclone or a large baghouse. In the third variation, the excess capacity was contained in a series configuration similar to that of a multiple stage gas absorber.

In conducting a reliability analysis of either of these two systems, the ideal approach is to describe the reliability models for major components, such as the air cleaner, in terms of the failure rates and failure probability distributions of its subsystems. The total system reliability model is then easily constructed from the component models. However, the type of data that are needed at the subsystem level for air cleaners and monitors is not readily available. Until this information is generated, an accurate system reliability analysis cannot be made. The most suitable alternative is a generic reliability analysis, wherein the major components are assigned a failure probability distribution and system reliability is studied parametrically. This is the approach that was adopted.

An example of the performance trends that can be derived from such an analysis is shown in figure 4. For each of the recirculation systems that were shown in the two previous figures, the probability of a total system failure is plotted as a function of operating hours after the system is placed onstream. The blowers and contaminant monitor were assumed to operate for approximately 6 years between failures, whereas the air cleaner was assumed to have a mean time between consecutive failures of slightly less than 1 year of continuous operation. The electronic automatic control system was assigned

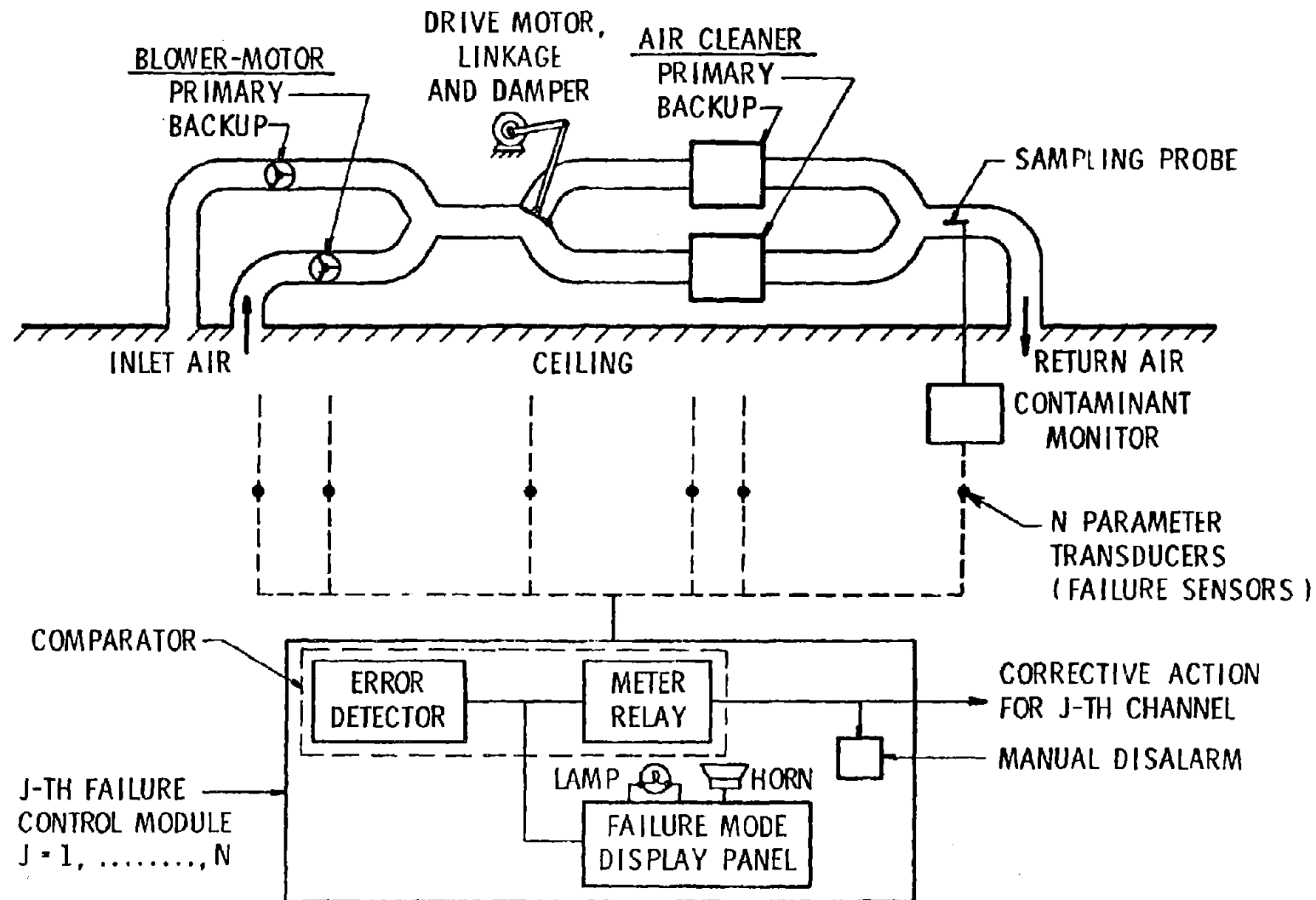


Figure 2. Physical recirculation model for Case I: redundant air cleaners.

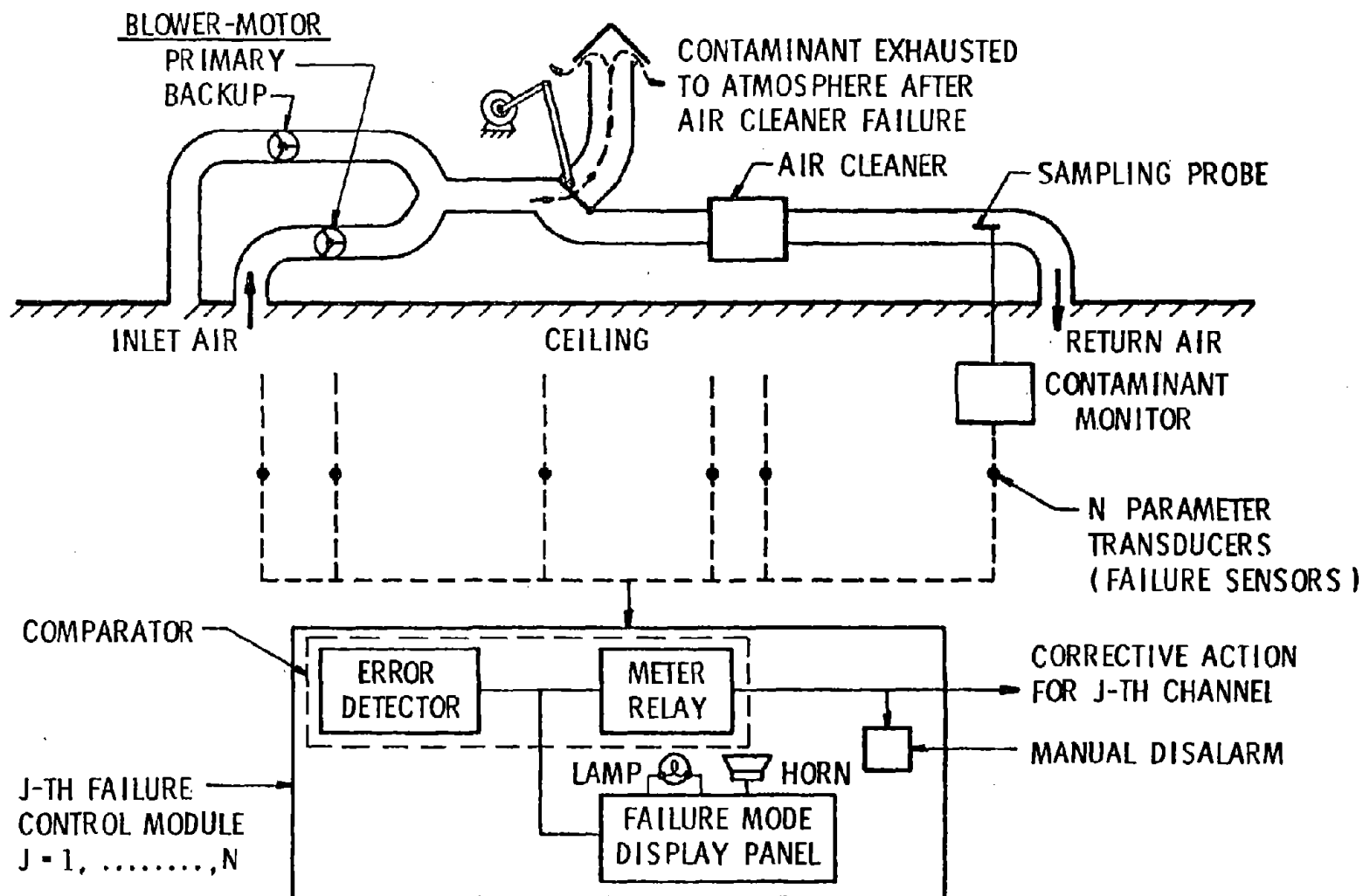


Figure 3. Physical recirculation model for Case II: air cleaning with bypass.

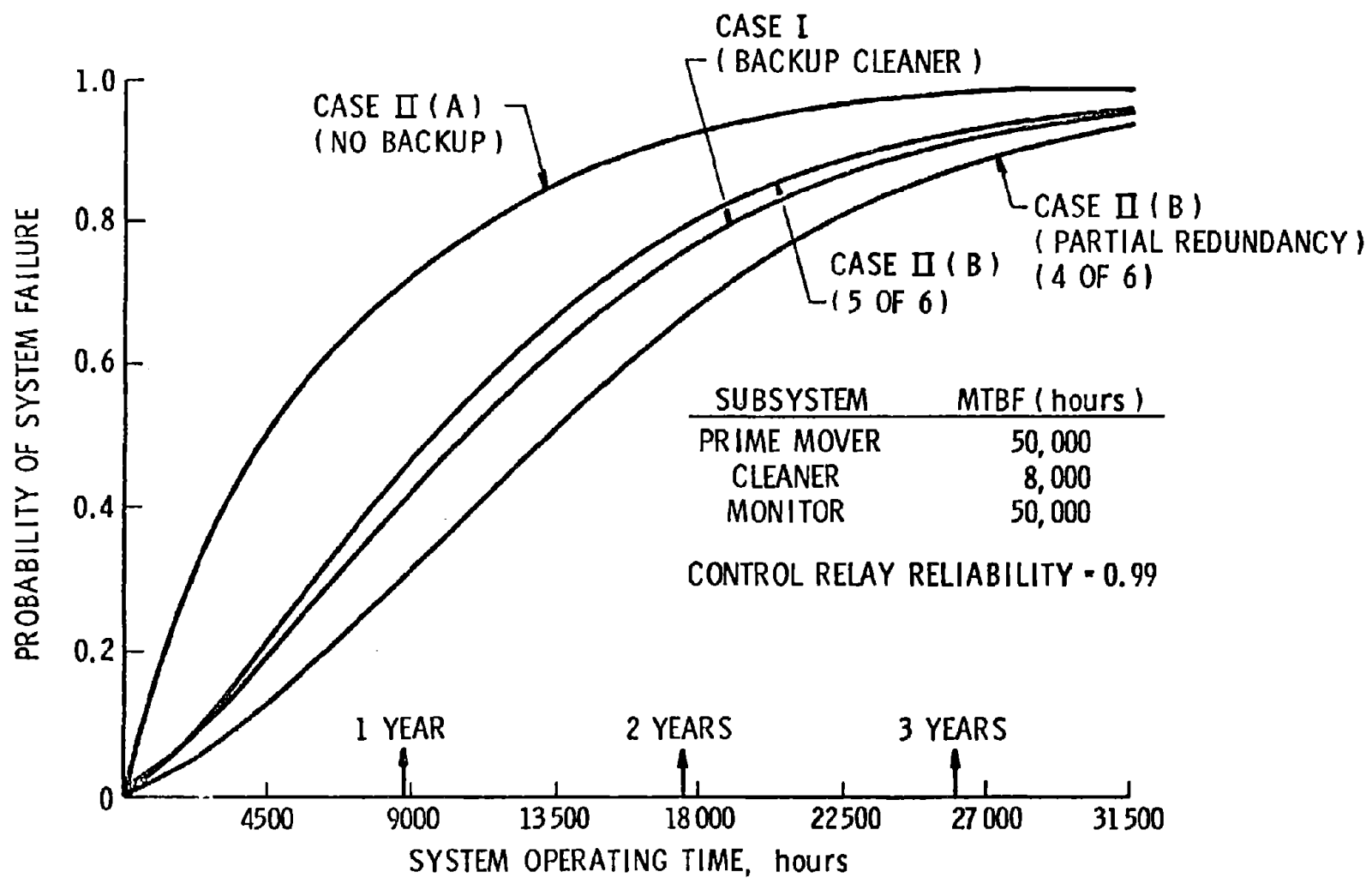


Figure 4. System reliability: Effect of air cleaner redundancy.

a realistic reliability of 99 percent. As would be expected, the odds that the system will fail at time zero are zero--the system is 100 percent reliable. As operating time increases, the probability of failure increases regardless of the type of installation. This figure demonstrates very clearly that some degree of redundancy in the air cleaning system pays significant dividends in terms of reducing the anticipated probability of a system failure.

The curve labeled Case I represents the recirculation system with an identical air cleaner in parallel. When identical backup cleaners are not feasible, and the air cleaner operates at 100 percent capacity, the system becomes less reliable for all operating times, as shown by the curve labeled Case II(A). If the recirculation system has a single air cleaner, and that cleaner has excess capacity in parallel, then the curves labeled Case II(B) would predict the probability of a system failure. For this latter case, the air cleaner was assumed to have six identical sections in parallel, and either four of six or five of six sections were required to be operating in order to provide the required level of air cleaning.

Figure 5 demonstrates the effect of placing increasingly stringent requirements on the reliability of the contaminant monitor. Regardless of the type of recirculation system, a point is reached where increasing the monitor reliability begins to produce diminishing returns in terms of the probability of system failure. It is interesting to note that as different parameters in the reliability model are exercised, the advantage of incorporating some degree of air cleaner backup or redundancy is consistently apparent.

Figure 6 depicts an arbitrary process that is generating a contaminant at a known rate. The majority of the contaminant is captured by a local exhaust system and processed by an air cleaner. A prescribed fraction of the branch duct flow rate is returned to the workroom. The remainder is bypassed to the atmosphere. One of the requirements of the air cleaner is that it remove a sufficient amount of contaminant from the recirculated air flow such that the mean room concentration C is at or below the appropriate TLV. Likewise, the monitor must be able to sense the limiting value of C_{in} that corresponds to the prescribed level of C .

The fourth and final task effort on this program consisted of developing a mathematical model of the system described above to predict the time-dependent variation of C and C_{in} as a function of the other system parameters. By specifying the quality of the workroom air as some fraction of the contaminant TLV, it was possible to define the minimum air cleaner efficiency or minimum bypass ratio, Q_B/Q_R , that is necessary to achieve that desired level of air quality. The model is quite versatile. The response of the system can be studied parametrically under normal operating conditions. The air cleaner can be assumed to fail at any time, and bypass of the contaminant to the atmosphere can be initiated at any prescribed time before or after air cleaner failure. Under steady-state operation with no bypass to the atmosphere, the model agrees with the expression for the allowable recirculated concentration that is presented in the latest edition of the ACGIH Ventilation Manual (ref. 7).

In order to facilitate system design, the room concentration equations were displayed graphically in nondimensional form, as shown in figure 7, which applies to normal operation with no bypass and a constant contaminant generation rate. A similar set of curves was developed for 33- and 50-percent

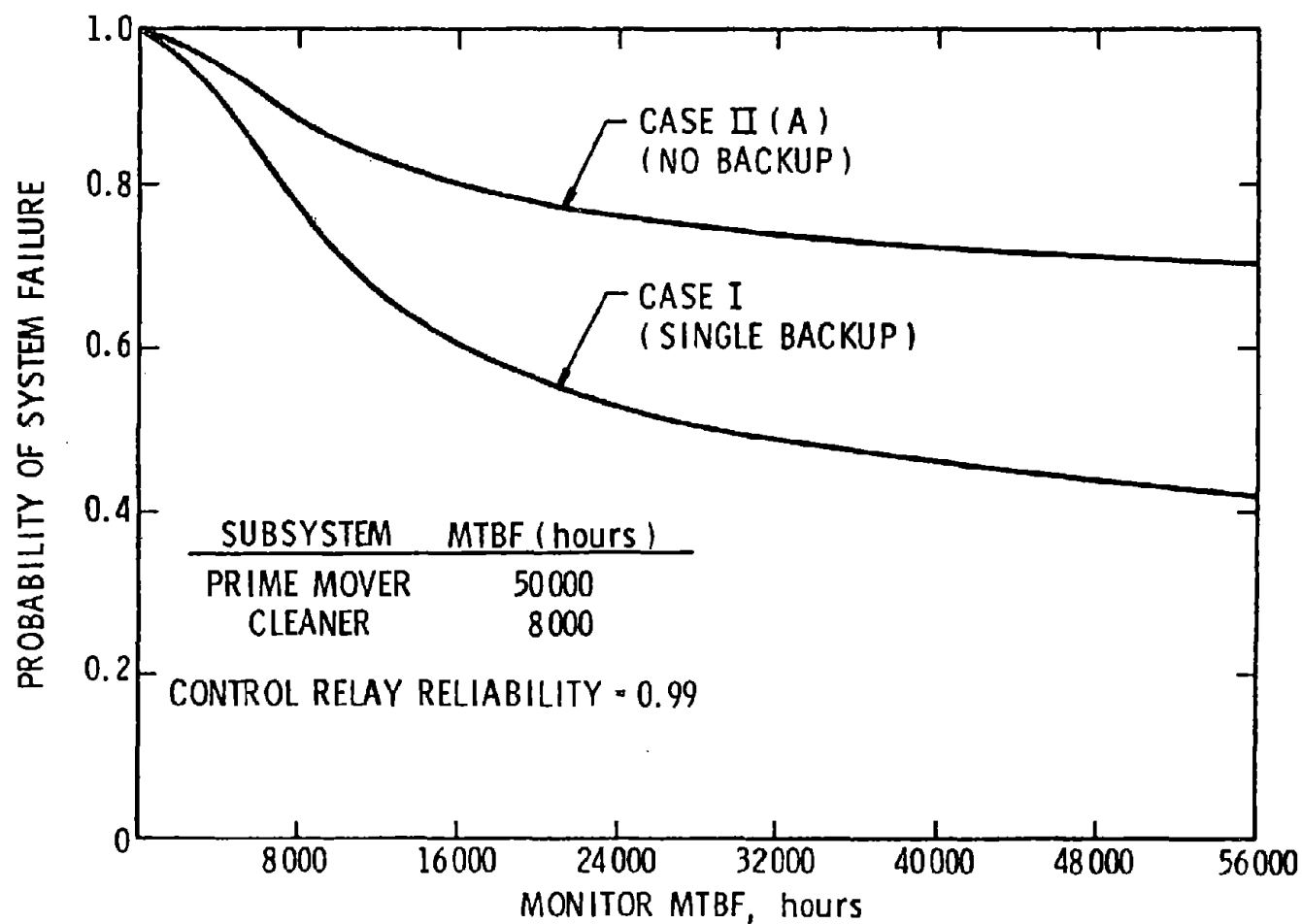
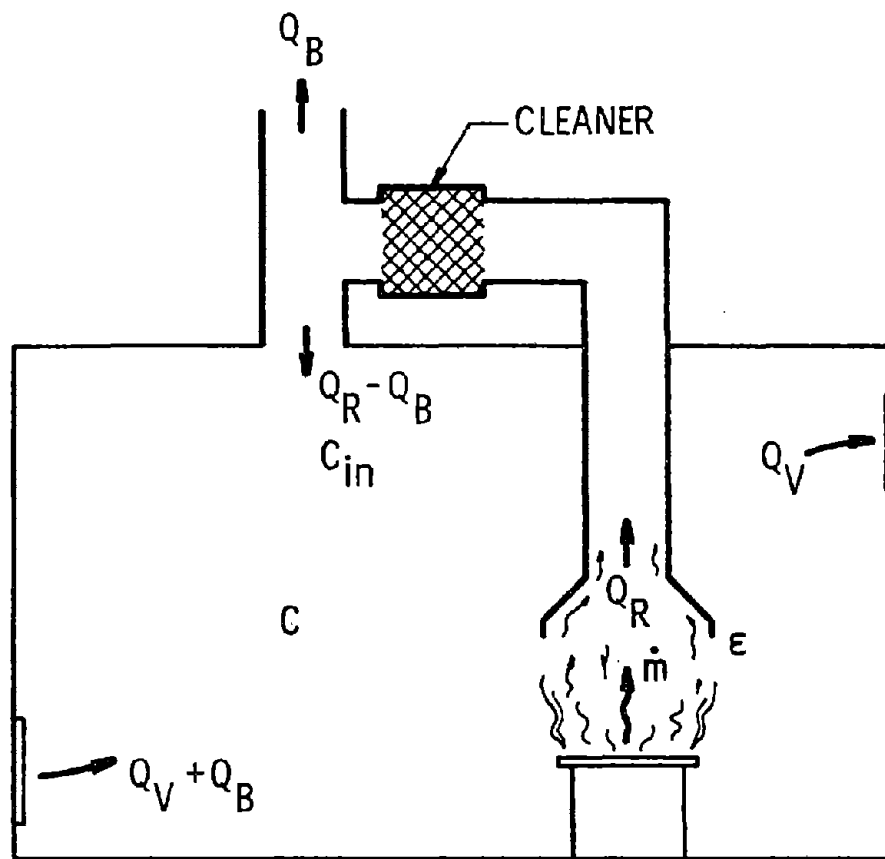
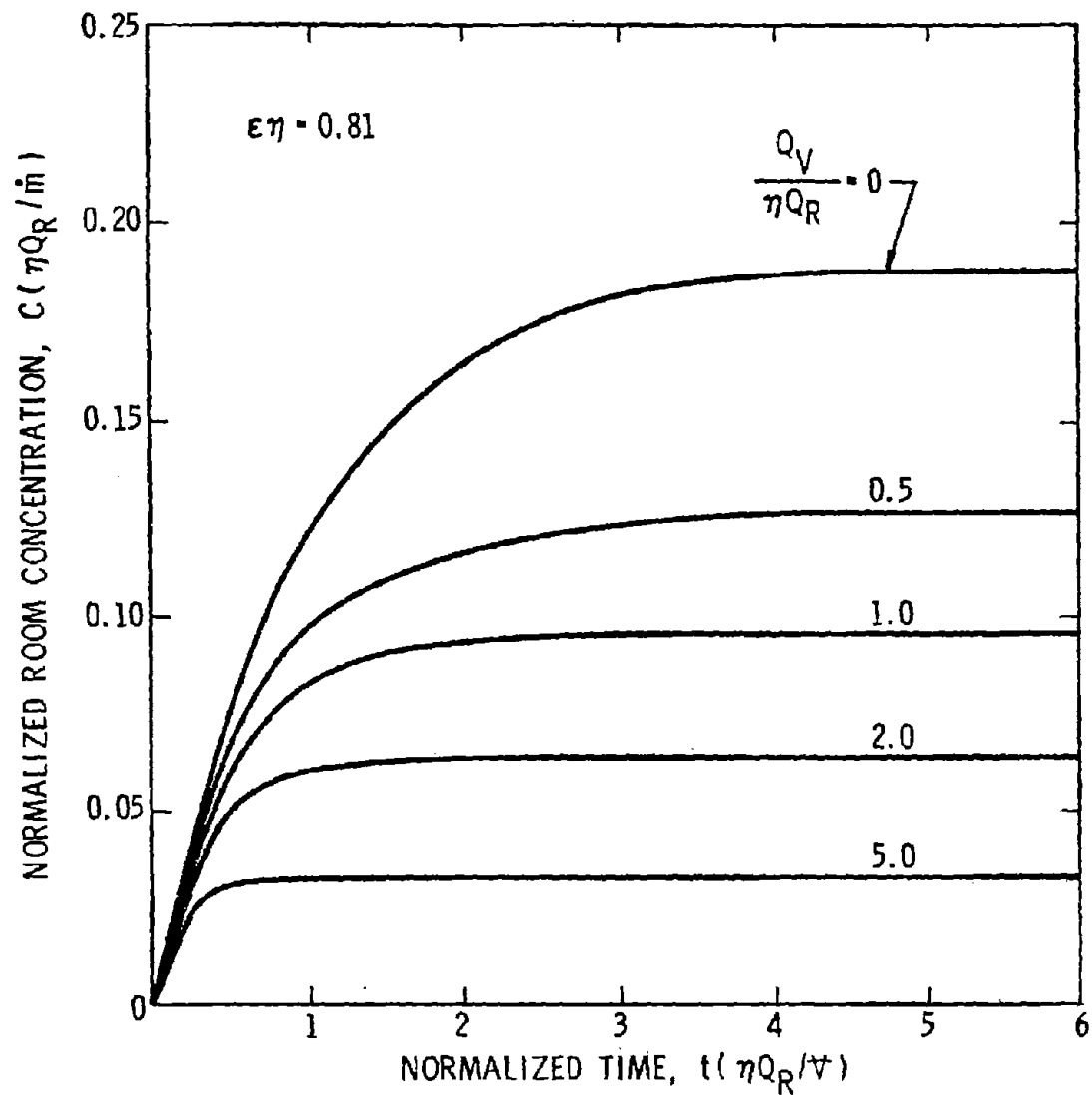


Figure 5. System reliability: Effect of contaminant monitor MTBF for a 1-year operating interval (8,760 hours).



- $\dot{m}$ = Contaminant generation rate
- ϵ = Hood capture efficiency
- C = Room concentration
- C_{in} = Recirculated air concentration
- $Q_R - Q_B$ = Recirculated airflow
- Q_B = Bypass airflow
- Q_V = General ventilation airflow
- η = Air cleaner efficiency

Figure 6. Recirculation model with partial bypass.



NOTE: The concentration for other values of $\epsilon\eta$ can be obtained by multiplying the values from the graph by the factor $(1-\epsilon\eta)/0.19$.

Figure 7. Normalized room concentration as a function of normalized operating time and local exhaust recirculation air-flow rate.

bypass of the recirculation duct flow rate. In this example, the room concentration begins at zero when the contaminant-generating process and the recirculation system are brought onstream. The room concentration rises to a steady-state value that is a function of all of the system parameters with the exception of room volume. Room volume essentially controls the time required to reach steady state.

There may be occasions when the air cleaner will fail. The designer must be able to predict the amount of time that is available before the concentration in the workspace builds up to a predetermined level. At this point, contaminant generation must stop, the backup cleaner must be activated or, in the absence of air cleaner redundancy, some level of bypass must be initiated.

An example of the effect of bypass is shown in figure 8. For the system parameters that are shown in the upper left-hand corner of the figure, the room reached a steady-state concentration of slightly less than 20 ppm. Under steady-state operation, the air cleaner failed, and the system continued to recycle contaminated air until the concentration reached 80 percent of the Butanol TLV, at which time 50 percent of the exhaust system flow was diverted to the atmosphere. The time to reach 80 ppm was approximately 100 minutes. Following the initiation of bypass, the room concentration begins to decline and will continue to do so until a new steady state is reached.

In these last two examples of the use of recirculation models, it was assumed that there is homogeneous mixing of the air cleaner effluent and the workroom air. That is, the concentration in the workroom is uniform. In practice, however, nonperfect scavenging of the contaminant and nonuniform airflow distribution may result in localized areas or dead spots where the contaminant concentration exceeds the TLV even though the concentrations elsewhere in the workroom are acceptable. To account for this situation, a mixing factor K is usually employed, and it enters the analysis in such a manner as to insure that the peak concentration for the actual distribution of contaminant in the workroom is below the TLV.

The problem that everyone has encountered is in obtaining a quantitative prediction of the required mixing factor. This factor is usually specified by highly experienced individuals. If an inexperienced individual makes an overly conservative estimate of the pooriness of mixing, the result could be a requirement for an air cleaner whose efficiency and cost are larger than needed. A brief analysis was conducted to obtain some indication of the system parameters that affect the value of K . In general, larger values of K are required when generation rates and exposure hazards are large. Likewise, large rooms require smaller values of K than do small rooms.

In closing, I wish to emphasize that recirculation of exhaust air in the industrial workplace appears to be a feasible concept. There are aspects of recirculation that need to be investigated so that we may proceed from the conceptual stage to the stage of practical applications.

As we have seen, there is a need to develop a quantitative method of predicting the mixing factor that appears in the system design equations. Such a development could conceivably involve theoretical analyses of air flow and concentration distributions as well as practical pilot plant studies.

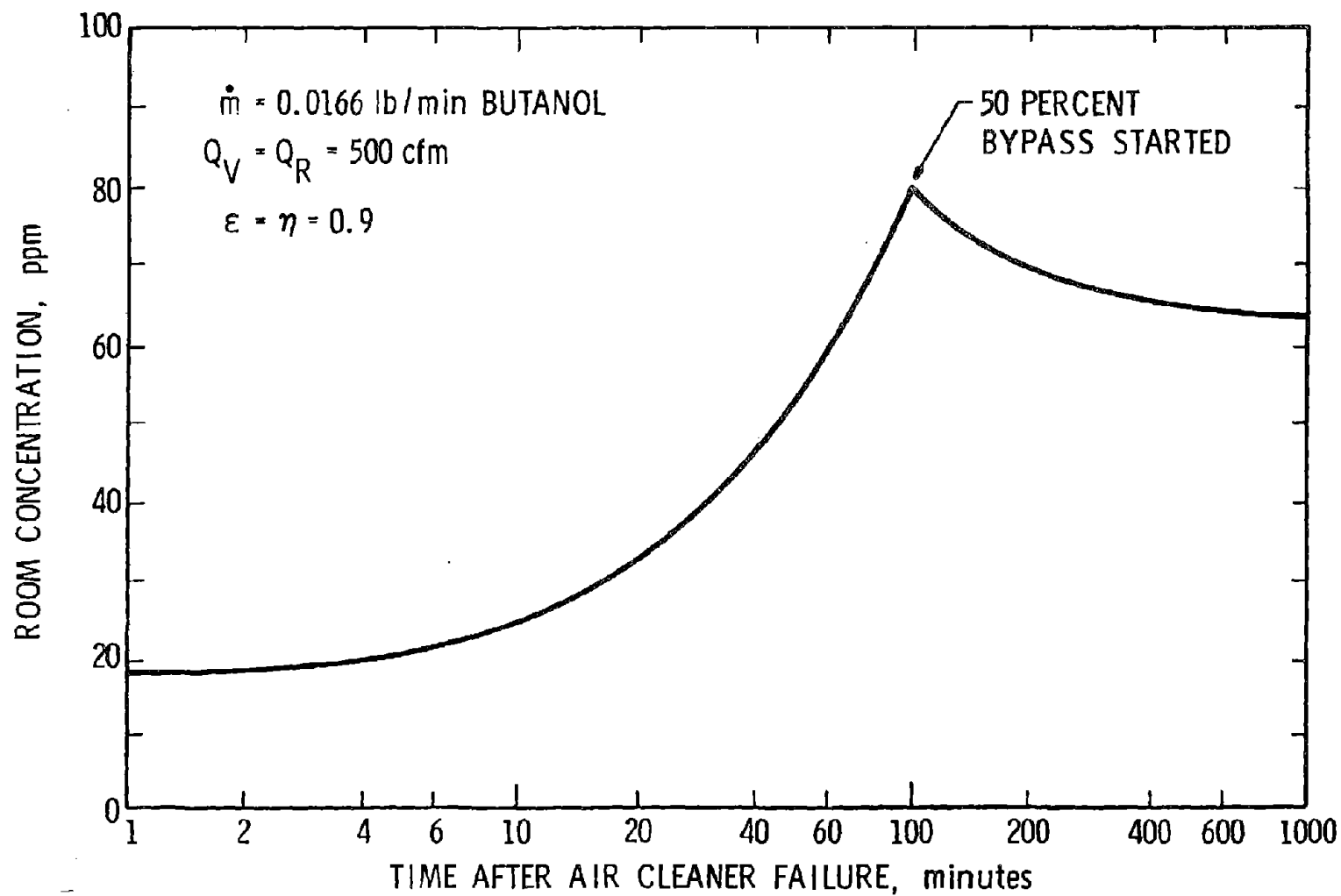


Figure 8. Room concentration as a function of time after air cleaner failure with partial bypass.

Recirculation of nonnuisance particulates at this time is impeded by the lack of a continuous monitor that is specific for given particulates. Since this device is in the developmental stage, hopefully it will not be too long before this problem area is eliminated.

Accurate reliability data in terms of subsystem failure rates and failure probability distributions are needed for air cleaners and air monitors. Without these data, it is difficult to accurately calculate the most reliable recirculation configuration.

Finally, an economic analysis of recirculation systems is needed. The analysis should include such items as the initial expenditure for capital equipment and installation, projected utility rates, and maintenance and repair costs. Such an analysis, when combined with engineering design evaluations, will hopefully permit the selection of the optimum recirculation system for a given application.

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DISCUSSION

MR. THOMAS L. ANANIA (NIOSH, Cincinnati, Ohio): Bill, are you talking about 100 percent recirculation here or are you talking about 75-25 percent?

MR. ASTLEFORD: Conceptually, Tom, that has to be determined for the individual process. We wanted to make our analysis general enough to accommodate an investigation of partial bypass or full bypass.

MR. ANANIA: The reason I asked is that you get into discussion here about whether the recirculation of air is feasible. The reason you got into it in the beginning was economics, because of the heating and cooling of air. Now it seems to me that the equipment that you put on line there

with monitors and so forth, you could really make it feasible; but would it be economically feasible to put this material in line as against something 100 percent outside?

MR. ASTLEFORD: That is what I referred to in my last comments regarding economic analysis. We have to take a look at what are the tradeoffs between maintaining the status quo, that is, exhausting to the atmosphere with replacement of tempered makeup air during all seasons of the year, and we must weigh that against the initial investment for recirculation equipment and the increase in costs per unit time that go along with increasing utility rates and maintenance and repair and costs.

I don't think that you can categorically say that recirculation can be applied without considering the economic impact of that decision, because for many organizations the type of equipment that we are talking about here is relatively expensive.

MR. ROBERT CONFER (Exxon Corporation, Linden, New Jersey): You used an abbreviation in your viewgraphs, MTBF. Was that maximum time before failure?

MR. ASTLEFORD: No, mean time between failure. If you have a box of lightbulbs and you turn them all on and measure the operating time until they fail, and then take the average, that would be the mean time between failure for that type of lightbulb.

MR. CONFER: You gave for monitoring equipment 50,000 hours as the MTBF. I think there is really a good data base on this and that is the air pollution monitoring people. We operate an air monitoring station in our research center and I can assure you that the mean time before failure for the equipment that we operate (we operate quite a bit of it) is nowhere near 50,000 hours.

MR. ASTLEFORD: I hope I didn't lead anybody to the conclusion that those numbers were meant to be realistic. They were selected purely at random just for demonstration purposes. The model is sufficiently versatile to accommodate any MTBF for any component.

MR. CONFER: I think there is a good data base from the government for this, and that is the air monitoring stations they operate.

MR. JAMES WOODLING (Goodyear Tire and Rubber Company, Akron, Ohio): In the presentation that you made to us, Bill, you have indicated that there obviously are economic considerations involved here. However, it appears that alternatives have not been presented which I feel are perhaps as important or more important than just recirculation or not recirculation, and this is consideration of heat conservation devices. Somewhere along the line there is an optimum point beyond which you decide to eliminate, or, because of economic reasons, you can't afford, the recirculation air cleaning devices. At that point you go to conservation devices, whereby you can conserve 70 to 80 percent of the heat and at the same time not be exposed to these fail-safe situations under any circumstances. You've got a reliable system there that will work or will not work and still not present a hazardous condition.

MR. ASTLEFORD: That is a very good point. I have a page and a half in my manuscript dealing with alternate methods of energy conservation. Because of time limitations, I couldn't work it in. Of course, it is a very valid argument that there are alternatives that have to be considered, such as heat recovery. I believe that Bob Stotz, who will be our leadoff speaker

tomorrow, is going to discuss heat recovery systems as they may apply to recirculation of exhaust air.

Further down the road we could look toward something more exotic, such as solar energy for preheating of water for hot water heaters or for supplying warm water for forced air heating, but at the present time it is my understanding that solar energy collection and storage efficiencies are not high enough to justify this alternative at this time.

CHAIRMAN HUGHES: I would like to add a note to the discussion on heat recovery and other methods, and I do not mean to say this in a manner to discourage any discussion on these areas. The purpose of the work that was done by Bill was specifically towards the recirculation of exhaust air. We recognize that there are many other methods of energy conservation and perhaps in many cases an industrial environment having a hot processes where recirculation would not be practical and the heat recovery would be an ideal situation.

MR. JAMES C. BARRETT (Department of Public Health, Lansing, Michigan): You describe the current state of our ignorance on the K factor pretty well. Of course we use it in a lot of calculations. Along the way when you were examining it, were you able to define any particular K factors for certain configurations?

MR. ASTLEFORD: We tried it by modeling the dead spot as a spherical surface centered in the corner of the room. In taking a look at the mass diffusion of contaminant into that dead spot of radius, say R, and looking at the diffusion out of that volume, we were able to come up with an expression that included in the description of K such items as the room volume, the contaminant generation rate, the radius of the dead spot, and the diffusion coefficient for the particular contaminant. We tried to calculate some K values by assigning what we felt were realistic numbers and we came up with values that were significantly higher than 3 to 10.

MR. BARRETT: The 3 to 10 is all relative. It depends upon the total context in which you are looking at the problem. Everybody's right about the K factor, and I think it is a very difficult thing to model, and those of us who occasionally have the opportunity to take air samples in the field become aware of the importance of knowing more about K than we have in the past. You can very often in field situations get valid actual data, and we have been indulging in that recently; surprisingly enough, most of our findings are the K factor is down around two to three.

MR. CAPLAN: In actual situations, you can sample the breathings of the worker and the total or completely mixed contaminant airstream. So it is certainly ignorance on all of our parts, but it is the kind of ignorance that can be alleviated. It does not take too many more samples in situations in which you evaluate the worker exposure to get the rest of the data that you need to compute the K factor.

CHAIRMAN HUGHES: I think one thing significant Bill showed in the report is that any analytical method to determine the K factor requires another arbitrary K factor.

DR. RALPH R. LANGNER (Dow Chemical, U.S.A., Midland, Michigan): In your criteria you excluded those things with ceiling value, maximum values, neoplastics, or carcinogens. I would like to know who made this decision that these were uncirculatable and what is the evidence on which this decision was based.

TECHNICAL CRITIQUE OF RECIRCULATION CRITERIA

Knowlton J. Caplan*

Abstract

A review is made of the approach to the problem of recirculation taken by the authors of the subject report. In the opinion of the reviewer, the method of using the TLV tables in establishing whether or not a specific contaminant can be recirculated is inappropriate, and in some specific cases leads to a result exactly contrary to the opinion of the reviewer. The models chosen for mathematical analysis are not appropriate models of real-world systems. In considerations of reliability, the essential parameter of power failure is omitted and the failure of the sensor element of the monitor receives very light treatment. For problems of this sort, "failure" should be defined as failure to adequately protect the health of the workers. The report presents no useful "criteria" for recirculation.

GENERAL CONSIDERATIONS

In reviewing the technical validity of the report "Development of Criteria for the Recirculation of Exhaust Air" (ref. 1), a number of serious deficiencies are found. Not the least of these is the fact that no criteria are presented which are useful or liable to become useful in the foreseeable future. It appears that the approach, that of creating a generalized mathematical model, is not viable for several reasons. First, there is such a large variety of probable systems that a generalized model is not applicable. Secondly, numerical values for the parameters involved in the model are not available and will not become available in any general sense in the foreseeable future. Thus, the criteria are absent upon which to base any workable and safe real-world system.

There seems to be an unstated assumption throughout the work that nonrecirculating systems have a very high degree of reliability, and that recirculating systems must therefore compete with that high degree of reliability. Such is not the case.

Industrial systems in general (not just exhaust systems) are highly variable in their reliability. Only a very few major items of equipment possess anything like the reliability or redundancy designed into other types of enterprises, such as space travel. The industrial reliability system rests, in fact, on a much broader base and wider scope, with many more options available. It depends in general on the availability of a good deal of operational flexibility, many choices of operating actions, excess capacity to permit catchup following shutdown, etc. It does not usually attempt, through perfection of design and redundancy regardless of cost, nearly absolute operating reliability of a given subsystem. Translated into the subject of hazard control, typical options available in event of exhaust system failure include one or more, or combinations of, the following steps:

1. shutdown of contaminant-generating process;
2. use of personal protective equipment;

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3. use of emergency ventilation systems,
 4. opening doors and windows normally closed;
 5. evacuation of room or building;
- and many other actions specifically tailored to the circumstances.

There seems to be a lack of understanding of the usual configurations of exhaust systems and the reasons for such configurations. Therefore, the configurations of the models chosen for development are, in general, not applicable to real-world systems. There also seems to be a lack of appreciation of the fact that as far as safety of the employees is concerned, it is only the reliability of the air cleaners and return air monitors that is different from the reliability questions concerning existing types of exhaust systems.

In addition, there is a lack of definition of terms, two of which are very important. The term "failure" is not specifically defined but is obviously construed to mean the failure of the mechanical functioning of some part of the system. If failure of some component of the system is the question, any experienced practitioner would disagree with the results obtained in the theoretical analysis, in that mechanical failure rates are actually going to be significantly higher. A more appropriate definition of failure would be the failure to protect adequately the health of the workers; this is a different type of failure and is not enlightened by the subject study. Another term not defined is the "efficiency of the scavenging action of the exhaust system." This is more complicated and will be enlarged upon later in the chapter-by-chapter analysis.

One major aspect of recirculating systems which deserves consideration has been completely overlooked. That is the opportunity that presents itself, with proper recirculation systems, to provide even better health protection for the workers than is now available or will be available as the energy shortage worsens. In most industry and in most parts of the country, makeup air is essential for the proper functioning of exhaust systems. The design of such systems is important and in some cases even critical to the success of the health protection effort. Makeup air is energy-expensive. As energy becomes more expensive and more difficult to obtain, it is predictable that the exhaust volumes to be handled in exhaust systems will be minimized to the point where their effectiveness may be marginal or inadequate. Another predictable eventuality is that exhaust systems will be installed without the makeup air systems that are necessary for their proper functioning, and again the attainment of the objective will be aborted.

With a reasonable and workable set of recirculation criteria, the air volumes handled can be more generous, and the number of contaminant sources controlled can be increased. In general, the tremendous pressure to cut corners and minimize the exhaust system will be relieved. In the absence of regulation, this will take place automatically due to economic factors, as it becomes worthwhile to spend more funds for better engineering and better equipment in order to effect savings in the ever-increasing cost of energy. It is necessary for engineering standards to be developed. It is necessary for regulatory agencies to take a not unduly restrictive approach, with the realization that excessively restrictive rules concerning recirculation will inhibit its use and will have the net end effect of worsening, rather than improving, the working environment.

A chapter-by-chapter review follows.

MR. ASTLEFORD: The initial decision to eliminate those carcinogens that are labeled as such in the TLV table as well as those compounds that are labeled as MAC was made within NIOSH. It was one of the ground rules under which we conducted the study. Our further evaluation of the literature indicated that perhaps there were additional compounds or chemical substances that should appropriately be placed in that category also.

CHAIRMAN HUGHES: The decision was a rather arbitrary decision to start with and I think we all agree that the list of those things which are not recirculatable is definitely open for review. I would not want to say that it is definitely final. This is one important area that I hope we are able to get more information on and better define in future efforts.

DR. LANGNER: Would you mind commenting on what is the base for NIOSH decision.

CHAIRMAN HUGHES: It was a rather arbitrary decision made by me originally. Not a lot of research went into it. It was really a base at which we could start and form a list to work with. It is definitely open for discussion.

MR. ASTLEFORD: I think it is worthwhile mentioning that these compounds that were excluded because of listed carcinogenic potential are completely consistent with the carcinogenic quantities that have been listed by OSHA in the Federal Register, so there is no inconsistency on these 14 or so contaminants that are listed in the Federal Register.

DR. LANGNER: I take question to that because I think if you looked at 14 carcinogenic standards, there is no level given. In the case of vinylchloride there is a definite level, one ppm, and in the case of asbestos the present standard is 5 fibers, so I do not think you can say this is consistent with the OSHA requirements.

MR. ASTLEFORD: It is consistent in that their list and our list both contain the same labeled carcinogens. There was nothing in our study that looked at the promulgated ceiling or threshold, or acceptable exposure concentrations for those compounds.

DR. LANGNER: But the 14 carcinogens do not have values given in the standard.

CHAIRMAN HUGHES: I cannot comment with any authority on that.

MR. ROBERT W. MODRELL (Goodyear Tire and Rubber Company, Akron, Ohio): They do not know of any acceptable safe level for vinylchloride, but even in view of this, and because of the information, they are setting one ppm limit, but they admit they do not know. There is a safe level. And this comes around again to the debated concept now of threshold versus linear response, and it appears that there may not be any provisions set. In fact, the response from them will be the linear function.

I had a question I would like to ask. This 80-percent action level that you set for the recirculation of air is in contrast to what OSHA said, 50 percent.

MR. ASTLEFORD: That selection or decision was strictly arbitrary, and was for example purposes only.

MR. MODRELL: And one other thing. Has the work that has been done by NASA on life support systems in the Navy and submarines ever been valued by you?

MR. ASTLEFORD: Any input from those sources came early in the program when we conducted several computerized literature searches, namely the EPA-APTIC and the NASA Technology Utilization Computer Bank. So yes, those inputs were reflected, but here again we are dealing with 500 and some odd contaminants and to look at each one individually over an extended period of time is prohibitive. But yes, we did go to those sources to obtain information.

MR. GUY CUSUMANO (Clarkson Industries, Manhattan, New York): Did you see that a redundancy study which showed models for what I would call parallel redundancy set up a model for series where you have two, back to back, so to speak?

MR. ASTLEFORD: I did not show that in the slides, but the reliability model for that particular situation is identical to the one for a single air cleaner operating at 100-percent capacity. In other words, the modeling equations apply to that situation as well as a single air cleaner, but it was not shown in the graphs.

CHAPTER 2

Chapter 2 is an attempt to separate the substances listed in the current TLV table into six groups according to eligibility of the substance for recirculation. A meaningful analysis of this sort would, with some few exceptions, require an in-depth analysis of each individual substance, which has not been done in this case. The origin, evolution, and method of arriving at TLV values was apparently not understood by those making this analysis. The values in the TLV table are intended for professional use and require much interpretation and understanding in a case of any complexity, which condition certainly applies to the contemplation of recirculation. The numerical TLV values do not represent suitable "computer input" and the variations are far too great to permit any hierarchical classification, as was attempted in the subject analysis.

Furthermore, serious liberties were taken with the TLV list. The authors arbitrarily placed chemicals in various restricted categories merely because some literature reference was found which indicated that, in some investigator's opinion, such action might be warranted. The TLV Committee, on the other hand, conducts a critical review of all the available information. Certainly, in these days of prolific publication, critical reviews are most necessary before any conclusions are reached.

The implications of the above statements may perhaps be better appreciated by reference to table 1, taken from the National Safety Council book "Fundamentals of Industrial Hygiene" (ref. 2) and attributed to Stokinger (ref. 3). This is an analysis of the origin of the values for the TLV table as of that year. Obviously, this same breakdown would not apply strictly to the current table, but it does give an understanding of the methodology and processes involved.

Specific exception is taken to some of the statements and assignments of group numbers. Page 4, paragraph 3, states that some materials were relegated to group 6 (which includes known carcinogens) "because of proven or otherwise experimentally determined adverse health effects." That statement is applicable to almost all of the materials found as environmental contaminants, whether natural or manmade. Hence, it is almost meaningless as applied to a specific substance.

Table 1. Distribution of procedures used to develop ACGIH
TLV's for 414 substances through 1968^a

Procedure	Number	Percent total
Industrial (human) experience	157	38
Human volunteer experiments	45	11
Animal, inhalation--chronic	83	20
Animal, inhalation--acute	8	2
Animal, oral--chronic	18	4.5
Animal, oral--acute	2	0.5
Analogy	101	24

^aExclusive of inert particulates and vapors.

Another category, group 5, is also established as not eligible for recirculation. Four reasons for assignment to group 5 are given on page 6. Three of the four reasons given are highly subject to challenge.

One reason given is "an MAC or ceiling concentration as suggested in the literature is not reflected in the TLV table." The mere suggestion in the literature is inadequate: a critical review of the literature is required before such assignment of a ceiling value is made--a responsibility assumed by the TLV Committee.

Another reason given for assignment of materials to group 5 is "systemic effects are produced at concentrations that fall within the excursion factor for the appropriate TLV." The inclusion of the excursion factor in the TLV booklet is, in the opinion of many, a mistake on the part of the TLV Committee. It was apparently made in response to never-ending demands for some kind of guidance as to an upper limit that might be suitable for various substances. The excursion factor table given is as shown in table 2.

Persons familiar with the problems of sampling and analysis for occupational contaminants will immediately recognize that the size of the excursion factor is related to the difficulty of securing accuracy and precision in the sampling and analysis, rather than to the hazard represented by the substance.³ There is no toxicological reason why, if a TLV value is below 1 ppm or 1 mg/m³, a 300 percent excursion is tolerable, whereas if the TLV is 200 ppm, only a 25 percent excursion is tolerable. It is patently ridiculous to apply the same excursion factor to different chemicals which have widely different modes of physiological action. The TLV Committee itself made a disclaimer in that section of their booklet concerning the use of the excursion factor. Again, the TLV values are suitable for professional use, require interpretation, and are not suitable input for the hierarchy of a logic diagram.

The third reason given for assignment of materials to group 5, existence of a "C" value, may or may not be valid because C values are assigned for a variety of reasons.

A review of the report failed to disclose any clear definition of groups 2, 3, and 4, so no discussion will be attempted of those groups. Group 1 is the category which the report proposes as clearly eligible for recirculation.

Table 2. Excursion factors

TLV > 0-1	ppm or mg/m ³ , excursion factor = 3
TLV > 1-10	ppm or mg/m ³ , excursion factor = 2
TLV > 10-100	ppm or mg/m ³ , excursion factor = 1.5
TLV > 100-1000	ppm or mg/m ³ , excursion factor = 1.25

The method by which chemical name synonyms treated is not understood. Two examples will suffice.

1. On page B2, the compound alundum has been assigned to group 6. The reason given is that it is a synonym duplicate with the chemical corundum, which may be found in group 5. On page C3, corundum is to be found with the synonyms aluminum oxide and alundum, and the reason for assignment to group 5 (not eligible for recirculation) is "experimental neoplastic effects have been demonstrated in the literature." This reason apparently is one of those to which objection was made previously. And now the same substance is found in both categories 5 and 6. Alundum is found in the TLV list in appendix E under nuisance particulates; i.e., the TLV Committee funds no specific toxicological or physiological effect attributable to this substance. As a practical matter, it should be recognized that alundum is the basic abrasive material in a very large proportion of the grinding wheels used throughout industry. Most grinding wheels, if small in size and infrequently used, are not connected to any kind of an exhaust system, and have apparently no harmful effects over many, many years of such use, with very large numbers of workers so exposed. Yet the analysis attempted in the recirculation report places it in the nonrecirculation category.
2. Similar confusion exists over another example on page B2 for 2-aminoethanol. The reason for assignment into group 6 is that it is a duplicate or synonym of ethanolamine, which is to be found in group 1. Group 1, if the reader will recall, is the group which is declared eligible for recirculation.

Many more similar examples exist which will not be detailed. In general, the concept of placing the same substance in two mutually exclusive categories merely because there are two names for it is not understandable.

Chapter 2, page 7 states that crystalline and amorphous forms of silica do not appear to be suitable for recirculation. The reason given is that free silica is capable of producing fibrogenesis, also commonly called pneumoconiosis. Upon consideration, this would seem an entirely inadequate line of reasoning. Concentrations of free silica particles reasonably above the TLV limits require an exposure of at least 5 years, and typically 10 years or longer, for any detectable degree of pneumoconiosis to develop. Thus, the course of the disease is slow and chronic in nature and adequate time will exist, in the practical case, for a correction of any deficiency in the recirculation system. There would even be time available for an expected routine inspection on the part of the various regulatory authorities. Furthermore, from a dust collection point of view, those dusts containing free silica are usually, although of course not always, of a physical and chemical nature such that known and valid air cleaning techniques are applicable on an economical basis, and with a very high anticipation of success. Certainly, of all categories to be outlawed, this is not one of them.

Page 8 of chapter 2 sets forth the thesis that particulate material is a classification of doubtful application for recirculation, because the group preparing the report was unable to make recommendations as to suitable air cleaners. One of the reasons cited for this lack was the absence, in the published literature, of "adequate" data concerning the size distribution of various particulates. The absence of large amounts of published data concerning particle size distributions is due to two factors. In the first place, such determinations are usually made for a specific scientific or application engineering purpose and do

not really constitute publishable material on an individual basis. Secondly, the size distribution of a given chemical species will vary widely with the process or operations which generate that particular species. There is a great deal known about the general particle size ranges of materials from various processes, certainly enough to permit adequate air cleaner specification in very many cases. In those cases where the data do not exist, it can usually be obtained at relatively modest cost and the application engineering can proceed from there.

Particulate collectors of the fabric filter and in-place filter types are in general much more reliable and much more efficient than gas absorbers or adsorbers and, in fact, offer the most attractive and most immediate opportunities for recirculation systems. Assuming that the particulate is entirely or mostly of one generic species, contaminant monitors for such systems can be designed to operate on a mass basis only, thus increasing the reliability and reducing the cost because chemical analysis is not required. Furthermore, such monitors of reasonable reliability already exist on the market, and in appropriate sensitivity ranges for this application.

In brief, the opinion derived from technical review is exactly opposite to that expressed in the report. Particulate material is the most likely to be recirculated in the near future and offers the best chance of successful application of recirculation systems with currently available technology and hardware. It was an application of this type, as a matter of fact, that was chosen by the ACGIH Ventilation Committee as an example of a good way to provide for recirculation.

CHAPTER 3

Chapter 3 is a state-of-the-art summary of commercially available air cleaning equipment. While the statements are essentially correct, they are far too brief and not in sufficient depth to be useful in selecting equipment when recirculation is contemplated. The chapter contributes nothing toward a criterion for recirculation.

CHAPTER 4

Chapter 4 deals with the reliability of recirculation systems. The approach taken here requires a "model" of such a system and two models are depicted. These models are reproduced here as figures 1 and 2, figures IV.1 and IV.2 in the basic report. Neither model is appropriate for such analysis because neither model reflects the kinds of systems most likely to be required and installed for recirculation.

Figure 1 does not represent a highly probable system for several reasons.

1. The blower motor is shown with a primary and a parallel redundant unit, which is almost always not necessary. If such backup is required, it is a relatively unique situation and is required in its own right independently of whether or not the system is recirculating.
2. The air cleaner is shown with a primary and a backup, but the backup is in parallel rather than in series with the primary. Certainly for a particulate contaminant, and probably for many others, a much more economical and much safer arrangement would be to have the backup in series with the primary. If a series arrangement is designed rather than a parallel arrangement, and if the contaminant is a particulate, a very much simpler, less expensive, and more reliable control system or warning system is then available,

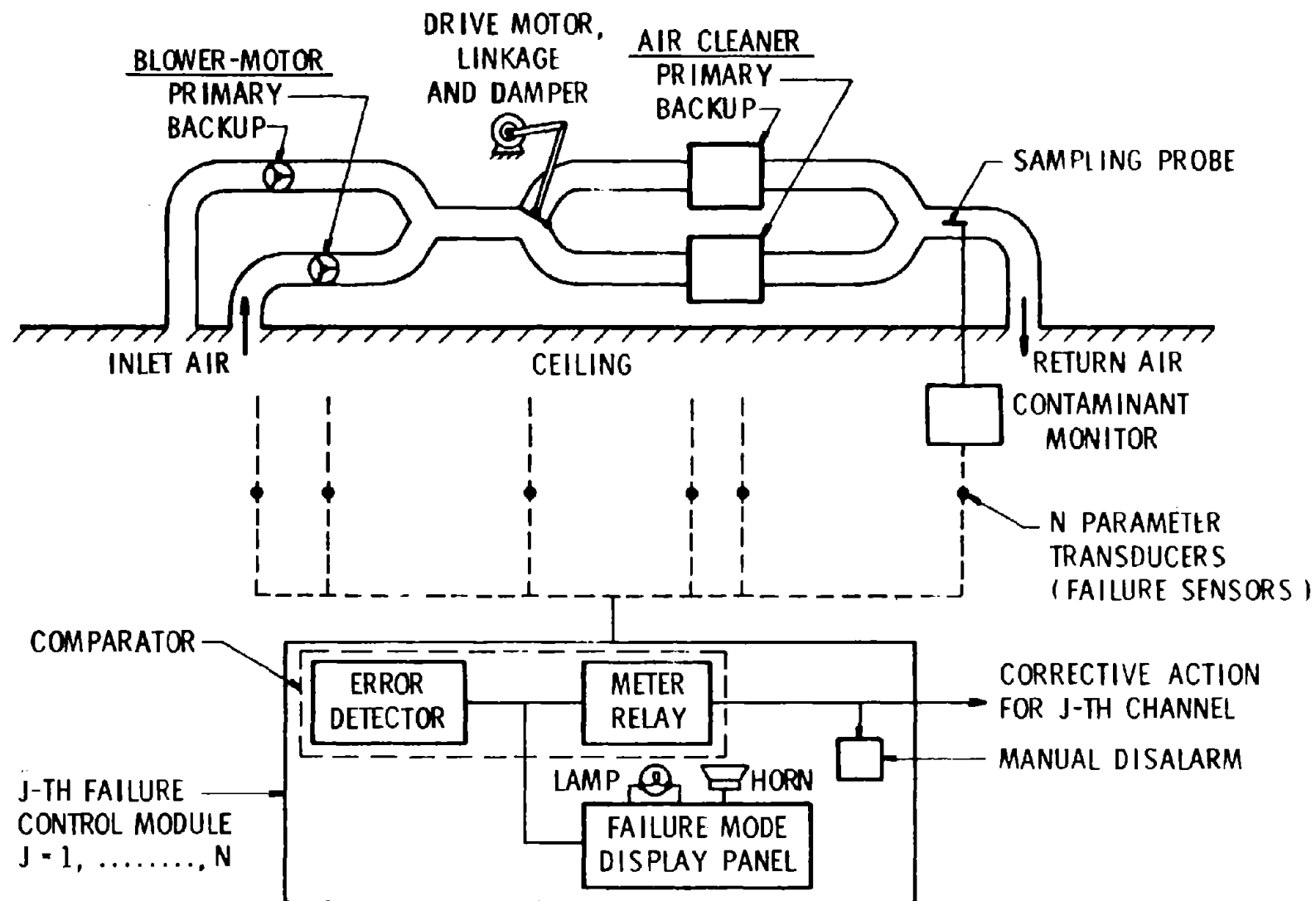


Figure 1. Physical recirculation model for Case I: Redundant air cleaners.

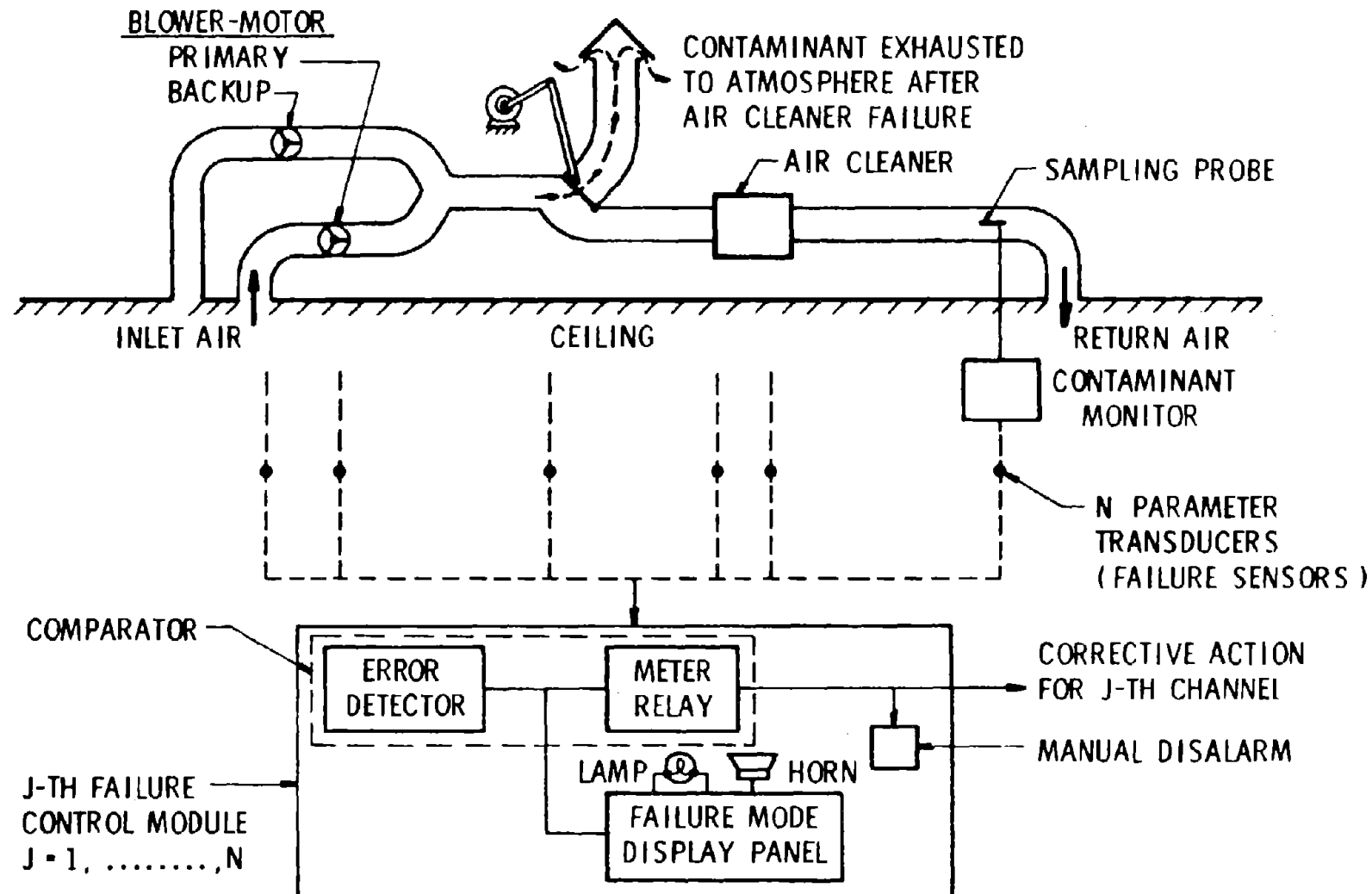


Figure 2. Physical recirculation model for Case II: Air cleaning with bypass.

based on a simple measurement of the pressure drop across the backup or secondary filter.

3. A bypass system would be required, of course, if the primary and backup air cleaners were arranged in series.

Figure 2 shows again the redundancy of the blower and motor--inappropriate, as previously discussed. A single air cleaner is shown offering no redundancy in air cleaning capabilities and a bypass is also shown. The safety of this system depends on the performance of the contaminant monitor, which is usually the least reliable of all the system components.

Based on these two inappropriate models, sets of exponential equations are derived for expressing the reliability of the system. The meanings of the term "reliability," or its inverse, "failure," in the context of this report are not defined. If left to the assumption of the reader and derived from the context of the study, the definition of failure would be assumed to mean a failure of some component of the system. A more meaningful definition, for this study, would be failure to protect the working environment to an adequate degree.

Following the development of the equations, various numerical values are given in table IV.2 on page 51. The values in that table, abstracted from literature sources (some of which are relatively unavailable) are not in agreement with a general observation of the reliability of such equipment in the industrial setting. The MTBF, translated into years, becomes 6.85 years for a fan-motor combination operating on cool clean air and 4.0 years for a combination operating on the hot dirty side of a collector. These values as means are extravagant and are seldom achieved in actual practice. The 11-year MTBF proposed for the power supply, presumably of the control circuit, appears to be equally extravagant when industrial-grade rather than aerospace-grade equipment is contemplated.

The values in the table are equally startling in that there are no MTBF estimates made for two of the failure events that are obviously, and of common knowledge, of much higher frequency than any values in the table. One of these is a general power failure. It is difficult, of course, to include a general power failure in this type of a "model" because just what actions should be taken in event of a power failure depend on the particular circumstances involved.

In most cases, a general power failure requires no special provisions for the exhaust system, because typically, whatever is producing the contaminant also ceases to operate and no more contaminant is produced. This is not always the case, however, and in a finite number of specific situations it is advisable and sometimes absolutely necessary to provide an emergency power supply for the operation of exhaust ventilation, or, for partially redundant systems, in order to prevent immediate life hazard situations for the occupants of the factory. In the ordinary case, general power failure is to be anticipated with higher frequency than the assignment of MTBF to the system components.

The second omission in table IV.2 is the sensor element of the monitoring subsystem. While the various components of control systems, such as power supplies and relays, can be built with MTBF's as tabulated, the weak link in the monitor system is the sensing and/or analytical apparatus. At the current state-of-the-art, the reliability of such apparatus is very poor and has a much shorter MTBF than any of the other components listed in the table. The MTBF for many

such sensors would appropriately be a few hundred hours. "Appropriate preventive maintenance" is not generally a practical answer to poor reliability of the sensor and monitor system. If the level of sophistication and financing of preventive maintenance in the establishment is unable to keep relatively simple machinery like motors, fans, and air cleaners operating, whence will come the sophistication to keep the monitoring instruments working?

As an aside from material specifically germane to this review, it is a fairly common procedure to specify some monitoring instrument that will perform some function or give the alarm in the event a hazardous situation arises. In all too many cases, this represents a "safety engineer's cop out." Once having specified the furnishing of a "monitor," the engineer feels that he has done his job. The fact that a month later the instrument is hanging on the wall unplugged from its power supply because it continually gives false alarms is then someone else's responsibility. Whatever protection that instrumentation was supposed to provide is not being provided, and if it was really needed in the first place, people's health or lives are at risk. Good engineering will seek some other design solution on a considerably higher priority basis.

Although not stated in the text, the graphical depictions given of system reliability tabulate an MTBF for the air cleaning device of 8,000 hours. This is somewhat on the high side and represents "the best" in preventive maintenance of such equipment. The monitor MTBF is tabulated as 50,000 hours, in contrast to the previously expressed opinion that, for most equipment of that kind at the present state-of-the-art, MTBF will be a few hundred hours.

In view of the disagreements with the models and the basis of reliability data described above, no further comment is warranted on the graphical depiction of the probability of system failure given in the remainder of chapter 4. It certainly is agreed in general, however, that there will be a finite probability of system failure more frequently than once a year, and the objective of the criteria and of the design should be to prevent, in event of such failure, any immediate hazard or serious health consequences to the occupants of the workspace.

The review given of stack sampling parameters and techniques is somewhat in the category of the review of air cleaning equipment, correct but insufficient to be useful. There is one serious error, in that figure IV.23 on page 93 depicts a balanced tube sensor or "null probe" which is, in general, not reliable except over a fairly narrow range of velocity. There is a null probe proposed by Muhlrad (ref. 4) that overcomes this problem but that work has never been checked by any other investigator as far as is known, and it has not received, for some reason, wide acceptance in this country.

CHAPTER 5

Chapter 5 presents the results of analytical recirculation models. Since the models are inappropriate, the results of the analysis of such models are also inappropriate. Furthermore, some of the parameters chosen for the derivation of the equations are also inappropriate in that they are largely undeterminable. Basic to the whole scheme is the value M , the rate of generation of contaminant. With a few notable exceptions, M is a value that will not be known even approximately, for the typical industrial situation.

The amount is usually far too small to be determined by process material balance, being lost in the "noise" and among other process losses. The suggestion is surely going to be made that M can be determined by duct sampling of

exhaust hoods or systems, but that procedure is not generally applicable. Exhaust hoods typically remove much more material, and of a different size distribution if particulate, than would become of breathing zone significance in the absence of the hood. The duct sampling approach will of course be valid for some sources, with the decision as to the validity necessarily left to the expertise of the investigator.

The value E, "the efficiency of the scavenging system," is inadequately defined, and will be very hard to define adequately. It will be even harder to assign a numerical value.

The authors of the Government report, on pages 120-121, take exception to the proposals of the ACGIH Ventilation Committee and use the derogatory term "fictitious" for the parameter proposed by that committee, the concentration of contaminant in the workroom air without recirculation. This value, while not easy to determine, at least can be determined in a real-world situation. It is directly determinable for an existing exhaust system for which recirculation is proposed. For many new systems, it can be estimated with reasonable accuracy on the basis of experience with closely similar workroom situations. As need for use of this equation grows, more and more such data will become available.

There is one factor affecting the workroom concentration of contaminant that has been entirely overlooked in the analysis. It may be described somewhat as follows. If it is assumed that well-designed hoods are used with adequate capture velocities and volumes, the contamination in the workroom air does not usually result from lack of effectiveness of the exhaust hoods, but rather from the generation of contaminants from stray, minor, and uncontrolled sources. It is not always true, of course, that the hoods are so completely efficient, and if they are not, the contaminant released into the air as a percentage fraction of that removed in the ductwork will be almost impossible to determine in view of the background from other sources. The existing concentration in the workroom however, is determinable. Thus, this "fictitious" parameter is directly measurable in many cases, reasonably estimated in many others, and is at least a parameter which goes directly to the ultimate required result on a "performance standard" basis--that is, "what is the concentration of contaminant in the breathing zone of the worker?"

The presentation of concentration as a function of time, representing the transients that may be involved when small sources are present in large rooms, is interesting. The basic equations for the transient buildup or decay of such contamination have been presented many times before. Depending upon such transients for maintaining safe contaminant concentrations is, however, a risky procedure. One of the things that is easiest for any production facility to change, with minimum lead time and little or no capital investment, is the number of hours or the number of shifts during which a given activity is conducted. It happens in many cases that such prompt changes in production are essential to the survival of the enterprise. Short of almost daily surveillance by some inspection authority, the increase in hours of production will not be delayed waiting for redesign, capital appropriations, equipment deliveries, and installation of changed ventilation systems. It is on this basis that the recommendation is made that, although the transient situation is interesting and is indeed applicable in some few situations, it should not generally be relied upon. Estimates of transient conditions are useful for estimating the time available for appropriate action following system breakdown.

SUMMARY

A review shows the report to have several serious deficiencies:

1. No criteria are presented which are applicable to actual systems.
2. The reliability analysis overlooks the fact that the only significant differences between recirculating and nonrecirculating systems are the reliability of the air cleaner, monitor, shutdown, or bypass portions of the system.
3. The classification scheme of substances in the TLV list is subject to severe criticism in that:
 - a. Generalities and uncritical review of literature sources were used to override the TLV Committee recommendations;
 - b. The same substances are found in two mutually exclusive categories merely because synonym names exist;
 - c. The "excursion factor" is applied in apparent ignorance of its derivation and in spite of the disclaimer by the TLV Committee;
 - d. The category, "Particulate Matter," was incorrectly relegated to being not eligible for recirculation.
4. Significant terms, "failure" and "scavenging efficiency," are not defined, and definition derived from context is inappropriate to the problem.
5. The summary of air cleaning equipment is inadequate for any real problem and contributes nothing to any criteria for design.
6. The models of recirculation systems are inappropriate in that they do not reflect any category of commonly used or proposed systems;
7. The reliability data used show extravagantly high values for some components and completely overlook the problems of general power failure and the extremely poor reliability of contaminant sensors;
8. Parameters to be used in predicting allowable recirculation are in general incapable of being quantified;
9. Since the models are not sufficiently "real" and since numerical values for necessary parameters are and will continue to be generally unobtainable, the predictive curves presented are not very useful;
10. In general, reliance should not be made upon transient concentration build-up relationships because the hours and shifts of production are so easily and quickly increased.

REFERENCES

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2. J. B. Olishifski and F. E. McElroy, eds., "Fundamentals of Industrial Hygiene," National Safety Council, Chicago, 1971, p. 423.
3. H. E. Stokinger, "Criteria and Procedures for Assessing the Toxic Responses to Industrial Chemicals," in "Permissible Levels of Toxic Substances in the Working Environment," Occupational Safety and Health Series, No. 20, International Labor Office, Geneva, Switzerland, 1970.
4. W. Muhlrud, "Use of Zero Pressure Probes to Measure Dust." Staub, Vol. 26, No. 7, July 1966.

DISCUSSION

MR. WILLIAM J. ASTLEFORD (Southwest Research Institute, San Antonio, Texas): I would like to clear up one point, and that was where you talked about compounds being in mutually exclusive groups. I think there was a statement in the report to the effect that when we are going down this logic tree, those compounds that had synonym duplicate names and did not exhibit an experimental carcinogenic potential or a capability of requiring a ceiling concentration, then passed down to the decision level where all five toxicity criteria were applied equally.

Some confusion may have resulted from the manner in which the writeup was presented; however, Groups 6 and 5 should contain only those compounds that have carcinogenic or MAC labels. Beyond that, if a compound had two names and it did not bear either of those two labels, then the five toxicity criteria were applied equally.

Another comment that you made regarded the specification of air cleaning equipment for particulate substances and the bulk of your comment was directed toward process application. By definition, the way that this program was conducted is that it was process independent. Therefore, some of the quantities which would be known for process application were assumed not to be available at that level.

MR. CAPLAN: Yes, but you wound up with the general conclusion that because you did not find data on particle size distribution you couldn't select particulate air cleaners, and this made particulate cleaning air circulation...

MR. ASTLEFORD: It was not meant to imply that. I do not think there is a manufacturer of air cleaning equipment that will recommend a device for air cleaning without first having particle size data provided by the potential user. That service may be purchased by the user from the potential supplier. This type of data we did not have access to.

MR. CAPLAN: I agree with and understand what you just said, but that should not lead to the conclusion in the report that air contaminated with particulate is not a good idea to approach for the recirculation.

MR. ASTLEFORD: I regret that you were led to that conclusion.

One of your comments pertained to the MTBF table in the report for fans, blowers, and the number of hours of mean time between failure. Those data were obtained from the mil. spec. handbooks and from the nuclear engineering industry.

MR. CAPLAN: Well, I thought the reference that I tried to find there was some Hughes aircraft in-house report.

MR. ASTLEFORD: It was part of a study for the nuclear industry, I believe. It appears that we have a disparity between a conceptual study, which is the direction that we took, as opposed to a study the results of which can be picked up and put into immediate application. We took the conceptual study approach, and for that reason we considered the reliability and recirculation modelling that we did. Eventually, you are going to have to get down to applying some type of a model in a practical application; but our study was a conceptual approach.

CHAIRMAN HUGHES: I would like to address one question. This was brought up previously regarding the list of recirculable contaminants.

Are there any suggestions or recommendations of an approach that could be taken within a reasonable level of effort that you could determine what could or could not be recirculated? Should all contaminants be recirculated?

DR. RALPH LANGNER (Dow Chemical, U.S.A., Midland, Michigan): I would like to address that question. There is no reason why anything cannot be recirculated. What we need is a performance standard. Tell industry what level is required for safety of the worker. That is what has been left out of this whole study--the safety of the worker, the health of the worker. You tell us what level is required and then let us do it in the best way possible for the particular industry, for the particular company affected. One company will use one method, another company will use another method, but please give us the latitude, give us the ability to use our judgment as to what is the best for our particular situation.

CHAIRMAN HUGHES: I think a performance standard, as you have recommended, is of course valid. The thing that I personally would like to see in a study like this, is to allow everything to be recirculated that can be. You can probably clean anything that is being generated by the appropriate application of cleaning devices. As long as you clean it and you do not have it in the return airstream, there is no problem. What happens when failure occurs--and failures will occur--is that you will be dumping the contaminant back into the environment. I think you have to put some kind of a restriction on certain contaminants. There must be certain contaminants that, if they are recirculated uncleaned will have a catastrophic effect.

MR. JEREMIAH R. LYNCH (NIOSH, Cincinnati, Ohio): I think Bob put it quite clearly but I would like to add one or two more words to that.

The categorization of which contaminants are eligible for recirculation would depend on the consequences of failure of the recirculation system, both in terms of seriousness of the consequence and the time period of the consequence. We can categorize air contaminants in those terms; for example, if a system that was recirculating air contaminated with carbon monoxide were to fail, it would be serious and the time period could be very, very short. On the other hand, for pneumoconiosis-producing dusts the time period is much longer. That kind of classification can be made, and you see then what you come to immediately is the decision as to the probability that you are willing to allow of this unauthorized event occurring. Those probabilities are really the end result of this classification.

We have heard Knowlton Caplan talk quite knowledgeably on the reliability of industrial equipment as it actually exists. I think all of us who are in the position of being regulators, whether we like it or not, have to deal with the facts of life of industry. (Not the aerospace industry but the kind of industry that Caplan is talking about, where most of the time things are not well maintained and they sometimes work and they sometimes don't). So there is a practical limit on what you can recirculate at this point. I think that when the attitudes and when the processes in industry have changed such that, for example, the level of maintenance of air cleaning equipment and hazard control equipment reaches the level of maintenance of process equipment, we could allow yet another stage of reliability. That reliability which could reasonably be anticipated would

reflect itself in the categories of contaminants that could conceivably be recirculated. Beyond that, speaking in regulatory sense, for those very, very exceptional industries that far exceed the kind of reliability that Cap has seen and that all of us have seen, there is the variance procedure.

MR. CAPLAN: I would like to add one more thought to what Jerry said. For different kinds of contaminants, the state-of-the-art permits a redundant protection of the workers--in some cases quite extreme reliability, almost foolproof--to be added to a system which is not better than the original system that failed, but which at least gives you the redundant feature. For example, on some particulate contamination problems one can have a fabric filter, the emission from which might normally be safe to breathe if properly operated, and maintained, and a backup filter (in series, not in parallel, which is essentially 100-percent efficient, and for which technique exists for leak-testing in place). If the primary cleaner were to fail, the secondary cleaner with almost absolute certainty would continue to protect the worker. It would serve as a sampling or monitoring device.

So in addition to the variables that Jerry points out, you have what is available in the way of air cleaning hardware. How reliable a package can one put together?

A REGULATORY PERSPECTIVE ON THE RECIRCULATION OF EXHAUST AIR

James C. Barrett*

Abstract

Federal and State laws on the recirculation of industrial exhaust air are in general permissive. Michigan's Department of Public Health stresses performance in recirculation systems; airborne contaminants must be held below their acceptable threshold limit values. The department evaluates on a case-by-case basis the type of system that would be most productive and safe, considering such factors as the existence of mixed contaminants in a plant and the possibilities for equipment deterioration. Adequate protection to the worker in a plant that recirculates exhaust air may be costly, but the technology for optimum system performance is there. The central role of the State regulatory department is to protect the health and safety of the employee, while assuring that the demands on industry are realistic.

In considering the recirculation of exhaust air, the use of the word "perspective" in the assigned title of this presentation is particularly intriguing. Engineers are accustomed to thinking of a perspective drawing as a detached view of an object in which parallel lines are seen to converge on a single point. This seems quite appropriate to this subject, where our (parallel) lines of thought must of necessity converge on a single point or objective: the protection of workers' health. Certainly in terms of occupational health, the regulatory position must be consistent with this aim.

It is also well to consider that recirculation of exhaust air is only one of several lines of approach that can be used in the overall perspective of preserving workers' health and conserving energy. Improved ventilation design, whereby through proper selection of exhaust hoods and system components contaminants can be captured and removed from the space with minimum air volume, is an attractive first approach regardless of what is done with the air after it passes through the system. Another approach is the recovery of thermal energy from the exhaust air when the air is not returned to the space.

Turning now to recirculation, the regulatory position is quite simple. Federal OSHA rules relating to occupational health and our Michigan rules require performance: the workers' exposure to airborne contaminants must be below the level specified by the appropriate threshold limit value (TLV).

Some Federal rules and occupational health rules in Michigan do specify ventilation rates for certain operations, however recent decisions in contested cases have held that so long as the airborne contaminant levels are controlled, the ventilation requirements are secondary. This further reinforces the concept of the standards as performance measures.

In all of the OSHA rules with which we are familiar, there is only one specific mention of recirculation; recirculation of air from spray finishing operations is specifically prohibited. In all other respects, the rules and the act itself (Williams-Steiger) are silent on the subject of recirculation.

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Speaking from our standpoint in the State of Michigan, we have had experience for the past several years with ventilation systems which recirculate air. Some of these experiences have been good, some have been otherwise. Our Michigan occupational health rules take specific note of recirculation by placing some restrictions on recirculation systems. (In the following direct quotation from the rules (ref. 1), please note that in our Michigan terminology, maximum allowable concentration (MAC) is defined as the same as threshold limit value (TLV). The difference in terminology is a matter of drafting.)

"R 3101 (10) Recirculation of Air from Exhaust Systems:

- (a) The recirculation of air containing a contaminant whose MAC is equal to or exceeds 1,000 ppm, 15 mg/m³ air or 50 mppcf, shall be permitted if the exhaust ventilation system is equipped with an air cleaning device capable of reducing the contaminant concentrations to 10% or less of their MAC in the returned air.
- (b) The Director may allow the recirculation of air containing a contaminant whose MAC is less than 1,000 ppm, 15 mg/m³ and/or 50 mppcf if the toxicity of the contaminant and the degree of air cleaning to be achieved will create an environment which will not impair the health of the workers and if the contaminant concentrations in the return air shall not exceed 10% of the MAC.
- (c) A recirculation system shall include an alternate air duct connection to discharge the return air outside of the building if necessary to protect the workers' health."

These rules are quoted for information only, i.e., to illustrate our response to the question of recirculation of exhaust air. We want to be sure to see the plans of installations which involve a contaminant of significant toxicity and we require a bypass duct connection which can discharge the air out-of-doors in the event of an equipment failure or at certain times of the year. We do not view these rules as perfect or all-encompassing.

Since their adoption in 1970, there have been changes in the TLV's of inert or "nuisance" materials which change their status from Rule (a), permissive, to Rule (b), requiring review, and further, the rules do not describe with any specificity the testing and monitoring of system performance which our experience indicates is essential.

We believe that the recirculation of properly cleaned exhaust air is practical and permissible in certain instances. We have approved a number of applications for recirculation of systems and at other times we can be very discouraging when it appears to us that a particular application is not feasible.

Recently we approved the installation of a system to recirculate air collected at welding stations in an apprentice welding training school. The system will be equipped with a high-performance particulate collector, a bypass duct, and operating controls similar to the illustration in the current 13th edition of the Industrial Ventilation Manual (ref. 2). The system was designed by a competent industrial hygiene engineer and will be checked by him for contaminant removal as well as the presence of welding gases after the installation is complete. The system has been designed for partial exhaust, i.e., not 100 percent recirculation, and dependent upon test results, the exhaust/recirculation rate will be adjusted. As an interesting sidelight, this apprentice training school is operated by a labor union. Thus we have an instance where the employer is a labor union.

Here is another example, this time with discouraging results. We were contacted by a foundry operator desiring to recirculate air from a dust control system in the foundry. The plan was to discharge the air into a roof-level penthouse, thus "pressurizing" the room to keep extraneous contaminants and building heat out of the expensive switch gear. Our review of the installation indicated that worker exposure to the recycled air would be minimal since there were no permanent employees in the penthouse and the area was occupied only during routine maintenance operations. Our review also indicated that there would be some moisture pickup as the air passed through the wet collector and that the moisture and residual contaminant (no collector is 100 percent efficient) would not necessarily be compatible with the switch gear and other equipment in the penthouse. We approved of the installation with the feeling that the job would not recirculate long before the minimal moisture and dirt became a problem. It is our understanding that the air is now being exhausted out-of-doors.

We will say only a few words about technology. Other speakers are better qualified to discuss the performance characteristics of commercially available air cleaning equipment. We believe that air cleaners are available now for nearly all classes of contaminants; the major question becomes one of cost. With increasing contaminant toxicity, or where there are physical characteristics of substances that are unusual, the equipment must necessarily be more sophisticated and will be more expensive. Multiple-stage cleaning may be required to achieve the necessary air cleanliness.

The question of mixed contaminants also arises. In our experience, it is a rare situation when a single contaminant appears in the ventilation airstream. It is most often mixed with other materials, as for example in welding operations where the "smoke" may consist of material from the rod, the rod coating or flux, the substance being welded, and various gases such as ozone, CO, and oxides of nitrogen that may be generated under different conditions. The recirculation system may need air cleaning devices for both particulate matter and gases; thus the equipment will be more complex and the cost will increase.

The cost of equipment is not strictly our "business" but we cannot ignore it either. We have the responsibility to see that workers' health is protected and have a corresponding responsibility to insure that our requirements are realistic. The ultimate decision as to whether a system is feasible or not, however, does have a direct relationship to capital costs and operating costs, which must be balanced by the employer/owner against potential energy savings.

We also have a great deal of interest in the reliability of the system. It's worth repeating that we are concerned with system performance. We need to know that the system will perform reliably and on a continuing basis, first of all to make sure that the workers' health is not in jeopardy and secondly to insure that the system does not become a source of complaints which would require an undue amount of our time. Quite often this is a psychological matter.

One of my first field jobs as a brand new industrial hygiene engineer some years ago was in a small machine shop. In this shop there were a number of high-speed grinders shaping carbon steel and tool steel. The grinding wheels were synthetic abrasives, the metal dusts were of low toxicity, and in an effort to maintain a clean, enjoyable workplace the employer had installed a number of small unit-type collectors with direct (recirculating) discharge. Unfortunately, these collectors were placed next to the walls which were painted an attractive pastel color. You can imagine the result: even the minimal amount of dust passing through the collectors left a smudge on the walls similar to that seen around the diffusers in air-conditioned buildings. The workers were concerned:

"If the dirt is marking up the walls, what is it doing to our lungs?" It took a lot of our time and effort to explain to the workers that in spite of what they could see, their health was not in jeopardy.

There have been many similar instances. We can recall one buffing plant where there was an acceptable ventilation system with a wet collector returning the air to the workroom. The fan discharge, unfortunately, was directly against the roof and the minimal passthrough of material resulted in a considerable staining of the ceiling, considering that the ventilation system was handling 30,000 to 35,000 cubic feet of air per minute. Again the workers were concerned about what their eyes were seeing and it took a considerable amount of air sampling and investigation before they were convinced that airborne dust concentrations were not harmful to their health.

Reliability of the recirculation system requires much more than care in installation. The system must be continuously maintained in a proper manner so that it will operate as it was designed to. In considering the necessary maintenance and repair, attention must be paid to the possibility of failure and the result of that failure, i.e., what will happen if a bag breaks or if a collector runs dry. Controls or operating procedures must be established to insure that in the event of collector failure the air can be promptly and directly bypassed to the out-of-doors.

Some years ago we were asked to evaluate a series of ventilation systems exhausting from a decorative chrome plating line. Samples of the collector effluent taken on a number of occasions indicated that the majority of the collectors were capable of performing satisfactorily and that the air could be recycled to the plant. We also observed that on a daily basis it was difficult to predict whether or not there would be any water in the collectors! Obviously when there was no water the collection performance was unsatisfactory. We advised management that recirculation would be all right providing they established maintenance schedules to insure that the collectors had an adequate water supply. After serious consideration, management decided to dump the air out-of-doors.

The gradual deterioration of the system performance over time cannot be overlooked. Here we look for changes in the overall system performance as well as in the air cleaning device. Often the two are directly related. A fabric filter, for instance, which relies on the filtering of air, does not operate at a constant static pressure drop; rather the static pressure increases with time as the interval after cleaning increases.

If not considered in the overall system design and operation schedule, this increased pressure drop will result in a reduced air volume through the exhaust fan. This in turn may lead to inefficient capture of contaminants at the point of entry to the ventilation system and may increase worker exposure. Similarly, plugging of certain types of wet collectors will lead to decreased system performance. These factors must be considered in choosing the instrumentation necessary to monitor the system performance and in establishing maintenance schedules.

Briefly, we have tried to describe the regulatory position as well as our concerns about recirculation of air from industrial ventilation systems. It would also be fair, we believe, to point to what we see as some encouraging trends. First, the impact of air pollution control nationally has led in some degree to improved design of air cleaning equipment and accessories. And air pollution control responsibility, when properly assumed by management, results in a higher level of maintenance and care of ventilation systems and air cleaners.

Secondly, there are certain features of present OSHA occupational health standards, and new ones under consideration, which we believe will encourage the application of recirculation systems. There are two aspects to this: (1) OSHA ventilation standards now require the testing of certain types of ventilation systems on a regular basis to insure that airflow and system performance are maintained; (2) New occupational health standards are expected to require monitoring of the air in the workroom as an ongoing measure of worker exposure to various contaminants. It is logical to expect that an employer who has the capability of providing the necessary maintenance of systems, who has the air cleaning equipment already on hand because of air pollution control regulations, and who is monitoring worker exposure to contaminants may request permission to recirculate all or part of the exhausted air.

To summarize, present Federal and State laws, standards, and rules are permissive except in the specific instance of prohibiting recirculation from spray-finishing systems. The technology is here in large part. Questions of application, operation, and maintenance of recirculation systems remain to be solved on an individual basis, evaluating each set of circumstances and considering the expected or known contaminants. We do not believe that there can be a "cookbook" approach to recirculation except for the simplest systems involving innocuous or "nuisance" substances. We believe that for most systems the performance must be tested by a competent industrial hygienist to evaluate worker exposure before and after the system is installed. The system must be carefully maintained and the system performance monitored to insure optimum performance for adequate health protection.

REFERENCES

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2. "Industrial Ventilation, A Manual of Recommended Practice," 13th edition, Committee on Industrial Ventilation, ACGIH, Lansing, Michigan.

DISCUSSION

MR. JAMES C. WOODLING (Goodyear Tire and Rubber Company, Akron, Ohio): I have a question here that is not particularly related to your comment, Mr. Barrett. Do you have or does somebody have a crystal ball in which one can see when EPA will start limiting emissions into the exterior, at which point we are going to have to go to these circulatory cleaning devices and will no longer have the option of blowing outside versus recirculating?

MR. BARRETT: Well, first of all, if I can't speak for OSHA I surely can't speak for EPA, but they already have emission limits on certain things. These are not highly refined as yet. They are mostly gross particulate type emission. Perhaps there are some others. I expect that as EPA discovers that materials are toxic, they will be coming along with specific emission limits. Whether or not these emission limits would be lower than the TLV's, that is, the emission at the pipe would be lower than the TLV, or lower than what we may have to achieve to get satisfactory recirculation, I can't comment on that. That takes a better crystal ball than mine.

MR. CHARLES D. SEEGER (Caterpillar Tractor Company, Mapleton, Illinois): I understood you to say that you have reviewed and approved several recirculating systems which involve wet collectors. Is that correct?

MR. BARRETT: Yes, sir. We have no ax to grind over one type of collector or another as long as it will work and they keep it working.

MR. SEEBER: Related to the same question, on what type of applications can that air be used after it is recirculated? You mentioned the high humidity factor on the switch gear, and I appreciate what you are saying.

MR. BARRETT: Most of the wet collector recirculation jobs that I have seen have involved buffing and polishing, and we have experienced a few little kinks in there. Some particular types of collector design do not work quite as well as others in terms of operating. In our experience, the type of collector that maintains a somewhat static bath of water may develop a mat of fibrous material from the buffing operation and then this mat tends to disturb the collector performance. We seem to find better performance with those that break up the water and squirt it around inside. But most of the wet collector operations that I have seen are buffing and polishing. I think of one or two foundries where particular circumstances are such that, let's say they are ventilating some operations in the basement (perhaps a typical example would be transfer point under a shot blast, something like that) where it is practically impossible to get the duct outside and they are recirculating.

MR. SEEBER: My question is what are they doing with the air off the wet dust collector and how are they using that--just dumping it into the air?

MR. BARRETT: Yes, putting it into the space.

MR. SEEBER: I think humidity would be creating a problem.

MR. BARRETT: It has not been a problem that I know of. The problem has been in maintaining the collector because of the iron that comes through and tends to form a heavy thick deposit.

MR. SEEBER: I have another comment, if I may. The feeling that I seem to get is that when you consider recirculation, you look at the economic aspect without respect to the energy saved. I assume that those people who have commented this way are not being faced with an extreme energy shortage, as we are beginning to experience in the central part of Illinois. There the economic considerations are whether to put in recirculation or conservation through heat-exchangers, and so forth, or to find some other energy source and build a steam facility, coal-fired, if that is the energy source available. You consider that economically, but basically it is just a consideration of either we begin to recirculate, we begin to conserve, or in 5 years, 6 years, 7 years we will not operate.

MR. BARRETT: We have not been faced with that particular thing in any significant numbers yet with different industries, but I expect some of it is coming.

In the context of my remarks, we look at what the system is going to do to protect the workers' health, and we may have to tell the person who proposes the system that we want to see this particular redundancy or that type of control, or this type of maintenance, and then he has decided up to this point in time whether he, the respective owner, wants to spend that kind of money to save that kind of air. The major concern that we all have is that that choice may be taken away from us, it may be a case of either recirculate or not ventilate at all, as Professor Caplan referred to in his remarks. I think we have to prepare ourselves to meet that situation because I do not think it is too far away in some parts of the country.

MR. RICHARD COOMES (Proctor & Gamble Company, Cincinnati, Ohio): Jim, in your experience with systems that have recirculated air containing particulate matter, have you ever seen any circumstance where there has been a significant buildup of submicron particles, or particles in the whole gamut of respirable range? Has that ever become a problem?

MR. BARRETT: Not to my knowledge. That is not to say that it cannot become a problem. What you are saying is have we ever seen a system that failed because it did not collect enough material?

MR. COOMES: Because of small stuff getting through.

MR. BARRETT: I have not seen that. When we look at the set of plans we look at what is available dilution ventilation in the area. We look at most all of the factors that are listed in the ventilation manual and have been discussed here, and we haven't had any adverse problems.

PANEL DISCUSSION:
OVERALL ASSESSMENT OF CRITERIA DEVELOPMENT TO PRESENT

CHAIRMAN HUGHES: The purpose of the panel discussion is to tie the discussions up to this point together. If anyone has come up with any more questions or ideas he would like to address to any member of the panel, please do so. The floor is open for questions or comments.

MR. ROBERT STOTZ (R. B. Stotz, P.E., Inc., Panama City, Florida): I would like to know what consideration is being given to the position we in the United States are placing ourselves in competitively with manufacturing companies in Germany, Japan, and so forth, with the requirements we are putting on industry.

CHAIRMAN HUGHES: You're referring to requirements such as the TLV's, the health and safety regulations?

MR. STOTZ: All of these regulations and the cost of installing, primarily the cost of installing.

CHAIRMAN HUGHES: That is a good question. I will be quite honest about it, I'm neither prepared nor qualified to answer that. Does anybody on the panel care to answer?

MR. KNOWLTON J. CAPLAN (Industrial Health Engineering Associates, Inc., Hopkins, Minnesota): No, not really. As good a question as it is, it isn't why we are gathered here today. One look at why we are gathered here today is that if we do manage this one little part of the job well, it will be helpful rather than harmful to our competitive position. I would offer that thought.

MR. STOTZ: I guess really the point I'm trying to drive at is that it is essential that we do come up with methods of conserving energy if we are to maintain our position worldwide and at the same time produce the results that we want to from the standpoint of health or safety of personnel.

MR. WILLIAM J. ASTLEFORD (Southwest Research Institute, San Antonio, Texas): I would just like to make a brief comment regarding the unavailability of energy that the gentleman from Caterpillar Tractor mentioned this morning. His problem is in obtaining energy, not the price of it. It's my understanding that the Federal Power Commission is now in the process of considering deregulation of natural gas prices over the next 5 years. In other words, let the price float. There is a certain element of deregulation right now in that the FPC is allowing certain utilities, State agencies, and private industries to come down into gas-producing States where the cost of natural gas is not regulated, and purchase the volume that they need at the going rate. The competitive rate in a gas producing State like Texas is roughly \$2 to \$2.10 per mcf, or a thousand cubic feet, whereas the current regulated price is approximately 54 cents per mcf. So what we are going to see here, I think, is a floating of the price; perhaps there will be an increase in the availability but surely there will be a substantial increase in the price of gas.

MR. JAMES C. WOODLING (Goodyear Tire and Rubber Company, Akron, Ohio): Just yesterday at noon Congress did approve deregulation of gas.

MR. ROBERT G. CONFER (Exxon Corporation, Linden, New Jersey): Was there any effort in the development of your criteria to consider net energy gain with respect to recirculation of air? For example, was the total cost of such a system compared to the savings of so many Btu's of heat input in your considerations?

MR. ASTLEFORD: No, there was not. An energy balance considered in conjunction with an economic balance was not part of our input.

MR. CAPLAN: One way of looking at it is that the system can be designed so that you could not only recover essentially 100 percent of the heat in the recirculated air but you could also recover the heat represented by the inefficiency of the motors and drives, so that one way of looking at it would be that at least you're buying electric heat. You can in some circumstances essentially recover all of the energy that is involved, even though it may be a more expensive form of energy such as electric heat.

MR. CONFER: The thing is it may take a lot more energy to make the components of the system than you're going to recover from the system itself.

MR. CAPLAN: Well, it could.

CHAIRMAN HUGHES: I think it was brought up this morning that the components of a recirculation system, perhaps with the exclusion of some kind of a monitoring device, are basically the same components that you're using now for an exhaust system. But back to the original question on looking at the economics or the costs benefits--this was not a part of our initial request in the study. The basic reason for its being, at least at the time, was that the primary consideration of the study should be directed towards the health aspects. In other words, if you're going to put in a recirculation system, what do you have to do from the standpoint of protecting the worker? Once the protection matters were decided, and minimum criteria were in place and used, then the economics of whether to actually install a recirculation system, at least on the basis of comparing the cost of the recirculation system versus cost of makeup, would have to be studied by whoever was contemplating putting the system in. That would be a function of the situation at hand. We did not look at the economic comparisons.

Again it's like the other things we didn't do. We didn't exclude them because they are not necessary; we were trying to home in on one specific aspect of it.

MR. CHARLES SEEGER (Caterpillar Tractor Company, Mapleton, Illinois): The purpose of the study that was made and the purpose of this meeting today is to talk about criteria which I assume will lead up to probable regulatory developments, probably through OSHA. Is there any indication when this might occur?

The reason I ask is that many of us are involved in designing new facilities. Again using Illinois as an example, they have in effect adopted OSHA standards which do not include this particular area, so it is questionable what kind of a response we and others can get as we go to State EPA and other areas for approval of systems which we

can put in. I'm not asking for regulations particularly, but I assume they are going to come. Any feel for that, or how that might come about?

CHAIRMAN HUGHES: Let me answer that by stating that there is no specific or stated intention for any of the output of this work to become or to be recommended as regulations. The purpose is to provide criteria to be used in designing systems and providing a safe working area.

I would think that there may be certain specific things that should be required such as bypass provisions. But there would be nothing to say that it is a requirement that you must recirculate. There are no plans to transform these results into regulations.

MR. JOE KUKLA (Sentry Insurance, Stevens Point, Wisconsin): Do you have any feeling of offering the results to be included in the ventilation manual as recommended suggestions of designing?

CHAIRMAN HUGHES: There was some discussion earlier about the availability of the report. This report is being put together with some minor change, and will be put out as a NIOSH Technical Report. It will be available shortly.

The information and subsequent information that is developed from this, will be put out for distribution as a NIOSH Technical Report and that information will be available for the Ventilation Committee if the committee decides to use it in any shape or form.

DR. E. KARL BASTRESS (Arthur D. Little, Inc., Cambridge, Massachusetts): The comment I would like to make really comes from our own experience in dealing with our commercial clients, and from the standpoint that the nature of our business primarily is to consult with industries in this country on industrial hygiene problems as well as a whole host of other technical problems. I'm not saying that for advertising, I'm saying it because I would like to see this subject really put into a broader context.

Typically, when one of us goes to visit a client who is faced with a problem of contaminant control, we encounter a situation where that problem is put last on the list in the sense that, after everything else is done, then the client begins to worry about what the OSHA inspector will find and how to deal with that problem. To some degree you could say that, with the subject of recirculation, we are dealing with the problem in the same way. We're trying to isolate the question of recirculation and create criteria for using it, independent of other considerations of engineering control. Now I think that this is the only way it could be done up to this point. My own comment on the work that has been done by Southwest Research Institute is that it is very useful; I think that the report, combined with the output from this conference--which I think will be a very important addendum to the report--will provide a very useful reference for people who are not completely concerned with ventilation or industrial hygiene all of the time. It will serve as a useful document to identify those considerations that have to be worried about when one deals with the problem of ventilation and recirculation.

I think that future work in this area has to involve the problems of recirculation along with other methods of engineering control, and I

think the number one question is how do you design the equipment in the first place. How do you design the process equipment in the plant to minimize the generation of contaminants, and how do you also coordinate with that problem the design of the ventilation equipment and, if you choose to use it, the recirculation equipment?

It sounds like an enormous task, and if we were to continue in the vein that we have embarked on so far, it would be an enormous task to try to generalize it to industry. I think the answer is necessarily going to be looking at each process or industry individually, then developing criteria for minimizing energy and minimizing employee exposure on the basis of how you select process equipment, how you operate it, where you locate it, how you ventilate it, and to what degree you recirculate exhaust air. You cannot divorce this question of recirculation and its criteria from the earlier problems which the manufacturing manager faces as to how you plan your plant's operation in the first place.

We had an experience recently with a manufacturer of a chemical which presents a very low exposure limit, and this particular organization is building a new plant. They are designing it for optimum manufacturing operations, and they are hoping that they will be able to come along later and maintain this very low exposure limit, which is very unlikely in our opinion.

What we do in this case is to sit down and try to get them to think in terms of ventilation and contaminant control along with a whole other spectrum of things they need to worry about in this plant, but we focus only on one specific chemical process. That way, that particular problem is no larger than the problem of looking at just recirculation for the whole spectrum of industries. I'm not suggesting that NIOSH needs to do this. Each industry needs to do this and it will end up as being probably a thousand different problems, each one directed towards one particular industry or one particular type of process, many problems, but each of them tractable.

MR. CAPLAN: I was going to talk about something else before your last comment, but I happened to live through an experience where we had a plant that was built to operate only temporarily and it turned out to operate permanently. It had lots of different kinds of problems besides ventilation problems--radiation problems and so forth--but we fixed that one up marginally at a cost of 23 percent of the capital investment. A few years later we built a new plant with some variations of the same process. We did a much better job on health and safety for a total cost of 7 percent of the capital. So that you're right.

Is everyone, or almost everyone in the group familiar with the ventilation manual criteria, if you want to call them that, on recirculation?

My feel for the situation is that these are about as far as you can go in generalized terms. From there on you have to do like Dr. Bastress says, get down to a consideration of the specific circumstances and the process and little plant layout.

MR. GUY CUSUMANO (Hoffman Dust Control Manalapan, New Jersey): The question of foreign efficiency versus our standards is that, in my experience, in most cases where we have looked at an entire process and then put the ventilation in with a modernized process, the whole process has turned out to be so much more efficient than it was, due to the technology available and the quality of the labor force available, that the darned stuff turns out to be cheaper to build when you modernize your operation than it was in the first place.

Now on the subject of recirculation, I have noted the comments about monitoring and checking for material, and Cappy's very appropriate comments. You build the recirculation system, you get it running right. We check it, it's working properly, and then we monitor the operation of the system. One can monitor operation of a bag filter very simply by differential methods, and in some cases you can even on relatively inert materials use a smoke stack monitor, and check Ringelman numbers for zero. If it starts to show dirt you know you've got a broken bag. I think that in any approach to recirculation some consideration of monitoring indirectly certainly can be taken into account. I mean when we measured the size of the earth a few years ago, we did not stand off in space some place and check the angle that we saw. We used indirect methods, and I think that they are most appropriate and much overlooked in terms of the backup on dust control system of any sort.

MR. JAMES C. BARRETT (Department of Public Health, Lansing, Michigan): I agree with you, Guy. My comments on the monitoring were not meant to say that this has to be limited to air sampling in the worker's breathing zone. That just happens to be one form of monitoring that is being discussed. If I am correct, the recirculation guidelines in the ventilation manual do indicate indirect monitoring or testing or surveillance, whatever word you want to use, of that little simple system. I think they use static pressure control across the filter or use an airflow measurement, to monitor the system's operation. This is perfectly satisfactory. In fact, we can't exclude that. Any good ventilation testing practically demands that, and I think some of the OSHA standards actually address testing of ventilation systems, certainly much more than they address recirculation.

MR. CONFER: I would like to ask Jim Barrett a hypothetical question. He mentioned that the State of Michigan has three criteria for determining whether recirculation systems should, could be approved. One of them was that the recirculated air should be less than 10 percent of the TLV. In view of the recent direction which TLV's have taken (for example, asbestos going way down, lead going way down) if you had approved some system that was adequate to reduce the discharge air to less than 10 percent of the TLV, what would be your approach in the event that the TLV was going significantly below that on which the system was approved in the first place?

MR. BARRETT: Just as long as the worker exposure met or fulfilled the requirements of the new TLV, that would be our basic determination. Again, going back to performance, we wouldn't go back to our slide rules and say, "ah-hah, the discharge concentration is now 19.7

percent of the new TLV," or something like that. The criteria would be, what are the workers exposed to. We use these rules as guidelines to form the sides of a path to go down in looking at recirculation, but obviously 10 percent is an arbitrary figure. It has come down to us from our grandfathers in the ventilation industry. It is simply a benchmark along the way. The absolute criteria is the worker's exposure.

MR. CONFER: In view of the TLV directions, though, do you think it is practical to consider recirculation?

MR. BARRETT: I would have to say yes, I think it is still very practical. There is a lot to recirculation, you know. There is the matter of the selection of the equipment. There is the matter of distributing that recirculated or recycled air back to the space. It doesn't have to blow directly on somebody's head. You have an option of space ventilation independent of this for dilution purposes, so I think it is feasible still.

MR. CAPLAN: I think if you would use the equation in the ventilation manual, or the equation in the SWRI Report for a steady state condition, you would find that they essentially agree with each other. You would find that under many circumstances the concentration of the recirculated air could be perhaps as high as five times the TLV if all of the other criteria were adhered to, so that "10% TLV", as Jim said, came from a kind of historic policy type feeling rather than any design consideration. In the few recirculation cases that I have worked on (and they were all particulate problems), I have found that you can't exactly fine-tune the efficiency of the filter, so by the time you got through putting in your secondary or back-stop filter you had a big safety factor. In some cases your calculated risk, anticipating a future reduction in TLV, might be greater, and in others lesser, and it probably would have a greater impact on whether you controlled all the sources in the workroom in the first place than it would on your recirculation system design.

DR. BASTRESS: Mr. Barrett, you mentioned this morning that at present the OSHA regulations do not deal with recirculation in general, so from that standpoint a plant operator is free to utilize recirculation as long as he doesn't violate any other OSHA regulation. I gather from your comments this is not true in Michigan, that somehow recirculation is regulated, and to be used, permission must be obtained. Would you explain the background of that a little bit, and if you can, I would like to know to what extent this same situation exists in other States.

MR. BARRETT: Let's start with OSHA. It's my understanding that recirculation is not addressed in its rules and standards, and I believe that is the case.

In Michigan we operate on a performance basis. If the airborne concentration of silica, for instance, is below the TLV--that is, the worker exposure is below the TLV--that is our basic criteria. We do have these rules and the rules are intended, first, to insure that we get a look at the plans for recirculation of materials that may be significantly toxic. The reason for wanting to look at them is we want to assure ourselves that the specification is going to be for reliable equipment and that the plant operator understands the maintenance or

operational needs that the system will require. We also require the bypass duct, and as I explained, that is for the reason, among other things, of wanting to get the air outside seasonally, which many operators do. But we do not prohibit recirculation, and as Mr. Confer asked, what would happen if the discharge concentration no longer met the magical 10 percent of the TLV? The ultimate criteria is the worker's exposure.

As for what other States are doing, I can't answer that question. I think any States that have an approved plan under OSHA and State rules under OSHA which have to be "as effective as," (which essentially means identical to) will operate under the same requirements as OSHA.

MR. CAPLAN: A lot of States had rules similar to Michigan's before the Federal OSHA. My legal opinion here is that if the State has a rule and OSHA has no rule whatsoever, then at least that is "as effective as." So far as I know, there are two other States that are continuing to implement their rules, which are essentially" submit it to us, and we will render an opinion."

MR. WOODLING: Mr. Barrett, are you categorically saying if we have a plant up in Michigan that we design ourselves so we can put in a recirculation system, it must be presented to the State Health Department and be approved before we can get this thing in and operating?

MR. BARRETT: In a sense, yes, if the substance is one of these that is out of the nuisance category. If it is in the nuisance category, according to our rules, you can just go ahead and do it. If it is below the nuisance category, i.e., more toxic, yes, we need to look at these. And as a matter of fact, you do have a plant in Michigan and we have looked at it.

MR. WOODLING: Right.

MR. DON R. SCARBROUGH (Nordson Corporation, Amherst, Ohio): I would like to offer a commentary.

In the talk immediately before lunch, there was mention that the OSHA regulations prohibit recirculation of air from spray finishing processes. I would like to mention here that the OSHA regulations appear to have been drawn almost entirely, inasmuch as they bear upon spray finishing, from NFPA standards, and that the standard referenced predated one type of spray finishing, the dry powder coating operation, in which no organic solvents are involved. We find that the predominant method of ventilation used in virtually all States is one incorporating full recirculation of exhaust air after filtration and is quite successful. We find commonly that the tandem redundant filter is the controlled method used to accommodate failure, and that a simple pressure switch upstream of the secondary filter, a high-efficiency type filter, is adequate to serve to shut the process down in the event of failure. We have found the attitudes of most States and even the attitudes of some Federal representatives have been to address this problem as one involving a technology which postdates their existing regulation. They have been reasonable. We find that those installations which we have built and those which our competitors have built generally are accepted as being reasonable; their operation is quite workable and reliable.

On this basis I would like to offer just one comment, that I would hope to see in the development of new criteria considerable thought

given to utilizing the wisdom of experience as opposed to the purely theoretical approach in deriving and establishing new criteria. There are very few problems in engineering that have not been encountered previously by some one else. We can learn a lot from what his problems were and how he addressed them.

MR. BARRETT: Thank you. My reference to that particular OSHA regulation was with respect to the use of flammable solvents, and I think I said also that if it really came to the crunch that the ultimate determination would probably be on performance, i.e., the TLV.

MR. SCARBROUGH: Yes, I would comment again on that specific point. The newer edition of the source document, the NFPA standard, does permit recirculation of air from processes using organic solvents if adequate control mechanisms and monitoring mechanisms are used. So we hopefully will see this incorporated in the upcoming revision of the OSHA regulations.

MR. BARRETT: You're right, it does take a complete standard revision to do that type of thing.

I wanted to return a minute to the question asked by the gentleman from Goodyear, because it reminded me of something. I thought you fellows would be jumping on me about now in this business of a bypass duct. How do we put that on a unit collector--you know, the little ones in the tool shops, all mist collectors, that type of unit. Well, that question arose directly out of this review process that we were talking about. A company came to us and said, do you want us to put 60 or 70 ducts out through the roof of our plant every place we've got one of these unit collectors? That's something our advisory committee missed completely. We never thought of a unit collector at the time. So we made a policy decision, that anything smaller than a thousand cfm does not need to have this bypass duct.

I wanted to get that point across, that there is a recognition that small collectors are used in industry, and also that the review process works both ways. We learn from it as well as from other people.

MR. CAPLAN: That's one of the things that is missing in general from almost all OSHA standards, some kind of deminimus escape from the rules. The rules are all written as though you have a block square production plant. For example, the unexhausted grinding wheel that you see all over the place, is literally I believe a violation of OSHA standards. No?

UNIDENTIFIED SPEAKER: They revised that, they changed that.

MR. CAPLAN: Okay. We're moving in the right direction. But I think to generalize the point, that is the kind of a thing that I would hope would get into criteria documents and later standards, some kind of a deminimus exception from what is otherwise a good rule or a good standard.

MR. JOHN T. TALTY (NIOSH, Cincinnati, Ohio): There was an earlier question, I think along the lines of when are regulations expected on this subject. I think Bob commented that that really isn't planned. Let's

assume we come up with technical criteria that are accepted by the group here. What is the most effective way to start getting these criteria into practice and application short of regulations?

MR. CAPLAN: As I mentioned in my talk, the individuals in this room will answer for themselves the question of whether they have to, or can afford to, recirculate or practice some other form of heat recovery. I don't think we have to worry too much about "getting the word out." The crux of the matter is what kind of restrictions or regulations or rules or standards, whatever you want to call it, will inhibit that movement which is forced by the facts of life or economy. And I think our target should be to assure adequate health protection without excessive restraint or excessive inhibition of a trend that economics will take care of automatically. We don't have to get that word out. If we can come up with a good reasonable workable set of rules that people can live with and that does protect the workers, I think we will have done our part and Mother Nature will take care of the rest.

MR. TALTY: Are you saying rules are really necessary then?

MR. CAPLAN: Well, I would settle for the rule that the workplace concentration has to be below the TLV. Nonmandatory engineering standards are going to be useful and necessary for all the thousands of practitioners who don't do this all of the time and don't have the expertise at their fingertips.

CHAIRMAN HUGHES: I believe John's question is if these engineering practices are developed, short of putting these out as a regulation, what is the mechanism of getting these out into the workplace?

MR. TALTY: Are you a salesman?

MR. CAPLAN: Yes.

MR. JOE KUKLA: We are pretty much concerning ourselves with managers, the employer. Jim, have you had any resistance from labor for recirculation?

MR. BARRETT: Not specifically, Joe. I mentioned the type of complaint situation we get into when a system may be either poorly designed or sometimes just poorly located in the plant, and mentioned also that one of the plans that we have just looked at recently was the situation where a trade union was the employer. I can't speak for people in the Union movement or for all employees, but believe that we have a proper basis to stand on so long as we can demonstrate again that the workroom concentration is below the TLV and the worker's health is protected.

MR. PHELPS S. ESHELMAN (General Motors Technical Center, Warren, Michigan): A process that I have seen using asbestos is a good example. Here the asbestos is combined in plastic pellets, injection molding, and machining. The operation is ventilated and tested showing that the counts were below the proposed TLV, as a matter of fact in the three-tenths range. The union picked up the fact that asbestos is a harsh material to handling and on their health. I might go one step further. The air from the operation is being recirculated from a bag collector back into the room. Again, the union picked this up, and although they have taken

tests to show that it was below any health problems, the issue was never settled until the air was removed from the room. It became a real labor issue. So you have to watch this. All of the testing in the world won't solve all the problem.

DR. RALPH R. LANGNER (Dow Chemical, U.S.A., Midland, Michigan): I would like to address myself to John's question. I think if we have realistic information and publish it in the journals that are used by the engineers of the trade, it will be picked up.

His question reminds me of the group of some 20 people that I have just recently taken over. For any change I suggest in the operations the old people in the groups said, man, that's going to kill us. The young people want revolution! This is the problem that I see today; we have a group of young people who want revolution, we have a group of us older people who want no change, and somehow we have to compromise so we can remain in business and keep a viable industry in this country.

MR. ROBERT W. MODRELL (Goodyear Tire and Rubber Company, Akron, Ohio): The proposed lead standard which came out last week or the week before specifically prohibits recirculation of air from a lead operation, as I understand it.

MR. GEORGE E. TUBICH (George E. Tubich and Associates, Grand Rapids, Michigan): There is only one of them. The whole bit has been going on that the ultimate end result is protection of the health of the worker. Going over the roster here, most people here fit in the category of 400 or 500 employees. Nobody said anything about this little 50-man foundry. What is he going to do with a standard like this? We've got staff and people that are working on these problems. In our foundry industry, 75 percent of the plants have 100 workers or less. What are they going to do with a standard like this? How are we going to make it compatible to them so that they can understand?

CHAIRMAN HUGHES: I get the impression that you feel this is going to be a standard which is going to force this little 25-man plant to do something. That is not true.

MR. TUBICH: How is this little plant that has a half-time maintenance man going to maintain routine production equipment, maintain the collector, and maintain the monitoring? How can we help him?

CHAIRMAN HUGHES: You have a good point. The people who employ 400 or 500 employees have the facilities and the people to not only determine what to do but to do it. The purpose of our efforts is to provide recirculation guidelines for both the large and small employer. Again, these are not mandatory.

MR. CAPLAN: I would think that the provision of that kind of engineering for your 75-man foundry is a legitimate one and a useful field for consultants. I can't hire a ventilation engineer and an industrial hygienist full time and if I could, they wouldn't be happy and they wouldn't stay there, but I can afford to hire a consultant one day or one month or a quarter of a year.

CHAIRMAN HUGHES: There is one problem I addressed a couple of times this morning which nobody has brought up and I would like a little help on

what to do on it. We talked in some detail about the list of contaminants and whether they could or could not be recirculated. I think we established that there is definitely a difference of opinion of what can or cannot be. I would like to hear some suggestions or recommendations how we might approach this thing. I don't think it is something that you can just ignore.

It was mentioned that the TLV Committee is expert in this field. Should the TLV Committee be asked to come up with a list, or what?

MR. CUSUMANO: We recently turned down a request for design of some equipment, and I think it is apropos to your comments in terms of each man here designing and considering recirculation of a given material. Claypool from West Virginia was doing some research and the question to us was whether we could design a system that would do an effective job of industrial band saw ventilation. It happens to be a very simple ventilation problem relatively speaking. The followup question was whether we could assure them that because there are unknowns in this material, would they be happy working with this band saw ventilation system for 10 or 15 years. We walked away. And I think that that is very apropos from the point of view of industry, since there are alternatives in recirculation and there is a very limited number of materials for which that type of question is legitimate--asbestos, chrome, the 14 odd materials.

MR. CAPLAN: I have been accidentally involved in the fringes of some of these carcinogen arguments and I would make some kind of a long-range prediction. What we have going on right now is a transfer of the psychology of the Delaney Amendment in the food and drug world to the industrial environment. The Delaney Amendment, for those of you who may not be familiar with it, is a flat out forbidding of any material which can be shown to produce cancer in animal or man from being included in foods and drugs. They have plenty of trouble with that non-quantitative rule, but that philosophy has been transferred into occupational health via the famous list of 14 that has been mentioned so much today.

That probably is not going to persist indefinitely, I would predict. As a matter of fact, we have already departed from it on the subject of vinyl chloride and are in the process of departing from it on the subject of arsenic. I just accidentally happened to be sitting there hearing testimony from quite eminent authorities, to the effect that they do believe there is a dose-effect relationship in carcinogens, so I would expect that in the long run we are going to find that various materials which are carcinogenic will be related to the amount of dose and the length of the dose, and so forth. In fact, there are even some theories (which I'm not expert enough to pass on) to the effect that any foreign chemical or any foreign substance, even though inert, is carcinogenic, and the only problem is how long it takes you to get a cancer. If it is going to take you 400 years to get a cancer, you don't worry much about the properties of that particular material. Vinyl chloride and arsenic themselves are good examples. Arsenic shows up in epidemiological studies of people who have already retired from working many years in arsenic, whereas vinyl chloride, killed people in their middle working career. So I think that the magic bugaboo psychology of carcinogens is going to gradually disappear, or has already started to.

DR. BASTRESS: I would like to volunteer the point of view that you should not try to classify chemicals. If you put a chemical in the context of the whole plant, aside from the concept of recirculation, there is already some risk that the employee is going to be exposed to concentrations above the limit. Somebody drops a bag of the stuff or the ventilation equipment goes out of wack or a pipe breaks. Instead you could adopt a more general philosophy which says that if you're going to recirculate, then the risk of failure of the recirculation system has to be of the same order or smaller than the other risks of exposure of an employee. If you adopt a point of view like that, there is no need to classify chemicals.

MR. TUBICH: On this bit about the six groups, I think there should be some thought given to the mixed contaminants mentioned. I've got an operation which is just beautiful for recirculation, but MDI is involved; it's in group 6. I think that thought should be addressed to this area of the mixed contaminants. They are just listed individually--a, b, c--all of the way down the line, but I think someone mentioned synergistic facts.

CHAIRMAN HUGHES: We agree that the mixed contaminants are probably going to occur as many times or maybe more often than the single ones and it is something that needs to be addressed.

MR. CAPLAN: It is addressed in the ventilation manual, George. One of the rules is that all of the contaminants, not just the major ones, need to be considered.

MR. TUBICH: I think we all recognize that this list is basic and there is going to be continuous need for revision. In this particular example that I'm quoting, we have data that indicate no way that MDI should not be in group 6, and it is up to us to contribute this information.

MR. CAPLAN: The group 6 is only in that report. Nobody else has said it is group 6.

MR. TUBICH: Yes, but unfortunately, Cap, this is critical. This is going to be looked at as the guide. They are going to see compound Y, and it's right there, group 2, group 1, whatever it is. Bill's comment that this is conceptual, and is somewhat exploratory work in this area and that it is not gospel.

MR. ASTLEFORD: I would like to comment on that. I think, Bob, that it might be appropriate to insert a statement in the foreword to the document that you're going to publish to the effect that this is a conceptual study.
As far as the use of MDI is concerned, Mr. Tubich, it sounds like you're making urethane foam.

MR. TUBICH: No, this happens to be another use of MDI. It is used in the foundry as a binder.

MR. ASTLEFORD: It is also a component in creating urethane foam.

MR. TUBICH: That is TDI.

MR. ASTLEFORD: Excuse me, it is also MDI. And as a point of interest, the ceiling concentration of 0.2 parts per million for MDI is a direct take-over from the ceiling concentration on TDI.

MR. TUBICH: In putting data together, there have been some 50 million pounds of MDI used in foundries and we only have one suspected case of sensitization. The burden is also on us to provide a central source with these basic data, and we are objecting to the criteria document from NIOSH that they are lumping the two together.

MR. ASTLEFORD: I think if you will take a look at the documentation on the TLV's that are published by NIOSH, read TDI first and then go read MDI, and you will understand what the basis is for assignment at that level. When you're dealing with polymeric reactions with MDI, you also have other components like catalysts to worry about. These are just two components. And here again, you have a valid point that you have to look at the sum effect of every component that is present.

MR. TALTY: I just would like to make a comment that maybe supports classifying in some way. For some of these compounds, until a safe level is established one way or the other, it isn't very realistic for us to be talking about recirculating the compound.

MR. ASTLEFORD: One comment: Dr. Caplan showed a slide this morning that indicated that the majority of the TLV's in the table had been set by, I believe, human experience.

MR. CAPLAN: No, 38 percent.

MR. ASTLEFORD: A very small portion of them, if I saw correctly, were actually obtained from exposure studies to determine chronic levels or acute levels of exposure. It may be indicated here that we need to support any efforts to recirculate with studies to determine actual exposure limits, using various animals as test subjects.

MR. CAPLAN: I think if in the name of recirculation we bite off the whole TLV problem we are sure going to get indigestion, especially this group. But I think the way to approach the subject of the TLV's is not to try to preclassify them, but instead, at this state in our development, to get the very best advice we can from people who know more about it than we engineers do, as to the real risks involved as distinguished from the speed limit type number in the TLV list. In view of the safety factors that you normally would design into it, that it is the best you can do. The TLV numbers are going to change continually. I think they should change continually. They usually go down but sometimes they go up. The human experience numbers are the best in that you cannot translate very well from animals to man in many substances. Sometimes we learn, to our sorrow, that the effect on man is worse than it was on animals, and sometimes it is the reverse. So we are always going to be operating on the best information we have. This is one reason why it is probably inappropriate to try to preclassify and group substances according to that kind of information. It's perfectly possible that, the way these things go, you might design a recirculation system in all good faith and have it working according to the rules for 5 years and then something happens to that TLV and you no longer can use that system.

We are not leaping off of some cliff here with recirculation. We have been doing it accidentally or incidentally all of these years. In the workroom in which you have the recirculation system, when the TLV

changes, it changes the recirculation. It would have changed the score if you had an exhaust system and no recirculation. If you blow stuff out the stack and it goes over the edge of the building and back in the window, you're recirculating it, not through a duct, but you're recirculating it. So we ourselves are building a psychology here that we are about to take some tremendous plunge, which is true only to a degree. We have never had perfect control, even without recirculation, and we have in many cases been recirculating anyway.

All those systems are subject to changes in the TLV and I see no escape. I think they will continue to be subject to changes in TLV.

ENERGY CONSIDERATIONS*

David E. Hoglund†

Abstract

There are two solutions to the current energy crisis--efficient utilization of resources, or conservation, and new resource development. Contrary to some expectations, conservation is generally the most cost-effective means of handling the energy shortage, since resources saved are tantamount to resources produced. By reorganizing priorities, reducing imports, and attempting to reduce demand, among other things, political decisionmakers can promote an energy policy that is in the national interest. Engineers can contribute to the conservation effort through improving such heat recovery and recirculation systems as the recuperators, regenerators, and waste heat boilers. Statistics are given herein to illustrate the present nationwide energy outlook, and the potential for energy conservation through recirculation and heat recovery is assessed. Finally, specific suggestions are made for plant construction and operation.

I would like to thank the National Institute for Occupational Safety and Health for inviting the Federal Energy Administration to participate in today's seminar. I am particularly pleased that the seminar topic relates directly to a relatively untapped form of energy conservation, namely the recirculation of exhaust air. Let me first emphasize that while FEA encourages this from an energy conservation standpoint, we in no way would want to have occupational safety and health standards jeopardized as a result of it. As Mr. Frank Zarb, FEA Administrator, has said, "energy conservation represents the convergence of many divergent problems." Recirculation of exhaust air is certainly one of these. We have to conserve and use energy wisely, but not at the expense of citizens' health and welfare.

Let me begin by giving you some information relative to the national energy supply/demand situation. I will then depict the potential for energy conservation by giving some specific examples of energy conservation through heat recovery and recirculation of exhaust air.

I would like to quote a recent statement by Roger Sant, Assistant FEA Administrator for Conservation, to the Conference Board in New York on September 30th. I believe that it illustrates the close ties between the two solutions to the energy crisis: efficient utilization--call it conservation if you will--and new resource development.

I am not by any means opposed to developing new supplies in line with our future needs for them. But, the purpose of any energy policy must be to fill the gap between the increasing demand and the decreasing supply on the basis of what's cheapest--what's environmentally the most attractive, and what's fastest.

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No matter how hard we work at developing new supplies, we will not be able to bring them on fast enough to do us much good in the near future. Conservation is available to us here and now--when we need it. There should be no dispute over conservation's desirability from an environmental standpoint either. It's obvious that cleaning up emissions is substantially less beneficial than not creating emissions in the first place.

But it may be news to some people that the most compelling reason for conservation by far is an economic one.

The fact is that energy is only a means to economic well being, not the end product. If an energy source becomes overly expensive, or unavailable, then common business sense dictates that the thing to do is replace it with the lowest cost substitute.

In that light, conservation is merely the process of putting in place nonenergy substitutes like insulation or controls, while resource development is producing energy substitutes. In the tradition of our economy, we have been indifferent as to whether we choose an energy substitute or a nonenergy substitute as long as we choose the lowest cost option. It then becomes apparent that a barrel saved is equivalent in value to a barrel produced. Thus, from an economic standpoint, conservation is itself a form of supply. Each conservation project has a cost per barrel, just as every supply project does.

The point is that conservation projects are not only viable alternatives, but generally represent the most cost-effective way we have of dealing with energy problems. Again quoting from Sant, "the problem faced by those of us who support this objective is how best to go about breaching the established barriers, i.e., (the institutional inertia and first-cost bias)--with information about opportunities for economically attractive conservation projects." Viewed from Sant's perspective, that is, that conservation means improved energy efficiency and not simply reduced consumption, energy conservation becomes an equal partner with efforts to increase supplies. Quite literally, a barrel of oil saved through adaption of cost-effective energy conservation measures is at least equal to a barrel of oil produced through expansion of domestic production.

We somehow believed, perhaps by default of a contrary position, that GNP growth was married to energy growth and we furiously developed Arabian deserts, offshore platforms, massive tankers, huge automobiles, infinite gas and electric appliances, glass buildings, and on and on. Why not; coal was set aside for central power use and cheap gas, oil, and petrochemical feedstocks became the mainstay of our economy, if not our very sustenance.

The bubble was waiting to burst. Energy sources could become expensive. Traditional continental U.S. fossil fuel sources could eventually become in short supply; newly developed foreign supplies could be used for political purposes not in the best interest of the U.S. or its allies. If only one of these situations occurred it would constitute a crisis in our economic growth pattern. All of these things happened.

Let's take the case of cost and supply. Reduced supply in an expanding economy means higher prices for the available resources. It also means a larger portion of goods and services goes to the energy account (building heat,

light, power, cooling, heat treatment, foundries, plating, drying, transport, plastic products, etc.). This results in less money available for replacement, capital expenditure, research, investment, and above all new jobs.

We have much evidence of this, particularly in Ohio where the normal sources for many thousands of firms were interrupted last winter and will again be severely interrupted this winter. Reduced natural gas supplies, where we have no OPEC backup, are causing firms to fall back on oil (of which we now import 38 percent of our needs) and propane. Supplies of both have been problems and the cost increases over gas are manyfold.

The FEA experience in conveying the message of crisis "has been less than successful with the general public," perhaps a few figures and facts will give you a rather hasty look at work reserves and oil consumption, the overwhelming comparative reserves of the Mideast vs. the United States, how the United States uses its energy, and that the gap that must be filled by conservation and new resources.

Exhaustion of world and U.S. resources is within sight, with oil and gas providing 78 percent of our present needs and the large resources of coal representing only a small percentage of our consumption. Natural gas accounts for only 2 percent of fossil resources but 32 percent of total energy use. Petroleum is 3 percent of resources by 46 percent of demand; coal accounts for 90 percent of fossil resources but only 17 percent of usage.

Figure 1 provides an excellent overall view of the energy problem. It shows how supplies will increase in the future, how demand will increase in the future, and how imports must increase in the future to make up the difference between supply and demand. It also shows what a significant impact conservation could have in reducing the gap between supply and demand, that is, reducing the amount of our imports. By 1985, conservation has the potential for reducing demand or alternatively increasing supply by approximately 15 million barrels per day of oil equivalent. Figure 2 is essentially the same as the first, depicting the actual and projected divergence of domestic consumption and production of energy.

Figure 3 is entitled "The Crux of U.S. Problem." Petroleum supplies the United States with 46 percent of its total energy needs, primarily used in transportation. The United States uses natural gas for 30 percent of its energy needs. Industries and residences are the major natural gas users. Coal is primarily used for generating electricity and provides the United States with 18 percent of its total energy needs. Hydroelectric and nuclear power are used exclusively for generating electricity; combined, they supply 6 percent of total U.S. energy requirements. The United States has enough coal to last for 300 to 500 years at our present rate of consumption. The Department of the Interior estimates U.S. oil reserves will last only another 30 years. If we were to close the increasing gap between demand and supply, we would be importing more than half of our oil in 1987 (10 years) at a cost of \$25 billion at 1972 prices and perhaps closer to 50 billion or more dollars in imports. Let me now give an estimate of energy consumption by end-user type.

Figure 4 shows the four major categories of energy users: industry; buildings (both residential and commercial); transportation; and electrical generation. Presently the industrial sector uses the largest amount of energy. In 1974, industry used 40 percent of the total U.S. consumption. Transportation presently accounts for 25 percent of total U.S. consumption and its projected contribution is expected to remain fairly constant for the next 25 years. On the other hand, electrical generation, which presently accounts for 27 percent of the total U.S. consumption, is expected to increase to 35 percent by 1985, making it the largest consumer of primary energy.

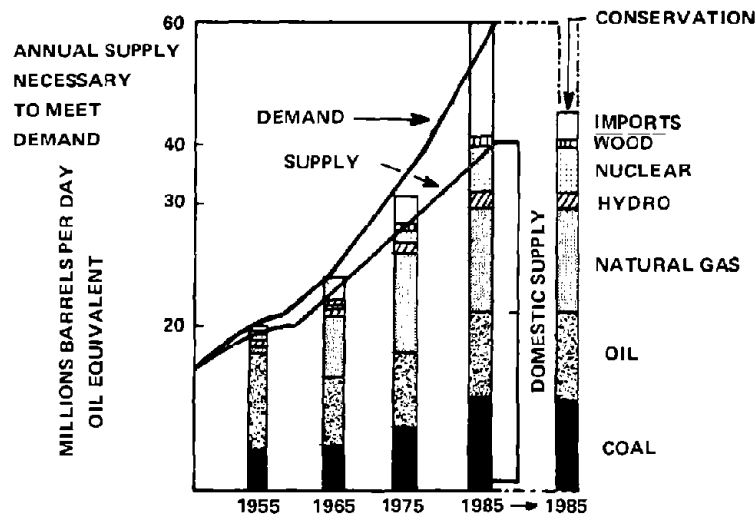


Figure 1. Sources of U.S. energy supply, 1955-85 (projected).

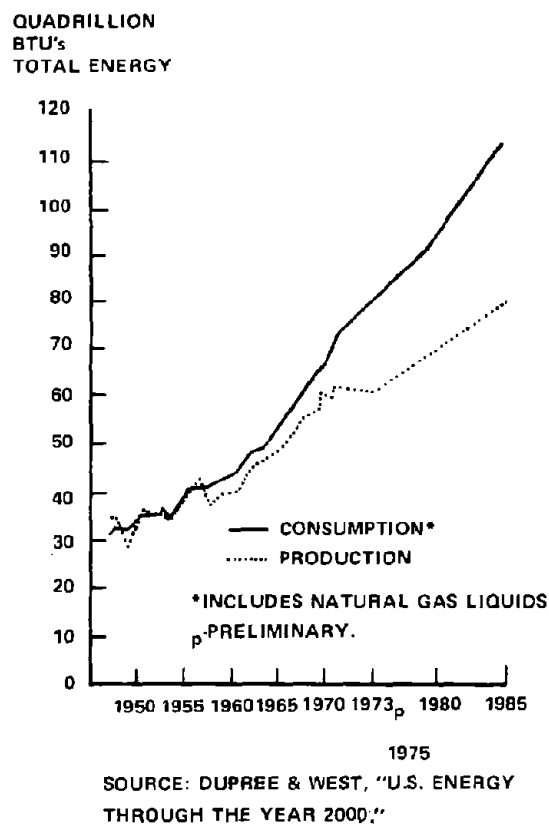


Figure 2. U.S. energy production and consumption from 1947.

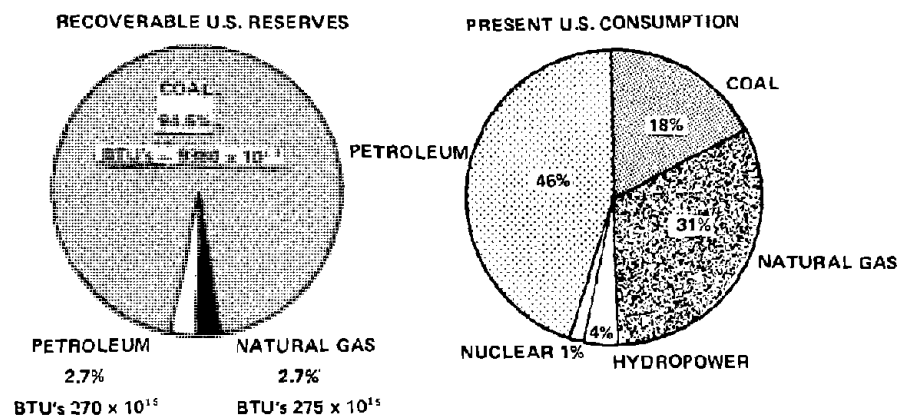


Figure 3. The crux of the U.S. problem.

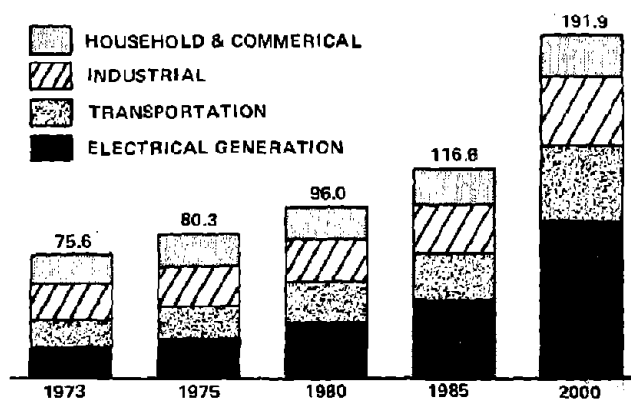


Figure 4. U.S. energy consumption by sector, 1971-2000, (quadrillion BTU's).

Figure 5 is a preliminary estimate of the 1974 annual energy consumption in the U.S. by end-use. The units are in trillion Btu's. I would like to emphasize the relative importance of the heating, ventilation, and air conditioning contribution to energy usage. Considering the commercial sector only, these systems account for 67 percent of the energy end use and approximately 10 percent of the national total. On the industrial side, one-third of the energy usage, or 16 percent of the national total, is in the form of process steam.

In order to put the dynamic energy situation in perspective, we must first determine what is an essential use of these resources and what is non-essential. These are basically political and administrative decisions supported by the objective advice and counsel of scientists and engineers. In your technical role as engineers, you can advise on material selections, product design, process conversions to alternate fuel sources, modes of transportation, and can serve as seers in anticipating such things as utilization of solar and geothermal energy, the quantities of undiscovered fuel sources in the ground, the environmental effects of alternative policies, the potential of fusion power, and the possibilities for an energy-efficient automobile.

When the political process of deciding priorities between economic and energy actions is finished, we may ultimately be left with:

1. restrictions by price or legislation limiting availability of the conventional established fuel and power sources, and
2. restrictions by price or legislation limiting the use and consumption of conventional natural resources.

Whatever form the political decision takes in the national interest, its goals will be:

- Goal 1: Reduce imports of oil and restore a balance of imported and export dollars, as well as preserve our national political integrity and options;
- Goal 2: Reduce demand for consumption of oil and natural gas regardless of whether it is used in primary ore reduction, utility power generation, or end-product use;
- Goal 3: Reorder priorities of energy usage to reduce or eliminate unessential or wasteful demand and apply these resources to higher priority energy applications;
- Goal 4: Increase the efficiency of energy conversion to heat power, from the extraction process the last Btu is accounted for;
- Goal 5: Develop conventional energy resources through extraction, modern technology, and construction;
- Goal 6: Explore new power resources (solar wind) and conversion of plentiful resources (such as coal) into liquid and gaseous fuels.

I realize that many of these goals are beyond the scope of today's seminar. However I would like now to attempt to relate the national energy picture more toward your interest. I would like to present some figures on energy conservation in public buildings. This may or may not relate to your interests, but can give at least some ballpark estimates of the potential.

SECTOR AND END USE	CONSUMP- TION [TBTU]	PERCENT OF 1974 TOTAL	SECTOR AND END USE	CONSUMP- TION [TBTU]	PERCENT OF 1974 TOTAL
RESIDENTIAL			INDUSTRIAL		
Space Heating	8,020	10.6	Process Steam	12,240	16.1
Water Heating	2,270	3.0	Electric Drive	6,160	8.1
Cooking	690	.9	Electrolytic		
Clothes Drying	340	.4	Processes	840	1.1
Refrigeration	1,040	1.4	Direct Heat	8,020	10.6
Air Conditioning	910	1.2	Feed Stock	3,570	4.7
Other	1,630	2.1	Other	270	.4
Residential TOTAL	14,900	19.6	Industrial TOTAL	31,100	41.0
COMMERCIAL			TRANSPORTATION		
Space Heating	4,970	6.5	Automobiles	9,230	12.1
Water Heating	730	1.0	Trucks	3,520	4.6
Cooking	170	.2	Aircraft	3,610	4.7
Refrigeration	800	1.0	Railroads	540	.8
Air Conditioning	1,710	2.3	Buses	90	.1
Feedstock	1,200	1.6	Waterways	180	.2
Other	1,770	2.3	Pipelines	180	.2
Commercial TOTAL	11,350	14.9	Other	1,350	1.8
			Transportation		
			TOTAL	18,700	24.5
			NATIONAL TOTAL	75,970	100.0

Figure 5. Preliminary estimates, 1974 annual energy consumption in the United States by end use.

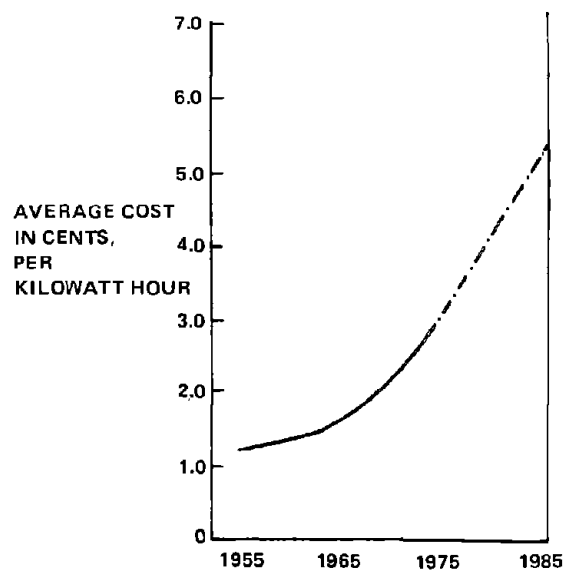


Figure 6. Electric cost trend per kilowatt hour.

I want to emphasize the importance of costs. While the magnitude may vary, most studies indicate that fuel costs will increase in time. Figure 6 projects the nationwide electric cost trend in kilowatt hours. Note that in 10 years electricity costs are projected to double, based on business-as-usual conditions. While this may not actually represent conditions in 1985, it does provide managers an indication that energy costs will be playing a more important role in their decisionmaking.

Relative to energy demand in buildings, figure 7 projects the growth to 1985 to approximately double. Superimposing the previous figure, the net energy costs (assuming 100 percent electrical mix) could possibly increase by four times. In figure 8, the pie chart on the left shows that the electric energy consumed in a typical office building can be broken down into three major components. The largest of these is the lighting component, which comprises about 42 percent. The next largest component is that used for heating, ventilating, and air conditioning; it is estimated at 30 percent. The remainder would be for such things as elevators, reproduction, business machines, and so forth. The pie chart on the right-hand side shows that a wedge corresponding to 25 percent of the total building energy consumed can be saved by energy management.

Production, industrial, and manufacturing engineers will be reevaluating the use of natural gas and oil as heat sources for equipment, tanks, furnaces, dryers, etc. They will be considering the conversion to electrical heat, diversion of waste heat from equipment and processes, and will be devising means to reduce the energy required by the process, eliminating the process in its entirety or modifying it, or perhaps replacing the material or component with a material or design demanding less process heat. The payoff can be producible products, reduced cost of manufacture and use, and a contribution to the U.S. capability to make decisions in its self-interest.

The plan is to sustain our national productivity and growth by using our energy resources conservatively and wisely. We can start with our buildings and the systems for heating, cooling, and lighting. We can find and stop the leaks in steam, ventilation, water, air, and fuel systems. We can reduce the levels of heating and cooling and lighting and operate them at this level only when the facilities are occupied.

Retrospectively, I would like to illustrate the effects of the 1973 oil embargo on the net electric load change. In the commercial sector, there was a 30 percent decrease Net Electric Load Change (LADWP) from the 1972-73 winter to the 1973-74 winter. In all sectors this amounted to a 10 percent decrease, as seen in figure 9. Figure 10 further breaks the commercial sector down into hotels, general merchandise, office buildings and apparel. Under the embargo conditions, managers were forced to reduce their electrical load involuntarily. We in FEA are trying to have managers voluntarily reduce their net energy load under nonembargo conditions.

Obviously the energy used to heat, cool, humidify, dehumidify, and light buildings is receiving more consideration and will increasingly receive more attention as energy costs escalate. I would like now to bring some of the more significant events to your attention.

ASHRAE 90-75 is a national recommended standard providing design requirements and criteria that will result in the efficient utilization of energy whether used directly or in a refined form in new buildings. It treats the

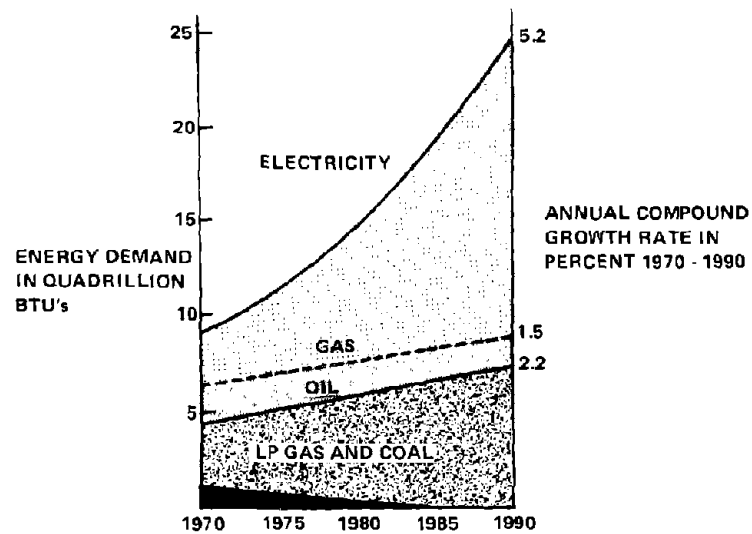
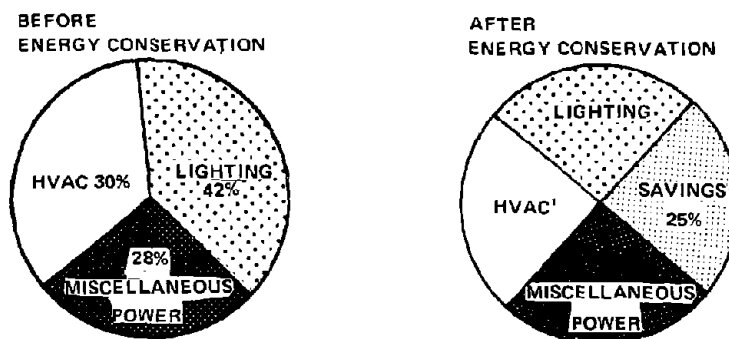


Figure 7. Growth of primary energy demand in buildings.



¹Heating, Ventilating, and Air Conditioning

Figure 8. Distribution of electric energy in a typical office building.

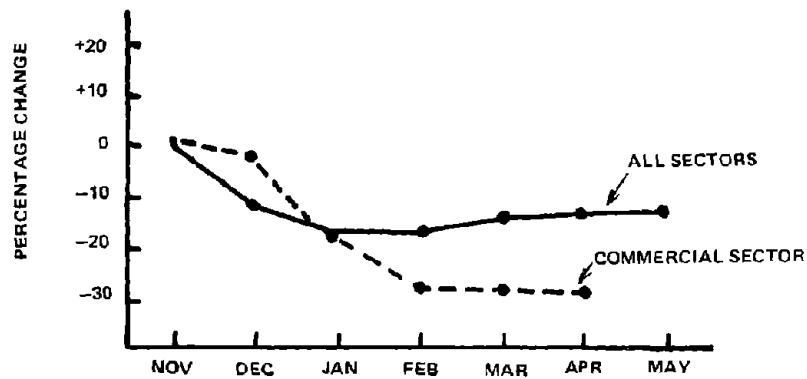


Figure 9. Net electric load change (LADWP),
winter 1973-74 vs. winter 1972-73.

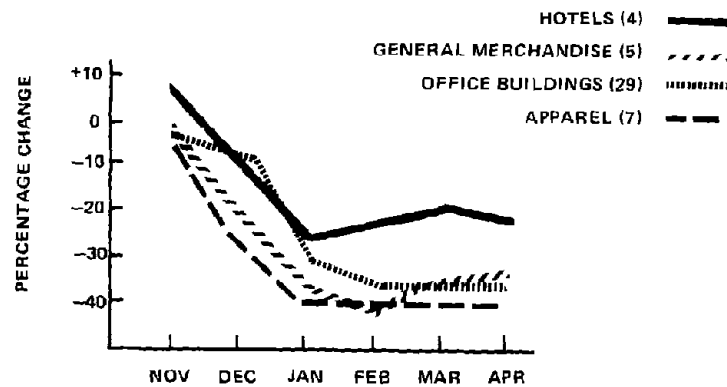


Figure 10. Net electric load change (LADWP),
winter 1973-74 vs. winter 1972-73.

building envelope thermal resistance and air leakage as well as mechanical, electrical, and illumination systems and equipment. The standard is intended to be flexible and permit innovative approaches to design solutions. The standard covers buildings that afford shelter for education, business, and institutional and residential occupancies as well as factory and industrial office space. Examples of 90-75 coverage are (1) HVAC - (Paragraph 5.0):

- Load Determination - Design Requirements
- Control requirements (sedentary and nonsedentary)
- Criteria for insulating, piping, and air;
- Side systems - duct construction

The United States is presently equipped with a large stock of buildings and industrial plant equipment designed for an era of abundant and inexpensive fuel. As the costs of fuel and electrical power rise, reflecting the exhaustion of cheaply developed fuel resources, the continued operation of this stable of buildings and equipment will be more and more difficult to justify economically. Thus, with low and declining fuel and power prices being a thing of the past, one may expect the efficiency of fuel and power utilization to emerge as a significant feature of public management decisionmaking.

Fred Dubin, President of Dubin-Mindell-Bloome Associates of New York, has stated in a Federal Power Commission Task Force Report, "Practices and Standards: Opportunities for Energy Conservation," dated December 1973, that:

- The type and location of glazing, the reflectance value of walls, floors, and ceilings, and solar control could provide substantial savings utilizing natural light.
- Selection of sites with the building shaded by large trees or other buildings and which permit all or partial depression below grade optimize energy conservation.
- Exhaust air be routed to areas with less stringent ventilation requirements.

He suggests that variable air volume and low-velocity air systems are preferable to high-pressure, high-velocity, terminal reheat, and electric resistance heating systems.

A few other ideas of Dubin concerned use of heat-of-light recovery systems, electric ignition gas pilots, and heating and cooling storage. Dubin also added that great savings are possible with decentralized onsite power generating plants with heat recovered in a waste heat boiler and used for space heating, domestic hot water, air conditioning, or process (and with efficiencies up to 75 percent plus). He also suggested recovery of heat from hot water drains in apartments and hospitals for preheat or domestic hot water.

Richard Stein of Richard G. Stein and Associates, Architects, in the American Institute of Architects (AIA) Manual Energy Conservation in Building Design, refers to the causes for excessive fuel consumption as follows: "Higher temperatures than necessary, poor functioning of combustion equipment, heat loss through inadequate insulation and storm sash, oversized equipment functioning at fractional loads, excessive heated air spilled outdoors by oversized fans, insufficient reclamation of heat from other processes."

With regard to cooling, he suggests judicious use of glass, use of reflecting glass, use of outside air when permitted, reduced lighting loads,

use of more efficient equipment (EER, COP), and localization of controls. Finally, Mr. Stein states that ventilation, which represents 10 percent of energy use, could probably be reduced in half with its savings for duct size and building volume, and related savings in not discharging unnecessary amounts of heated and cooled air.

In the past, high rates of industrial ventilation were required for health and safety considerations. Alternatives that could be considered and which you are no doubt already examining include:

1. Separation of smoking and nonsmoking areas;
2. Increased use of return air with filtration and odor control;
3. Controls to vary ventilation with changes in occupancy;
4. Heat transfer from discharge air to incoming air;
5. Isolated processes with selective ventilation;
6. Infrared localized heating;
7. Increased air movement with circulating fans; and
8. Greater use of electronic air cleaners.

Obviously, heat recovery and recirculation systems have not been discovered yesterday. They have been around for a long time and will become more economically competitive as energy costs increase. Modern technology has expanded their use into more efficient and highly sophisticated systems. Let me conclude by briefly describing a few of them.

1. The Heat Recovery Wheel. This is simply a highly efficient exhaust exchanger that can recover and transfer as much as 80 percent of the exhaust stream energy. Some are available for corrosive applications and temperatures up to 1,500° F.
2. The Static Air-to-Air Heat Exchanger. Where fresh air and exhaust air ducts are parallel, conduction is used to transfer energy with no cross contamination and minimal expense and maintenance.
3. The Heat Pipe. This functions as a counterflow heat exchanger with large numbers of sealed, super conductor heat pipes taking advantage of evaporation/condensation heat transfer.
4. Waste Heat Boilers. Where a demand for steam exists, process waste heat from fume incineration, industrial furnaces, gas turbines, ovens, or dryers can be fed directly into the hot gas flue passages of the boiler. A high-mass flow and heat transfer is obtained by convection instead of typical radiation heat absorption.
5. Recuperators. This heat exchanger continually conveys outgoing hot flue gasses past one side of a heat transfer surface and channels incoming air past the opposite side for preheating, with the potential of saving more than half of the energy needed to heat the cold air.
6. Regenerators. They are similar to recuperators, usually constructed of firebrick and two maize-like chambers. The flow of flue gas and air to be preheated is periodically reversed and heat is given up to the cold air with each reversal.

To summarize, I attempted to present you with details concerning the nationwide energy outlook, the potential for energy conservation, and some examples of energy conservation through heat recovery and recirculation of exhaust air. Let me again thank Mr. Hughes for convening this seminar and again offer any FEA support you would desire.

DISCUSSION

MR. JOSEPH F. KUKLA (Sentry Insurance, Stevens Point, Wisconsin): It has come up in discussions that one of the interests to industry is money, and you brought up cheaper fuel versus more costly way of operating a plant. Is it in your capacity to develop cost benefit data regarding what we have been discussing? For what size volume of air would it be worthwhile for a plant to consider recirculating heat; how much would he gain or not lose as a result of the recirculation?

MR. HOGLUND: I don't know if we've done this per se, but I do know we have done several studies and we have tried to look at what is called payback. We are trying to get around first-cost bias, trying to look at total cost--5-year, 10-year costs--for particular case-by-case problems. Just contact me, I could try to get you in touch with the right person, either at FEA or ERTA.

I didn't get into the real distinction between FEA and ERTA. FEA is really a short-term agency. We are due to expire next June. We have lost a lot of people to ERTA. ERTA, on the other hand, is the research and development arm of the energy picture in Washington. We are more or less the operational agency, although at the present time my division does not have any regulations to follow. We are strictly a voluntary type organization and controls have been extended up to November 15th on oil. If they are phased out entirely, we won't have any regulations.

MR. WILLIAM J. ASTLEFORD (Southwest Research Institute, San Antonio, Texas): At one point in your presentation you mentioned decentralized energy production by industry. This concept was contained in the GATE program that was sponsored by the American Gas Association. GATE is an acronym for Group to Advance Total Energy, and it involved the onsite generation of power with maximum utilization of heat. That program was eventually terminated because existing supplies of natural gas were fully committed. It is exactly the same program that you're talking about. I'm wondering if FEA or ERDA is considering resurrecting that program.

MR. HOGLUND: I really spoke in general terms. From an energy efficiency standpoint, I think we would like to minimize transmission losses, to look at total efficiency as opposed to proliferation of more new electric power plants and combustion of more coal; but I really can't be specific as to that particular program being resurrected. I could try to find out for you, though.

MR. JAMES C. WOODLING (Goodyear Tire and Rubber Company, Akron, Ohio): I have a general comment. This whole symposium today is directed towards providing a healthful work environment for employees, and it pertains essentially to how you do this at less cost and optimizing the use of energy. Could we be overlooking perhaps one of the easiest, least expensive ways of energy conservation--reducing temperatures in factories? Does anything tell me that I have to provide an environment of 65 to 70 degrees? I've worked in Scotland, France, and manufacturing organizations there where temperatures

in the workplace are 45 to 50 degrees. Scotland is number one in life expectancy. We are 10 on the list. And evidently exposure to lower winter-time temperatures hasn't affected their life expectancy whatsoever. As a case in point, we had a plant here this last winter that used up its gas supply for heating at the end of December. The employees were told if they wanted to work to put coats and sweaters on; at the end of March we got through our production tickets, and we produced what we were supposed to produce. In fact, I had heard comments that our production outlook was better during those 3 months than it had been before.

I see no legislation about and have heard no effects as a result of people being exposed to lower temperatures. Why does the putting a wall around this room tell me that I have to work at 65 degrees, when people in the chemical industries and refineries and so on are working out exposed to Mother Nature, essentially doing the same type of physical labor. Why not provide 45 degrees in the work place. What is wrong with that?

MR. HOGLUND: I think you raise a very good point. In fact, just as an analogy, the night lighting guidelines, FEA 10-30-50-foot candles are directed toward this basically the same thing you're referring to. What we're looking at is reducing the lighting where it is not needed.

We could carry this one step further, like you suggest. In areas that don't need heat, we have stated that our 68-degree winter temperature is an upper limit, not necessarily the limit, but I would have to maybe beg off to the labor unions and see what they would say.

MR. WOODLING: Seriously, what is the minimal?

MR. HOGLUND: There is no minimum other than local codes.

MR. WOODLING: Why don't we address ourselves to something in this direction that is not going to cost money? Maybe people would help you, too.

MR. HOGLUND: That could save a lot of energy, because the rule of thumb is that we have 3 percent for every one degree.

AIR CLEANING DEVICES FOR RECIRCULATION OF EXHAUST AIR

John M. Kane*

Abstract

There is a substantial backlog of experience with industrial particulate collectors used to recirculate cleaned air. Applications have been concentrated in systems where particulates are mechanically generated and are relatively inert or nontoxic. The fabric dust collector will be the usual cleaning device, although wet dust collectors have been used for a limited number of applications. Atmospheric air cleaners seldom have dust-holding capacity for particulate removal even from general ventilation exhaust systems used in industrial operations.

Where the contaminant is a gas or vapor, recirculation has seldom been applied. The cost/benefit relationship will be least favorable where a collector is not required except to achieve recirculation benefits.

Monitoring of the workspace rather than the effluent air from the air cleaner has certain advantages and compensates for in-plant relationships of infiltration, additional exhaust ventilation, building cubical content, volume of recirculated air, and its distribution.

The design and utilization of air cleaning devices will be dependent on factors such as contaminant concentration; particle size distribution, if particulate; the degree of removal required; and conveying gas characteristics including volumes, temperature, and water vapor content. In some systems, the fire or explosion hazard will influence collector selection. With wet-scrubbing devices, corrosive characteristics affect choice, and contaminant removal from the scrubbing circuit will require evaluation. Designs for particulate removal will seldom be used for contaminants in the gas or vapor state and vice versa.

PARTICULATE COLLECTOR TYPES AND CHARACTERISTICS

Particulate collectors fall into two basic groups: 1) industrial air cleaners for removal of the heavy concentration of particulates common to industrial exhaust systems, and 2) atmospheric air cleaners for removal of the very light concentration of atmospheric suspensions.

Industrial Air Cleaners These devices are designed to remove the heavy concentrations common to local exhaust of industrial operations where concentrations are generally in the range of 0.1 to 20.0 grains per cubic foot of conveying airstream (0.23 to 46.0 grams per cubic meter). There are four basic types of air cleaners grouped by their major separation mechanisms of 1) dry centrifugal, 2) wet scrubbing, 3) fabric filtration, and 4) high-voltage electrostatic precipitator.

Of these, the dry centrifugal and the electrostatic will seldom have application for systems recirculating cleaned air back to the workspace. Collection efficiency of dry centrifugals is insignificant and practically nonexistent on the particles measuring $\geq 5 \mu\text{m}$, so significant where recirculation

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is considered. Ozone generation and the types of applications (high-temperature combustion, calcining, and metallurgical stack gas cleaning) nearly rule out the high-voltage precipitator.

The design with the greatest capability for recirculation and the one with substantial application experience is the fabric arrester, known also as the fabric filter, cloth collector, and baghouse. Collection efficiency on small particulates is excellent--in fact, the highest of the mechanisms available for particulate removal. Although the collector is normally located outdoors because of its size, temperature loss is quite modest because of the limited surface available for heat transfer when compared to the pounds of exhaust system airflow. As most such systems operate in the range of 10" to 12" of water static pressure (SP), fan heat of compression produces a 5° to 6° F regain.

There has been limited application of wet particulate collectors for recirculation to the work area. Collectors are usually of the medium-pressure-drop (4" to 6" SP) range and preferably have low humidifying efficiency. Evaporation of water with the consequent increase in relative humidity can be a limiting factor in wet collector recirculation. Also, the lower collection efficiency on small particulates restricts application potential to ones of low concentration and/or larger particle size ranges. Examples would be dust from metal finishing operations and mist or droplets from plating tanks. Applications normally involve those for which fabric collectors cannot be used because of fire hazard, or adherence to or blinding characteristics to the cloth media.

Atmospheric Air Cleaners Because there are frequent attempts to use atmospheric particulate collectors ("air filters") for industrial exhaust applications, a brief discussion of this group of devices is pertinent. Collection mechanisms include dry centrifugal; viscous impingement; wet scrubbing, usually with oil as the medium; fabric filtration, including paper, cloth, and glass fibers; and low-voltage electrostatic precipitation, where ozone generation can be minimized. Devices are designed for the collection of the small-size particulates found in atmospheric suspensions, with good to excellent particulate removal ability.

Such devices are designed, however, to collect the light, invisible particulate loadings typical of outdoor air where concentrations are in the range of $0.05 \cdot 10^{-3}$ grains per cubic foot (115 micrograms per cubic meter). Because particulate loadings in local exhaust ventilation systems are seldom less than 0.1 grain per cubic foot or 2,000 times that of usual atmospheric concentrations, air filters can seldom be used for industrial exhaust air cleaning, because of their limited dust holding capacity. They do find occasional application as final cleaners after dry centrifugals on metalworking application where particle sizes are large and concentrations low. Removal of oil mist from machining operations is another example. Here the continuous draining of the collected oil drops from the collector surfaces produces a self-cleaning action.

Air filters cannot be used readily as a backup or fail-safe device downstream from a high-efficiency particulate collector without excessive maintenance costs. With a 5-grain inlet loading and a fabric collector removal efficiency of 99.9 percent, the escapement would be 0.005 grains per cubic foot of exhaust air or 100 times the usual application range for an atmospheric air cleaner.

There have been periodic efforts also to use such devices to remove the smokes, fumes, and other fine particulates that can accumulate and form visible haze in the roof truss area. Again, these concentrations are many times those of atmospheric loadings which result in excessive maintenance and replacement costs.

GAS AND VAPOR COLLECTOR TYPES AND CHARACTERISTICS

For the removal of gases or vapors from an industrial exhaust system, control devices usually employ the removal mechanisms of incineration, adsorption, or absorption.

Incineration High-temperature incineration is an effective mechanism for oxidation of organic gases, aerosols, and most odorous materials. For direct flame designs, usual temperatures are 1,200° F or higher, the retention time is 0.3 seconds or longer, and there is a turbulent gas flow. The fuel cost is substantial since most industrial exhaust systems are "lean," both because the contaminant provides little fuel value and because exhaust volumes involve so much air (10,000 cfm equal 22.5 tons per hour), generally at low to moderate temperatures.

Fuel consumption can be reduced by catalytic incineration in many systems with air entering temperatures in the range of 500° to 850° F, sufficient to sustain catalytic combustion. Gases must be relatively free of inorganic dust that would coat the exposed catalytic surfaces; free from metallics such as arsenic, lead, mercury, and zinc, which would inactivate ("poison") the surfaces; and free from gas suppressants such as halogen gases and SO₂.

Because of the high exit temperature and the gases of combustion, recirculation would be impossible except by means of an indirect heat exchanger. Indirect heat exchangers can have application to both the direct flame and the catalytic designs, although reclaimed heat is normally used to preheat the incoming gases rather than for makeup air systems.

Cost of incineration equipment and the high fuel requirements make the installation of incineration equipment impractical where air conservation is the only objective.

Absorption Wet scrubbing is the usual device for gaseous absorption. The gas flows in frequent and close contact with surfaces wetted by water often containing a reactive alkali or in some cases an acid. Packings that provide the wetted surface are usually plastic shapes with control dimensions in the 1" to 3" range. While gas flow can be horizontal (crossflow), the vertical counterflow tower is the more frequent selection for gas scrubbing applications. To provide the necessary mass transfer, beds can be 16 or more feet high with approach velocities of 300 to 400 fpm and pressure drops of 5" to 10" wg or more.

Normally, efficiencies of absorbers are tailored to meet atmospheric air quality standards and would have to be upgraded at considerable cost and power to assure in-plant air quality. Exit air is very close to saturation, making the problem of water vapor content another obstacle to recirculation.

Adsorption Where molecular weights exceed about 45, an adsorbent, usually activated carbon, will selectively capture and remove gases and vapors from an airstream. Air temperatures should not exceed 100° F, and presence of particulate matter and liquid mists contaminate the adsorbent, requiring more frequent regeneration.

Because adsorptive efficiency is reduced as retentive capacity is reached, monitoring to detect this "break point" will be essential where recirculation from an exhaust system is employed. Where more than one contaminant is involved, the one having the higher boiling point will displace the lower boiling point contaminant, requiring more frequent regeneration to maintain adsorption efficiency.

Carbon beds are quite large with airflow through the bed in the 50- to 100-fpm range. For most industrial exhaust system applications, regeneration in space

using live steam will be needed along with equipment to condense and store the dislodged contaminant.

FACTORS INFLUENCING RECIRCULATION

Recirculation from exhaust ventilation systems has the potential for the savings in fuel or energy that would be expended if exhaust air were replaced with conditioned outside air. Also saved would be the capital, operating, and maintenance costs of the makeup air equipment.

There are also special situations, as when using unit collectors for small-volume applications, where the cost of expensive ducting to the atmosphere is eliminated or where movement of the contaminant-producing operation makes such a connection difficult.

Salvage Value The savings from recirculated air from exhaust systems will be a function of exhaust volume, plant location, and operating hours. It will take a substantial air volume, probably in excess of 30,000 cfm on an 8-hour-day cycle, to justify the added costs where monitoring, bypass dampers, and return air ducts offset fuel savings. Larger air volumes would be indicated where air cleaning devices have to be added or upgraded.

The fuel savings will be a function of local outdoor temperatures, usual length of the work day, and the required temperature of the incoming air. For many industrial plants, heat generated within the plant will permit a 55° F air supply temperature rather than the traditional 65° F. The impact inlet temperature and plant location on heat savings can be observed from the comparisons reported in table 1.

Note that the degree days in table 1 assume 24-hour days and 7-day weeks. For a 40-hour week, the number would be reduced by 40/168, reducing each 1,000 degree days to 238. A volume of 10,000 cfm exhausted 40 hours each week involves for each 1,000 degree days in table 1:

$$\begin{aligned} \text{BTU loss} &= 10,000 \text{ cfm} \cdot .075 \cdot .24 \cdot 60 \text{ minutes} \\ &= 10,800 \text{ Btu/hr/degree F} \\ &= 10,800 \cdot 24 \text{ hr} \cdot 1,000 \text{ degree days} \cdot \frac{40 \text{ hours operation}}{168 \text{ hr/wk}} \\ &= 61,714,000 \text{ Btu/heating season} \\ & \quad (.075 \text{ lb/ft}^3 \text{ for air; specific heat} = .24) \end{aligned}$$

$$\begin{aligned} \text{Fuel equivalent} &= \frac{61,714,000 \text{ Btu}}{140,000 \text{ Btu/gal} \cdot .90 \text{ boiler efficiency}} \\ &= 397 \text{ gal fuel oil.} \end{aligned}$$

Table 1. Degree days per heating season
(based on 24-hour day, 7-day week)

Air supply temperature		55° F	65° F
Degree days in:	Chicago	3,743	6,315
	Indianapolis	2,829	5,297
	Louisville	2,294	4,180
	Memphis	1,284	2,950

Table 2. Fuel savings
(gal. oil/10,000 cfm recirculated air/40-hr workweek)

Replacement air supply temperature	55° F	65° F
Gallons of fuel oil saved in:		
Chicago	1,486	2,507
Indianapolis	1,123	2,103
Louisville	911	1,660
Memphis	510	1,171

For the locations reported in table 1, the resulting fuel savings are shown in table 2. In those industries for which summer cooling requires mechanical refrigeration, similar energy savings calculations will indicate conservation potential.

Monitoring For inert or nontoxic substances (generally those where large TLV's apply), monitoring of the cleaned airstream has seldom been practical or deemed necessary for recirculated systems. For more critical contaminants, monitoring of the workroom air in strategic locations has a number of advantages over monitoring collector outlet. The impact of abnormal contaminant concentrations in the recycled air will have a variable effect on the workroom air quality, dependent on:

- the contaminant, its concentration, and duration of the abnormal release,
- the exhaust volume recirculated related to room volume; amount of other exhaust ventilation; the quantity of infiltrated air, and
- the location of recirculated air release.

Impact will be minimal where recirculated air is discharged in an area where substantial exhaust of nonrecirculated air occurs, and maximum where recirculated air represents the major source of air supply.

For particulates, sampling of cleaned air effluent in the recirculated duct systems is difficult and expensive. It is hardly practical with present techniques for such monitoring duty. On the other hand, use of respiratory air samplers located at selected spots within the workspace can be readily obtained at reasonable cost. Samples could be taken daily, weekly, or less frequently depending on the contaminant, with the recognition that any short-term increase above TLV values has no "catastrophic" effect. Instead, this monitoring approach reflects and evaluates the other variables influencing air quality.

For gases and vapors, monitoring of the effluent air is technologically more practical. However, monitoring of workroom area would have the same advantages discussed for particulates. The rate of generation of most industrial contaminants is far from uniform, so monitors must gather a sample over a relatively long time interval to prevent triggering an alarm during a short-term surge.

Failsafe Protection In no case would the failure of a recirculation component introduce greater concentrations to the workspace than a component failure

of the exhaust system portion used to confine and convey the contaminant from the building. Yet backup of prime mover or other system components has seldom been found necessary, and indeed would be a rarity in present-day exhaust ventilation practice.

Likewise, it is difficult to visualize an air balance situation where air bleed-in would be required to compensate for bypassing to the atmosphere the air quantities designed to be recirculated. (Dampers in the building walls would be of little help; standby wall fans or tempered makeup air units would be indicated.) Industrial buildings are far from gas-tight vessels, and infiltration will repair any unbalance caused by bypassing the recirculation leg of an exhaust system during a malfunction.

FEASIBILITY OF RECIRCULATION

1. The area of greatest appeal will be the recirculation from existing particulate collectors, where the dust is mechanically generated (by crushing, screening, conveying, mixing, packaging, etc.). Mechanically generated dusts are relatively large in particle size and most readily collected. The collection efficiency of many of the connected dust collectors, especially those of the fabric type, is ample and would require no upgrading.

2. Recirculation from the above type of systems has greatest appeal for inert or relatively nontoxic materials having a high TLV value. For more toxic materials, fuel savings can be offset by cost of necessary monitoring and the potential for employee liability litigation (see item 7).

3. Recirculation of collectors removing fumes or smoke from local exhaust systems would be questionable. The size of the particles makes collection more difficult and the potential for significant release to the workroom more probable.

4. Fuel conservation for exhaust systems where contaminants are incinerated can best be obtained by indirect heat exchangers.

5. Recirculation from local exhaust systems employing absorption or adsorption types of collectors will require system-by-system evaluation due to lack of application experience and the multitude of complex compounds involved.

6. General exhaust ventilation for removal of stray or fugitive contaminants not confined by local exhaust systems is an area where potential for recirculation does exist, because of the low contaminant concentration. Since air-cleaning-device cost is a function more of air volume than contaminant concentration, cost benefits of recirculation will be offset to varying degrees by capital, operating, and maintenance costs of the control system.

7. There can be intangible or legal drawbacks to extensive use of recirculation. Factors to be evaluated could be:

- a) employee attitudes and relationships;
- b) the current trend toward drastic reduction in established TLV values;
- c) liability for unnecessary degradation of the workroom atmosphere. This concept, used so successfully regarding external air pollution, could readily spill over into in-plant environment. The basis could be the unnecessary increase of contaminant level with the only justification being that of monetary savings to the employer.

CONCLUSIONS

Where climatic conditions indicate, recirculation of exhaust-system-cleaned air offers a substantial energy savings mechanism. Cost benefits will be greatest for local exhaust systems handling mechanically generated dusts for which high-efficiency air cleaning devices are required for external air pollution control. Recirculation from local exhaust systems handling fumes, smokes, vapors, or gases will be the least practical.

Substantial air volumes handled by means of general exhaust ventilation through roof or wall fans, usually containing dilute contaminant concentrations, deserve study of their potential for cleaning and recirculation. The first step, however, would be an appraisal of needs. There appear to be many such systems where exhaust could be eliminated or drastically reduced. Both the low cost of air movers and the small horsepower involved are conducive to oversize selection and generous application of such general ventilation units.

DISCUSSION

MR. JAMES C. WOODLING (Goodyear Tire and Rubber Company, Akron, Ohio): We have the balloons, we have the blimp. Mr. Kane, would you perhaps make a comment to those who suggested that if redundant systems are required, that filters or air cleaning devices should be series, opposed to parallel.

MR. KANE: To place a backup collector in series introduces substantial added pressure loss and horsepower consumption that it is hard to justify. In the case of fabric collectors, the pressure loss on the downstream filter will build up to significant values, because reconditioning by any of the cleaning mechanisms is quite ineffective until a dust cake or mat of considerable thickness has been accumulated.

To place one in parallel on a standby basis, if the objective is the ability to recirculate the air during a malfunction of the initial collector, would in my opinion involve an investment that could not be economically justified.

MR. KNOWLTON J. CAPLAN (Industrial Health Engineering Associates, Inc., Hopkins, Minnesota): When you're pointing out your bit about the 8-hour day on the degree days, John, if it is a one-shift operation (which it probably would be--8 hours a day) take a close look at your temperature data. The degree days of course include 24 hours a day. It's always colder at night than it is at daytime, so that you get an even additional edge or break on figuring your heating during your daytime only, and this would push the economics against the value of recirculation.

MR. KANE: Right. The difference in the temperature on a 24-hour-a-day basis is pronounced. However there are so many other variables in a heat loss calculation that few designers attempt to refine the 24-hour data. Interestingly, it appears that the degree day average for either single-shift or two-shift 16-hour day is about the same.

MR. CAPLAN: The point I want to argue with you about is that we keep overlooking the fact that with a recirculating system we have the potential for a major advantage to the health of the worker. You can handle greater volumes of air and keep the workroom atmosphere cleaner, especially if it is the kind of job where you can't get an enclosing hood. I have worked with such a one. We didn't do it both ways, of course. I hate to tell you this, but it involves lead; we used 40,000 cfm instead of what you would pick out of the handbook (25,000) because of the difficulties of capture in the first place.

MR. KANE: But Cap, wouldn't 40,000 cfm makeup air exhausted to the atmosphere do a better job?

MR. CAPLAN: That's right, but it would cost too much.

MR. KANE: There is no such thing as too much cost when it comes to protection of labor, is there?

MR. CAPLAN: I was a little bit astounded to hear you add lead to your list of no-no's. That is a time-weighted average problem.

MR. KANE: If you're doing that, you would certainly want to monitor a lot more carefully than you would if it were limestone dust.

MR. CAPLAN: Certainly.

MR. DON R. SCARBROUGH (Nordson Corporation, Amherst, Ohio): I would like to take an adverse position, come back to the tandem filter arrangement, and raise a point--that you may be dealing with a combustible dust. Now, even though the TLV may be technically acceptable in the effluent from the collector, and you may have a very breathable concentration, you cannot tolerate the accumulation of sedimented combustible dust within the factory--you're building a bomb. In this case you'll want to run a very-high-efficiency, very fine filter serially with the dust collector to polish the effluent, and then install some system between the two filters to measure an increase in pressure, should the primary filter start failing, (start leaking) and loading the secondary filter. Having interlocked the sensing device, you should shut the whole mess down before you rupture the secondary filter.

MR. KANE: Okay.

MR. JOHN T. TALTY (NIOSH, Cincinnati, Ohio): About cleaning, you didn't mention too much about cleaning devices for gases, but how would you assess the state-of-the-art there? Is it advancing, as far as application to what we are talking about?

MR. KANE: My exposure to gas cleaning installations is not frequent enough for me to be quoted. In the plants that I visit, I see no efforts at recirculation for adsorption or absorption systems. Heat recovery from incineration has attracted substantial interest although the heat is generally used to preheat the incoming gases.

MR. GUY CUSUMANO (Hoffman Dust Control, Manalpan, New Jersey): John, does not serial redundancy (our experience would bear us out in terms not blinding) work with buildup on the second filter only if the first filter is not adequately sized? Where the first filter has been adequately sized, the second one is seeing maybe .005 grains at the top level and it just never does get around to building up. It serves as a backstop or last resort, you might say, when the bag breaks.

MR. SCARBROUGH: Exactly.

MR. KANE: You mean because you can never build up a dust mat?

MR. CUSUMANO: It never builds up a dust mat. It never builds up any additional resistance over and beyond what you are already paying for in the way of initial resistance in the safety factor.

MR. SCARBROUGH: Until you tear a bag in the primary filter.

MR. CUSUMANO: Right. And we have had this experience both with pulse collectors and shaker collectors, but very good shaker collectors. Manual shaker collectors I can't speak about because I'm not involved with them.

MR. JAMES C. BARRETT (Department of Public Health, Lansing, Michigan): John, would you say a word about low-voltage electrostatic precipitators? Otherwise we will be out checking for ozones.

MR. KANE: Low-voltage electrostatic air filters do not have the ozone generation characteristic of the high-voltage industrial design. Ionizer wires are of very small diameter, which reduced the arc over potential; and because the collector plates are so closely spaced (a fraction of an inch), the voltages involved are much lower--14,000 volts as opposed to 40,000 to 60,000 volts.

MR. CAPLAN: I wanted to add a note to this discussion about what goes through a fabric filter and what you can use after it. It's kind of ironic, but the fabric filters for so many years were regarded as so good that nobody did much in the way of measuring what came through, or else they were satisfied with just the concentration. GCA Corporation has been doing quite a bit of research for EPA on this topic as it related to atmospheric pollution. They find in general that the particle size distribution of the material that comes through a fabric filter on industrial dust loadings is usually about the same size distribution as the inlet. I have noted the same phenomenon in laboratory tests that I did, even though it sounds reasonable that you get only the fines through. But if you did get only the fines through, you would have trouble with blinding on the second filter. However, I believe the leakage from a properly operating fabric filter is probably not just blown through with the airstream; it's probably a mechanical or physical migration. And it comes out the same mix as it went in; there is just less of it.

MR. MAURICE W. WEI (Aluminum Company of America, Pittsburgh, Pennsylvania): I wanted to mention something with regard to the ozone generation. In the industrial and domestic type precipitators, the manufacturers generally make the discharge electrode positive, and that way you minimize the ozone production.

MR. KANE: It is my understanding that the lack of significant ozone generation in the low-voltage precipitator results from the wire diameter and the voltage. I can recall numerous discussions between air filter engineers about the influence of positive- or negative-charged ionizer wires, but they referred to collection efficiency potential.

The extensive use of low-voltage precipitators in residential and commercial air conditioning systems indicates, in any case, that ozone concentrations have been held to an acceptable range for air supply, whether makeup or recirculated.

CONTAMINANT MONITORING SYSTEMS

Clifford E. Decker and Carl D. Parker*

Abstract

The recirculation of industrial and commercial exhaust air, a step considered for energy conservation, must include safeguards against employee health hazards. The Occupational Safety and Health Act passed by Congress in 1970 required, among other things, that airborne workplace contaminants be monitored. However, a monitoring capability is the weak link in the technology of recirculating exhaust air. This paper examines existing contaminant monitors--source or stack gas, and portable monitors--that would be applicable to measurement of recirculated exhaust air. For industrial environment and ambient air measurement, comparison is made of required measurements, measurement levels/standards, and analytical techniques. Finally, problem areas in selecting monitors are identified and suggestions are offered regarding the acquisition and use of a monitoring system.

In 1970, Congress enacted the Occupational Safety and Health Act, the objective of which was to assure safe and healthful working conditions for working men and women. Specifically, the legislation states that no employee will be exposed to physical agents and substances that will cause impairment of health or functional capabilities or diminished life expectancy as a result of his work experience. One provision of the Occupational Safety and Health Act was to authorize the National Institute of Occupational Safety and Health (NIOSH) to develop criteria and recommend standards in the form of criteria documents. The purposes of these documents are to specify employee health hazards for toxic agents and to recommend safe concentration levels for airborne workplace contaminants. In addition, these criteria documents include recommendations for a variety of requirements covering medical surveillance, protective equipment, labeling and posting, educational material to inform employees of health hazards, safe work practices, storage and disposal, monitoring and recordkeeping, and methods for environmental sampling and chemical analyses.

Energy conservation is the primary objective behind the concept for recirculation of exhaust gases as makeup air in commercial and industrial buildings. The application of recirculated exhaust air systems to present and future industrial and commercial installations requires that adequate criteria be developed for recirculation systems and that safeguards be designed to provide for the safety and comfort of personnel working in any area where recirculation of exhaust gases is contemplated. Personnel safety and comfort in the work environment must always be the primary consideration and should never be compromised for energy conservation.

Threshold limit values (TLV's) established by the ACGIH constitute the official Federal standards for industrial air and were established to protect the worker from undue exposure to potentially harmful contaminants. Criteria developed and presented in the Southwest Research Institute (SRI) report, "Development of Criteria for the Recirculation of Exhaust Air," specify that the contaminant concentration anywhere in the work environment should not exceed the

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TLV as a result of recirculation. Contaminant monitoring systems and air cleaning devices, therefore, play major roles in (1) removal of undesired contaminants in recirculated exhaust gas and (2) documentation that contaminant levels are and remain below TLV levels for potentially harmful contaminants.

Energy considerations and the role that air cleaning devices play in recirculation of exhaust air were adequately described in the SRI report. Many potential processes are available and were described for removing harmful contaminants from exhaust air from any number of industrial processes, such as scrubbers, filters, collectors, thermal oxidizers, direct combustors, catalytic oxidizers, absorbers, etc.

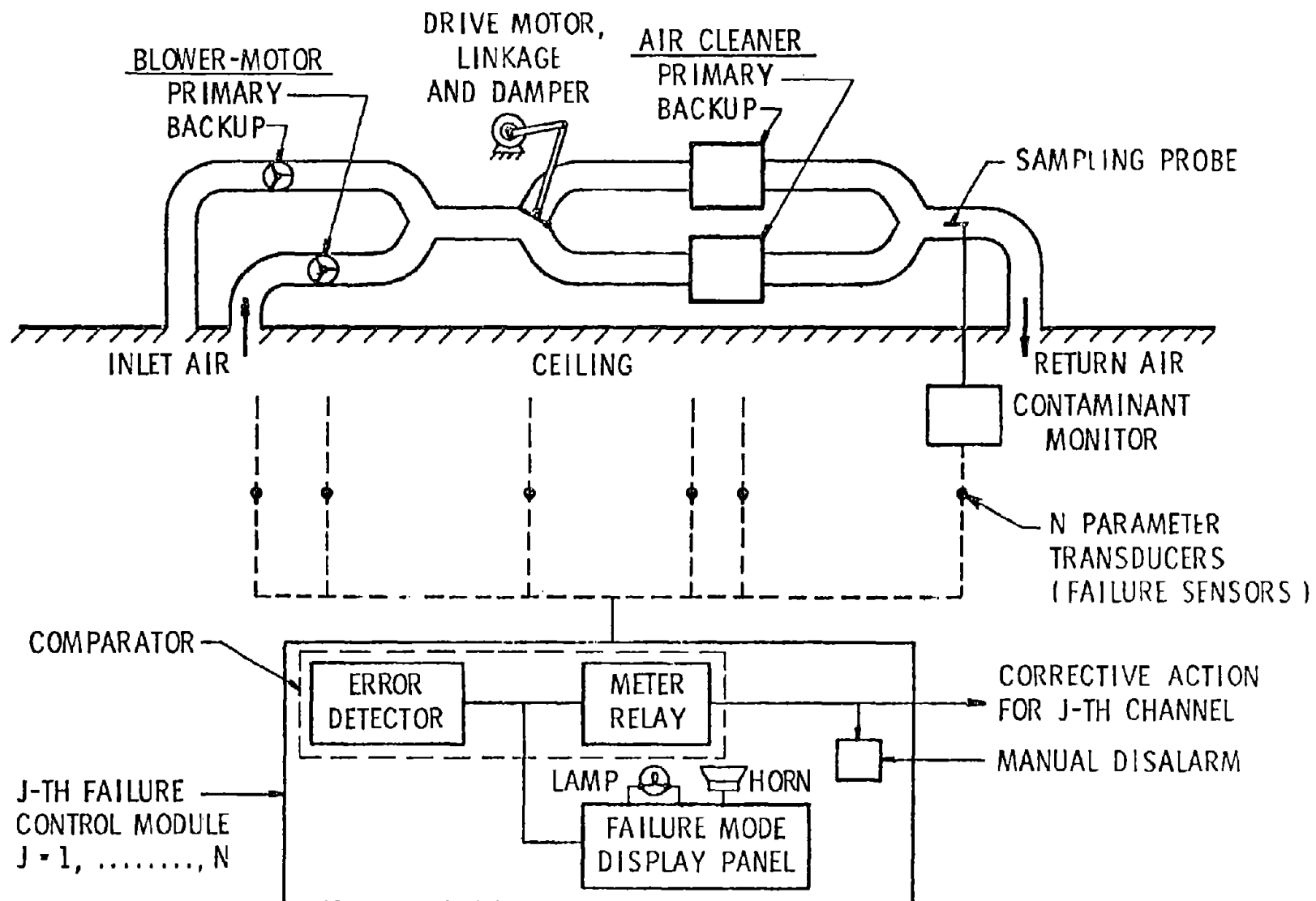
The function of a contaminant monitor as presented in the SRI report is to provide an indication of the contaminant concentration in the effluent duct on the discharge side of the air cleaner. A schematic diagram of one proposed system design showing the relationship of the contaminant monitor to the total recirculation systems is shown in figure 1.

The following performance characteristics and considerations were given in the report as being desirable for a contaminant monitor:

- a) The monitor should be specific for a given contaminant (interference-free);
- b) The monitor should be capable of continuous or continual operation (able to perform in situ measurements)--15-minute cycle acceptable;
- c) The minimum detectable should be less than the theoretical prediction of C_{in} (recirculated air concentration);
- d) A digital display of concentration is required for comparison to redundant manual sampling;
- e) An analog output signal proportional to concentration should be required for input to fail-safe control system.

Other constraints that are important relate to the development or specification of minimum performance specifications for minimum detectable concentration, zero and span drift, interference equivalents, response time, etc. A philosophy that requires the manufacturer to demonstrate that his monitor meets these minimum performance specifications is highly recommended. The monitor obviously serves two functions in the proposed configuration: (1) to document the concentration level of the contaminant present in the system at any point in time, and (2) to provide feedback to a fail-safe control system in the event the contaminant level exceeds the TLV for the particular contaminant or at some preselected level below the TLV that provides an adequate safety factor.

The SwRI report lists and categorizes some 560 compounds into six groups, with approximately 360 compounds being listed in the ACGIH TLV table as being recirculatable. The magnitude of the potential measurement problem faced by the industrial hygiene community (i.e., the sheer number of potential contaminants that can be recirculated) cannot be addressed specifically in this paper. Therefore, the purpose of this presentation is twofold: (1) to bring analogous experiences encountered in ambient air quality monitoring to the attention of those individuals faced with contaminant monitoring in exhaust gas recirculation, and (2) to provide performance data obtained by the authors and our experience with commercially available instrumentation that could be directly used to monitor certain contaminants in exhaust gases.



Similarities Between Ambient Air/Contaminant Monitoring System Requirements

An ambient air measurement system normally consists of an input or inlet system for sample introduction, a sensor, a signal conditioning and output system, and display and some type of recording system--be it stripchart record, magnetic or paper tape data acquisition system, or minicomputer or telemetry system. Contaminant measurement systems for recirculation of exhaust air should include most of the above-mentioned systems but may also require the following: sample condition unit (depending on process and environment) and interface or feedback to control unit with audible alarm.

Purposes of Monitoring

Ambient Air - To document exposure levels of the general population to protect their health and well-being. This is done through trend monitoring, compliance monitoring, enforcement activities, and research studies.

Industrial Environment - To provide an indication of the contaminant concentration in air supply system to protect the safety and health of the worker in the industrial environment.

Required Measurements

Ambient Air - National Primary and Secondary Ambient Air Quality Standards have been promulgated for O_3 , NO_2 , SO_2 , CO, NMHC, TSP. Therefore, routine measurement networks include instrumentation to measure these pollutants. Special studies, of course, require the measurement of a variety of gaseous and particulate pollutants--e.g., freons, acetylene, NH_3 , NO_3^- , SO_4^{2-} , metals, vinyl chloride, and many more. However, the measurements are not performed on a continuous basis. Integrated samples or grab samples are usually collected. Instrumentation is not available at this time for the continuous or continual measurement of pollutants other than these six. Of these six, the particulate sampling method (High-Volume Method) is an integrated 24-hr composite sample; NMHC and NO_2 are derived, not measured directly; and O_3 , SO_2 , and CO are the only pollutants for which continuous measurements are routinely recorded at field locations.

Recirculation of Exhaust Air - The SwRI report states that there are 356 compounds listed in the ACGIH TLV table that can be recirculated. The potential measurements required for recirculated exhaust air will necessarily be dictated by the industrial process or processes feeding into the system. Generally speaking, it is impossible to specify a general set of measurements to be made. A possible exception would be if combustion is involved--CO, NO, NO_2 would be good candidates for measurement. Ozone, for instance, would not be required unless it was known that it was being generated in some process.

Measurement Levels/Standards

Ambient Air - National primary and secondary ambient air quality standards have been promulgated for six pollutants.

Industrial Environment - ACGIH TLV's have been published--these levels are generally higher than for ambient air standards for the same compounds. The NAAQS for ozone is 0.08 ppm, for example, while the TLV is 0.10 ppm.

Analytical Techniques

These are a variety of detection and analytical techniques available for contaminant measurements for both ambient air and industrial environment applications. The SRI report lists 23 measurement techniques ranging from absorption to wet-chemical processes. Most of the measurement techniques listed have been used at one time or another for continuous measurement of ambient air pollutants. Some of the more important ones are as follows: chemiluminescence, colorimetry, coulometry, conductivity, gas chromatography-flame ionization detection (GC-FID), gas chromatography-flame photometric detection, nondispersive infrared absorption, colorimetric/wet chemical detection methods, etc.

Several of these techniques have been specified by EPA as reference measurement methods for various ambient air pollutants, such as:

Chemiluminescence - - - - - ozone
Chemiluminescence - - - - - NO, NO₂
NDIR - - - - - CO
Wet chemical/colorimetric - - SO₂
GC-FID - - - - - NMHC

Certain instrumentation currently used for routine measurement of ambient air pollutants could be utilized directly or modified for measurement of contaminants in recirculated air, for instance, O₃, NO_x, and CO.

The discussion so far has been limited to gaseous pollutant measurements. Particulates have been omitted for obvious reasons--real-time continuous monitors are not currently available for routine monitoring of particulates in ambient air. Particulate measurement equipment is needed for both areas of interest; that is, equipment that will give composition, size range distribution, and mass loading are needed.

The historical development for ambient air quality analyzers can provide information useful to the industrial hygiene community. Development of continuous analyzers for air quality measurements began with adaptation of manual and/or wet-chemical detection principles to continuous systems. Examples of this would be analyzers for measuring sulfur dioxide based on colorimetric, coulometric, or conductimetric principles. Typically, this first generation of instruments can be characterized as being costly, nonspecific, expensive to operate, unreliable, and requiring excessive maintenance. A second generation of instruments was developed with detection principles based on physical processes, i.e., chemiluminescence, flame photometry, gas chromatography-flame photometry or flame ionization, fluorescence, etc. These devices can be characterized as being highly specific, expensive, more reliable, and requiring less maintenance, but a better trained operator. The next generation of instruments should incorporate the reliability of solid-state detectors with microprocessors and advanced concepts for electronic signal processing and reproduction. Instrument development has progressed painfully slowly with much direction and funding from governmental agencies in recent years. Perhaps the most perplexing problem to the user of monitoring instrumentation has been the lack of a coordinated

effort to develop minimum performance standards and to force instrument manufacturers to demonstrate that their monitor meets these standards.

Source or stack gas monitoring systems also provide a reservoir of experience that is applicable to the requirements of a recirculation monitoring system. The contaminants measured are the byproducts of combustion processes and are also monitored as ambient air contaminants.

Source gas monitoring systems are routinely configured to conform to most of the criteria recommended in the SRI report. The minimum detectable concentrations are not satisfactory in most instances; however, the detection principles are the same as those used in ambient air monitors. Thus, one can conclude that all of the recommended criteria can be met for these few, common contaminants. Since these contaminants are byproducts of combustion processes, they are common to many industries.

Figure 2 is a block diagram of a source monitoring installation, and it has some features that a recirculation monitoring system will require. In the system, the various analyzers (or a single analyzer) can sample either a zero, span, or sample gas through a control module that provides an operator a convenient control switch for selection. Clearly, the function of the control module can be automated. An important, even essential, feature is that zero and span gases are readily available for convenient calibration. Calibration is a frequent, necessary procedure for the best available instrumentation.

A typical set of source monitoring instruments and some of their capabilities are tabulated in table 1. These instruments provide real-time, online measurements, and their outputs can be configured or conditioned to read concentration units, for example. In general, they cannot be characterized as reliable and it is not uncommon to find installations with meters which have never operated satisfactorily. New generations are evolving that are significantly improved, however, and these will also be adaptable to recirculation monitoring systems.

Turning briefly to the status of portable analyzers, portable meters for CO, SO₂, and NO-NO_x have been recently evaluated. These are common contaminants and will be encountered in many recirculation systems. One criterion for selecting a meter for evaluation was that its range reasonably span the TLV level for the respective contaminant.

Table 1. Typical source monitoring system capability

Contaminant	Detection principle	Ranges	Minimum detected concentration	TLV
CO ₂	NDIR	0-5/10/20%	0.05/0.1/0.2%	0.5%
CO	NDIR	0-500/1000/2000 ppm	5/10/20 ppm	50 ppm
SO ₂	NDIR	0-1000/2000/4000 ppm	10/20/40 ppm	5 ppm
NO _x	Chemilumin- escent	0-200/2000/2000 ppm	2/20/200 ppm	5(NO ₂) ppm 25(NO) ppm

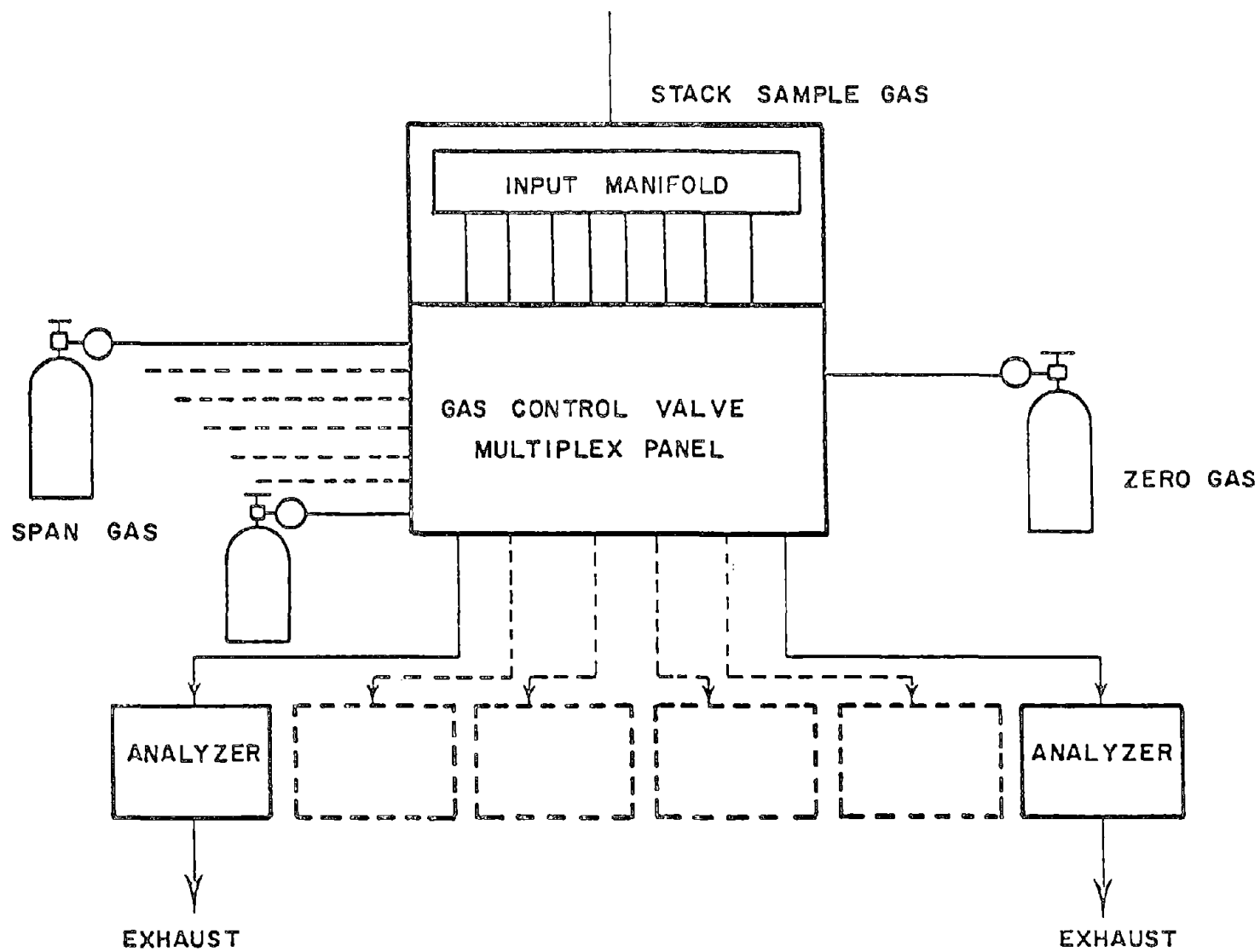


Figure 2. Block diagram of a source monitoring installation.

In general, suitable portable monitors were not readily available. For the three contaminant meters evaluated, literature descriptive of available meters was requested of approximately 150 manufacturers of contaminant monitoring instrumentation. Approximately 70 percent responded, many affirmatively. Ten to twelve meters were selected as being reasonably suitable for evaluation, and four to five were actually received. Few of these could even remotely be considered for monitoring an exhaust air recirculation system. For the less common contaminants such as solvent vapors--the bulk of the TLV list--few if any even remotely suitable measurement apparatus will be available. It is interesting to note that the portable meters evaluated are not significantly less expensive than ambient air or source monitoring instruments. Apparently, making meters portable, battery operated, and direct-reading is expensive. Fortunately, for the recirculation application, there is no need for portability.

Table 2 lists the portable CO meters evaluated, the detection principle, and concentration range. The Ecolyzer and Wilkes meters were good instruments and could probably be used in a recirculation system if they were carefully maintained. The Wilkes was not particularly portable. It is a variable wavelength IR meter whereas dedicated NDIR instruments are routinely used for stack and ambient air CO monitoring. The Ecolyzer is completely portable, and its electrochemical cell detection provided good performance. The metal oxide, solid-state detectors did not perform as well.

Table 3 includes similar information for SO₂ meters evaluated. The Wilkes IR meter also performed well for SO₂. The Environmetrics and Casella meters also gave reliable measurements of SO₂ concentration, and the Environmetrics is suitable for recirculation systems.

Table 2. Portable CO meters evaluated

Meter	Manufacturer address	Range (ppm)	Detection principle
Bullard Portable CO Monitor	E. D. Bullard Company	0-300	Metal oxide-Solid state
CO-Dackel	Dorthmund, W. Germany Dist. by: Daco Products, Inc.	50-300	Metal oxide-Solid state
Ecolyzer Model 2800	Energetic Sciences, Inc.	0-100 0-600	Electrochemical cell
EnMet Model PTM	Environmental Metrology Corp.	0-100	Metal oxide-Solid state
Portable Carbon Monoxide Indicator Model D	Mine Safety Appliances Company	0-500	Electrochemical cell
Miran I Variable Filter Infrared Analyzer	Wilkes Scientific Corporation	0-500	IR

Table 3. Portable SO₂ meters evaluated

Meter	Manufacturer	Range (ppm)	Detection principle
Casella SO ₂ Sampler T1400	C. F. Casella & Co., Ltd.	(Integrating Type)	Conductivity
SO ₂ Ultra Portable Analyzer U2-DS	CEA Instruments	0-20	Conductivity
Sulfur Dioxide Analyzer S-364	International Biophysics Corp. (formerly EnviroMetrics, Inc.)	0-100	Polarographic electrochemical cell (Foristor Technology)
Microcoulomb Detector Mod. 724-21MS	Mast Development Company	0-50	Coulometric
TitriLog III	Process Analyzers, Inc.	0-20	Oxidation-reduction (electrochemical)
Miran I Variable Filter Infrared Analyzer	Wilkes Scientific Corporation	0-50	IR

In table 4, the NO-NO_x portable meters evaluated are tabulated. The chemiluminescent meters (TECO and MEC) performed well and illustrated the advantages of this reference method. The Ecolyzer and IBC (formerly EnviroMetrics) meters also performed reasonably well and may be suitable for recirculation system monitoring.

A monitoring capability is the weak link in the technology of recirculating exhaust air. It is so weak that it has been suggested that monitoring be circumvented by employing control techniques. However, suitable instruments will greatly enhance the technology of recirculating exhaust air and provide for the needed documentation. Monitoring instruments cannot be satisfactorily circumvented and some priority must be given to the development of suitable meters.

Continuous monitoring, whether ambient air, source monitoring, or contaminant monitoring in recirculated exhaust air, is a new ballgame when compared to random in-plant surveys or measurements of short duration.

Some of the problem areas that are easily identifiable are:

- a) Reference measurement methods for specific contaminants;
- b) Minimum performance specifications which require the manufacturer to certify that his monitor meets these specifications;
- c) Calibration gases and standards (zero/span concentrations) that are reliable, stable, and accurate;

Table 4. Portable NO-NO_x meters evaluated

Meter	Manufacturer	NO-NO _x	Detection principle
Enolyzer Model 7100 (Prototype)	Energetics Science, Inc.	NO-NO ₂	Electrochemical cell
Analyzer Model N-322	International Biophysics, Corp. (formerly Enviro- Metrics, Inc.)	NO-NO ₂ -NO _x	Polarographic electrochemical cell - electrocatalytic oxidation or reduction of pollutant species. (Faristor Technology)
Mast Model 724-11	Mast Development Company	NO ₂	Coulometric (Oxidation-reduction of KBr or KI by NO ₂)
McMillan Model 2100	McMillan Electronics Corp.	NO-NO _x -NO ₂	(1) PMT detection of chemiluminescent reaction: $\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 + h\nu$ (2) Thermal conversion of NO ₂ to NO to measure NO _x .
Purad (Prototype)	Purad, Inc.	NO _x	Exothermic reaction of NO with NH ₃ : $\text{NO} + 2\text{NH}_3 + \text{O}_2 \rightarrow 1\frac{1}{2}\text{N}_2 + 3\text{H}_2\text{O} + 173\text{ KCal}$
Thermo Electron Model 8A	Thermo Electron Corpo- ration	NO	PMT detection of chemiluminescent reaction: $\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2 + h\nu$
UEI Model 7030	Universal Environmental Instruments, U.K. LTD.	NO ₂ -NO _x	Optical detection of stain on an NO _x sensitive tape.

- d) Formalized procedures for operation, calibration, and maintenance of specific monitors;
- e) Support from an analytical laboratory to provide backup measurements when needed;
- f) Quality assurance programs;
- g) Data acquisition (optimum methods must be devised for achieving data) such that if problems do arise, the plant/facility using recirculated exhaust air can easily produce records documenting the contaminant level and/or have the information available for retrospective health studies.

In addition, standards usually tend to revise downward so that monitoring requirements could change drastically as further information regarding health effects becomes available.

Briefly, let's examine several of the above-mentioned requirements and problem areas.

- a) The availability and use of standardized measurement methods and procedures will insure that industry will utilize the best techniques, equipment, etc., for performing measurements. This results in cost savings and goes a long way to insure that quality data are collected.
- b) The accuracy and precision of data is highly dependent on having stable, accurate calibration standards. The availability and use of calibration standards of the highest quality is imperative. If possible, these standards should be traceable to NBS or verified by reference or methods acceptable to the scientific community. Calibration schedules should be established and routinely performed by qualified technicians. It is not possible to buy monitors for continuous measurement of pollutants/contaminants, etc., off-the-shelf, install them, turn them on, walk off, and expect them to operate unattended without proper maintenance, calibration, and attention.
- c) Quality assurance is here and now for the ambient air monitoring community. It's not enough to say I'm generating good data--you have to prove it. All monitoring programs today require a minimum quality assurance program. Typical costs for a QA program today could range from 5 to 7 percent of the total expenditures. A quality assurance program should at a minimum consist of periodic onsite systems reviews, periodic point-in-time audits, and routine examination of data by competent personnel.
- d) Data acquisition and achieving of data that can be readily retrieved is an important aspect of monitoring. It is mandatory to preserve data for future use in the event of court cases, documentation, retrospective health studies, etc. Stripchart records are needed at a minimum.
- e) Monitoring costs money--monitors, accessory equipment, materials and consumable supplies related to operation, personnel time, etc., are expensive. The ultimate expense depends on how serious you are about data and how good a job you want to do.

DISCUSSION

DR. RALPH R. LANGNER (Dow Chemical U.S.A., Midland, Michigan): I can't allow these two gentlemen to make the statements they have without challenging

them and hopefully I might be able to enlighten them a little bit. There are reasons for taking measurements other than documenting exposure, and far more important than documentation. Basically, it is to prevent the workers from ever being exposed. We have fallen into the trap where we are taking measurements because it is the law. We in industry believe in continuous monitoring, but we do it to prevent exposure, not to document what the exposure has been.

MR. PARKER: We have not taken a position in opposition to yours. The necessity of monitoring is indeed a legal matter and it is a legal matter simply because we do wish to provide for the health and well-being of the American worker.

MR. DAVID E. HOGLAND (Federal Energy Administration, Chicago, Illinois): I have a question about the reference methods of EPA. Would most of the monitors you talked about qualify as a reference monitor?

MR. PARKER: Few of the portable or source monitors we talked about would be considered a reference monitor. Chemiluminescence, for NO, yes, those would conform to the reference method. There are equivalency documents coming out, and some monitors may be able to qualify under the equivalency.

MR. DECKER: The only thing I might add to that is the measurement principle would qualify, maybe not the analyzer. Chemiluminescence for ozone would; chemiluminescence for NO and NO₂ probably will. The final say on the method for NO has not come out, but it appears to be chemiluminescence, so the measurement principle would qualify; the specific instrument may not.

MR. WILLIAM J. ASTLEFORD (Southwest Research Institute, San Antonio, Texas): I would like to clear up a statement which Mr. Decker made. Apparently you're under the impression when the bell rings and the light flashes you don't know what has happened to the system. I think that if you will take a little closer look at the report you'll find out that each meter relay channel contains its own audiovisual alarm, and by the time the alarm has been activated, the appropriate course of corrective action has already been taken. By noting which channel has been alerted you have an indication of what the problem is.

MR. DECKER: Let me say this: I received the report about a week ago and I haven't read it in detail, and therefore some of the things I may have said may not accurately reflect what is there. I'm just saying I don't really know when the bell goes off whether I have a true problem or an instrument problem until I go take a look at the instrument itself.

DR. E. KARL BASTRESS (Arthur D. Little, Inc., Cambridge, Massachusetts): In my opinion, existing instruments offer a lot more potential for the occupational environment than might be implied by the Southwest Research Institute report. Mr. Caplan indicated this morning that there are existing monitors for continuously or semicontinuously monitoring mass concentrations of particulates. If you are dealing with a situation where you have a particulate in the atmosphere, you can assume that it is entirely or mostly the substance that you are concerned with. The mass monitor is just as suitable for that application as a monitor that is specific to that material. Similarly, with hydrocarbon monitoring, a very large number of the chemicals in the OSHA list give responses on hydrocarbon analyzers. There are many situations where the conditions are such that if you get a response on the analyzer, you can be pretty sure that it is the hydrocarbon you are worried about; you do not necessarily need the specific instrument. So I think there is a

potential for existing ambient instruments to a large number of occupational situations.

MR. ROBERT G. CONFER (Exxon Corporation, Linden, New Jersey): I would like to make a comment about some of the comments that Mr. Decker made. I certainly agree that performance standards should be developed for instrumentation to meet--at least when testing them in your laboratory--those which have been indicated by the manufacturer. But I don't agree that reference methods should be developed for every contaminant and instrument that is going to be used to measure that contaminant. I personally think it stifles future research and development.

And in addition to that, once the government gets on its books the fact that they have a reference method, it takes forever to get it off there. I think the Jacob-Hochheiser method was a good example of that. It was Bible until somebody else attacked it and it took forever for this thing to get off the book. So I don't agree that reference methods are the way to go.

MR. DECKER: The only comment I would have here is that a reference method is a reference method until something better comes along. Processes are in the wind, especially through the EPA equivalency documents; if a better reference method comes along it becomes the reference method. So there is a mechanism for change. I'll agree with you on the Jacob-Hochheiser method; it took forever and a lot of bad data were generated using the method; but it wasn't truly the Jacob-Hochheiser method. It was a modification of that method and Mr. Hochheiser is very sensitive about that.

DESIGN CRITERIA FOR RECIRCULATION EXHAUST AIR SYSTEMS

R. B. Stotz*

Abstract

The two most important factors in the design of recirculation exhaust systems are safety and energy conservation, and they must be considered in this priority. This paper will first discuss the advisability of such a system. Having established a favorable atmosphere, it will then consider the merits of various systems, system components, component arrangements, controls, and monitoring arrangements. Finally, operating and maintenance procedures to assure a successful result will be examined.

Exhaust air systems in commercial and industrial buildings have as their prime functions the preservation of safety and comfort for personnel working in the space. Therefore, each such system must be designed so as not to risk loss of these benefits.

Recirculation of exhaust systems has as its sole purpose the conservation of energy--certainly a most important consideration in this energy crisis. However, in process work recirculation is not the only means of energy conservation. Some processes may involve contaminants which will not permit recirculation without the possibility of serious immediate effects. And in certain instances, design for recirculation might even require more energy than is saved by reusing the treated air. Other energy conservation methods to be considered involving design of the exhaust air system are reduction in the amount of air exhausted and the use of heat recovery.

In moderating the ASHRAE+ forum on Laboratory Hood Systems in Atlantic City last January, it was apparent that no reliable standard for laboratory hoods exists. Further, for similar hood applications, minimum face velocity used varied over a wide range. One of three industrial users--all in the top ten list--went as low as 50-fpm face velocity while the others limited velocities to 90 fpm and 100 fpm respectively. And a large State university system held to a minimum of 150 fpm. No logical explanation can exist for such a variation--three times the minimum for the university.

Still another possible method of energy conservation is by means of heat recovery either through the use of heat recovery wheels, a runaround cycle, or refrigeration. Quite an energy saving is effected in the Walter P. Chrysler Styling Complex in Highland Park, Michigan, by heating and reheating with condensing water from three centrifugal chillers. A simple system balancing heat recovered with heating requirements is used.

The typical heat recovery centrifugal can differ from a standard unit only by the fact that two condenser tube bundles are supplied instead of a single one (see figure 1). When heating is required, the condenser heat is picked up by water circulating through the condenser tubes under the rear head and

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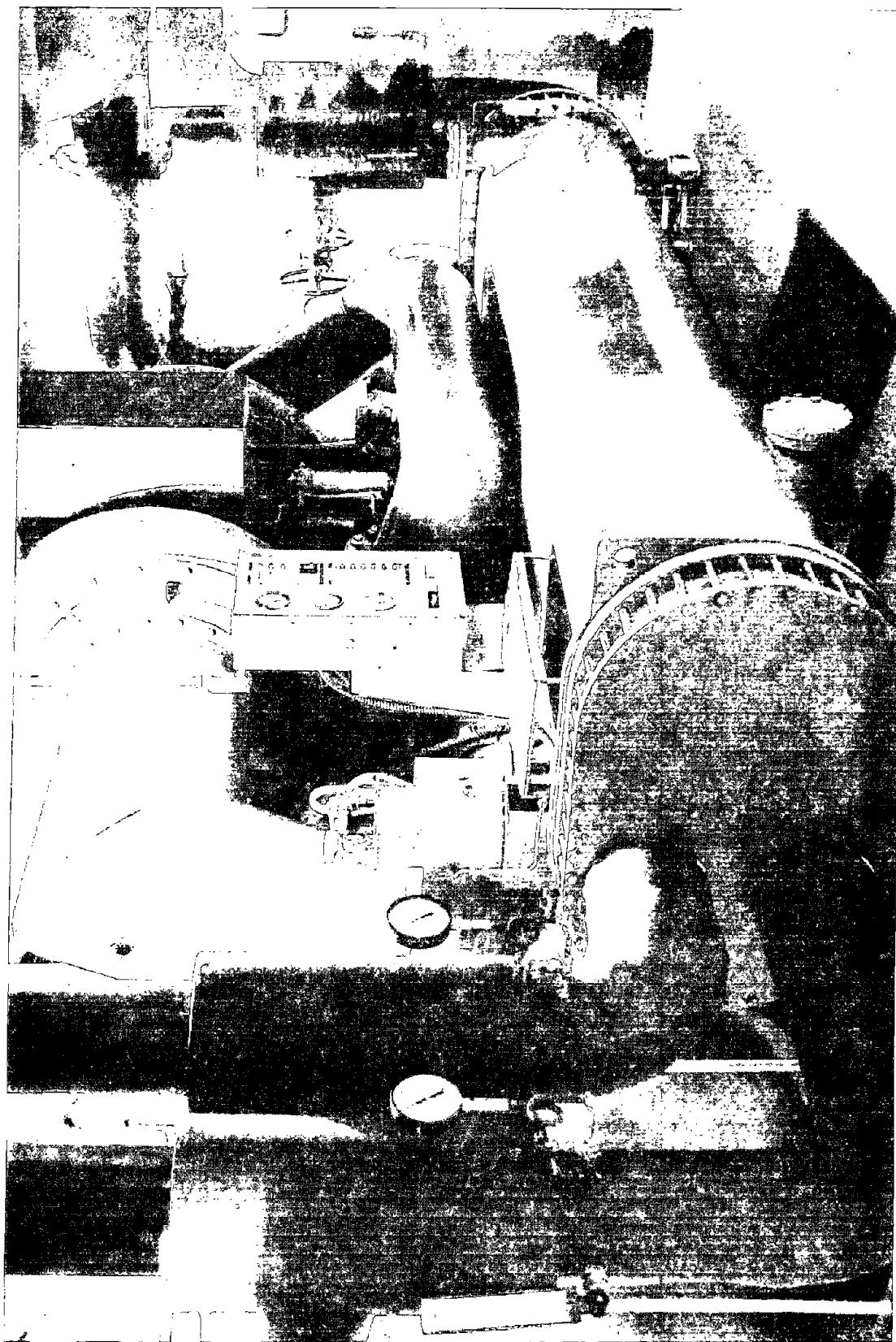


Figure 1. Typical heat recovery centrifugal.

conducted to the area requiring heat. If no heating is required, the heat is rejected to atmosphere through the tubes feeding the nozzles at the far end of the condenser in the forward section of the shell.

The heat generated by lights in the styling rotunda as used (approximately 12 watts per square foot) is always available. Normally this heat would be exhausted to atmosphere. However, when heating is required in perimeter areas, exhaust air is reduced and the heat absorbed by the chilled water transferred to the condenser water and used for heating. Since the heat is always available, there was no need for storage and a balanced system was selected to provide minimum energy consumption.

A similar centrifugal system provides year-round comfort and domestic hot water in the 26-story office tower of Canadian Broadcasting Company in Montreal. Here heat is recovered from the broadcast studios and transferred to the areas requiring it. Because instantaneous heating requirements sometimes exceed that available, storage tanks were included in the system. The additional cost for this system is small if indeed there is additional cost. Consider that a boiler and stack are eliminated, as is the space required for them.

A somewhat similar approach was followed by Weyerhaeuser International in its Tacoma, Washington, headquarters (see figure 2). However, it included the additional feature of a chilled water coil in the exhaust ducts in order to reclaim heat from minimum exhaust air streams. Actual results show Weyerhaeuser's total energy costs are only 33 percent to 45 percent of the costs for similar size buildings with conventional systems.

Systems like these three effect savings during the heating cycle only. Systems incorporating runaround cycles and heat recovery wheels have the capability of producing savings during both heating and cooling. Additional capital investment, however, may not prove justified by the results, especially evaluating the top coefficient of performance of over 4.0 to be expected from the refrigeration cycle. Consideration, then, should be given to each of these potential methods of energy conservation, and the risks to the basic function of the exhaust system, before the decision is made to recirculate. Your decision may be to include one or more of them in your system design.

While the work done by Southwest Research Institute was not process-oriented, it did much to establish information necessary for industrial applications. Using its report for our base, let us examine system design. Of the 514 chemical compounds commonly found in the industrial workplace and for which the American Conference of Governmental Industrial Hygienists has established Threshold Limit Values (TLV), 94 have been classified as not potentially recirculatable. An additional 64 are not recommended for recirculation systems. These are listed as Groups 6 and 5, respectively, in their report. Of the remaining 356 compounds in Groups 1, 2, 3, and 4, cleaners and monitors have been established for 68--a quantity which could no doubt be revised upward. It is almost certain that every industrial plant has one or more exhaust systems where recirculation is possible, whether practical or not.

It is significant that of the 68 compounds with established cleaners and monitors, 67 are from Groups 1 and 2. Group 3, consisting of 103 compounds, is made up of particulates. Here the particle size distribution weighs heavily in determining the proper cleaner selection. In addition, monitoring equipment for specific particulates is not presently available.

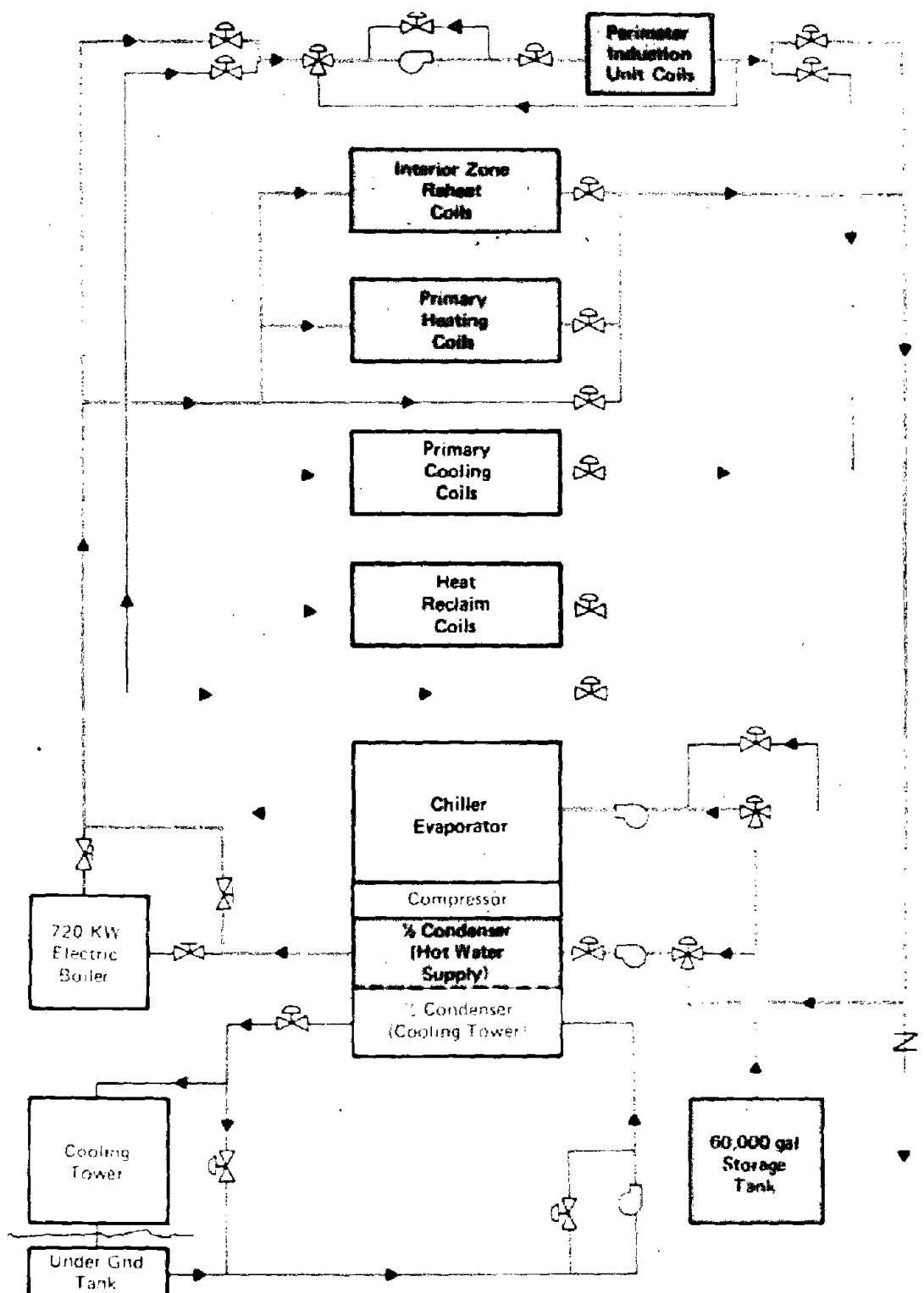


Figure 2. Maximum heat warmup cycle.

For the present, therefore, the report indicates that we can only specify recirculation safely for systems involving compounds in Groups 1, 2, and 4. However, cleaners for particulates in Group 3 are available and should be used as recommended by the manufacturer. We then must expend every possible effort to develop monitoring equipment in view of the energy crisis. The probability of legislation establishing energy budgets or indices for various industrial processes is imminent. Yesterday ASHRAE Std. 90-75 for new commercial and residential buildings was mentioned. A similar standard for industrial processes is being considered.

In designing a recirculation exhaust system then, our first requirement is to determine what contaminants are present for the process involved. Assuming that the contaminants include some from Group 3, although present state-of-the-art does not indicate safety in recirculation, it is recommended that particle size distribution be determined and checks be made with equipment manufacturers. Information similar to table 1 is now available from manufacturers and will surely be expanded shortly. Note the recommendations in table 1 for various industries--and this is only a partial list. In general, particulate air cleaners of some type--electrostatic precipitators, fabric filters, wet collectors, or centrifugal collectors--are commonly used in most industrial exhaust systems and may require little additional investment to do a proper collecting job. Monitoring, of course, is another problem to be solved.

Air cleaners suitable for gas and vapor collection fall into four categories:

1. absorbers or wet collectors,
2. adsorbers,
3. catalytic oxidizers,
4. direct combustors.

Of these, the latter two almost always require too much additional energy to be considered.

Table 2 shows one manufacturer's anticipated cleaning efficiency when his wet scrubber equipment is used with laboratory fume hoods. Note that multi-staging may be required but cleaning efficiencies generally approach 100 percent. Similarly, table 3 is representative of process-oriented data supplied for this equipment when used in various treatment operations. Again, this is a partial list only. According to the manufacturer, typical applications of these wet scrubbers include aluminum anodizing, pickling, electroplating, coating stripping, acid dipping, metal cleaning, electropolishing, metal etching, metal surface treatment, printed circuit etching, laboratory hood exhausts, and chemical operations--quite a widespread usage.

Lists such as that shown in table 4 are available for various adsorptive cleaners. Thus, by use of the manufacturers' recommendations for the contaminants found in the process involved plus a comparison of energy requirements, capital investment, and anticipated maintenance costs, the cleaners best suited to the process can be selected.

The next step in the design of the system is the arrangement of the components. Minimum redundancy requirements for systems involving contaminants dangerous to human life should be the use of duplicate exhaust fans. Therefore, the simplest arrangement is that shown in figure 3. Here a single cleaner is

Table 1. AAF equipment selections for industrial processes

Operation	Concentration	Particle size	Type D (p. 6)	Type D & skimmer (pp. 6 & 7)	AMER-clone (p. 6)	Type W arr. A (p. 10)	Type W arr. D (p. 10)	Type N* (p. 9)	AMER-pulse (p. 12)	Dust arrester cloth (p. 12)	Dust arrester paper (p. 12)	AMER-tube (p. 12)	Type R (p. 9)	KIN-PACTOR scrubber (p. 10)	Notes
CHEMICALS															
Materials	Lt. to hvy.	Fine to coarse	Occ.	Freq.	Freq.	Freq.	Occ.	Usual	Usual	Rare	Rare	Freq.	Usual	Rare	3
Crushing and grinding	Med. to hvy.	Fine to coarse	Occ.	Occ.	Freq.	Rare	Freq.	Usual	Usual	Rare	Rare	Usual	Usual	Occ.	4
Weighing and screening	Lt. to mod.	Fine to med.	No	No	No	Usual	Occ.	Freq.	Freq.	Occ.	Occ.	Rare	Freq.	Norm. not req.	5
Roasters, kilns, dryers & coolers	Heavy	Med. to coarse	Rare	Rare	Freq.	Occ.	Occ.	Usual	No	No	No	Freq.	Usual	Occ.	6
Bin ventilation	Light	Fine to med.	Occ.	No	Rare	Usual	Rare	Occ.	Freq.	Freq.	Occ.	Rare	Occ.	No	--
METALWORKING															
Production grinding	Light	Coarse	Usual	Freq.	Rare	No	No	Freq.	Rare	Rare	Rare	No	No	No	26
Portable & swing frame grinding	Light	Med.	Usual	No	No	No	No	No	Occ.	No	No	No	No	No	27
Tool room	Light	Fine	Usual	Rare	No	No	No	Occ.	Occ.	Rare	No	No	No	No	27
Polishing & buffing	Light	Varies	Rare	Occ.	No	No	No	Usual	Rare	No	No	No	No	No	28
Cast iron machining	Mod.	Varies	Freq.	Usual	Rare	No	No	Occ.	Occ.	Occ.	No	No	No	No	29

Table 1. AAF equipment selections for industrial processes (con.)

Operation	Concentration	Particle size	Type D (p. 6)	Type D & skimmer (pp. 6 & 7)	AMER-clone (p. 6)	Type W arr. A (p. 10)	Type W arr. D (p. 10)	Type N* (p. 9)	AMER-pulse (p. 12)	Dust arrester cloth (p. 12)	Dust arrester paper (p. 12)	Fabric collector (p. 12)	Type R (p. 9)	KIN-PACTOR scrubber (p. 10)	Notes
RUBBER & PLASTIC PRODUCTS															
Mixers	Mod.	Fine	Rare	No	No	Freq.	Occ.	Occ.	Usual	Rare	No	Rare	Occ.	Norm. not req.	37
Batchout rolls	Lt.	Fine	Rare	No	No	Usual	Rare	Rare	Freq.	Rare	No	Rare	Rare	No	38
Talc dusting	Mod.	Med.	Occ.	No	No	Freq.	Occ.	Occ.	Freq.	Occ.	Rare	Rare	Occ.	Norm. not req.	39
Grinding & buffing	Mod.	Coarse	Freq.	Usual	No	Rare	Usual	Occ.	Occ.	Rare	No	Rare	No	Norm. not req.	39
Plastics materials handling	Mod.	Med.	Occ.	Occ.	Occ.	Usual	Occ.	Freq.	Freq.	Rare	Rare	No	Occ.	Norm. not req.	41
Plastics finishing	Light	Fine to med.	Freq.	Freq.	No	Occ.	Occ.	Occ.	Freq.	Freq.	Rare	No	Occ.	No	42
STEEL MILLS & PELLETIZING PLANTS															
Kish	Med.	Med. to coarse	No	No	Usual	Rare	Rare	Rare	No	No	No	Rare	Rare	Norm. not req.	43
B.O.F.	Med. to hvy.	Ext. fine	No	No	No	No	No	No	No	No	No	Occ.	No	Freq.	44
Scarfing	Light	Ext. fine	No	No	No	No	No	Rare	No	No	No	No	No	Freq.	45
Electric melting furnaces									--SEE FOUNDRY--						
Coal and coke handling									--SEE COAL--						
Open hearth	Med. to hvy.	Fine	No	No	No	No	No	No	No	No	No	Occ.	No	Occ.	46
Pelletizing plant sintering machines															47-48
Bed exhaust	Med.	Fine to med.	No	No	No	No	No	Rare	No	No	No	No	Rare	Norm. not req.	49
End dump screen & materials handling	Hvy.	Fine to med.	No	No	No	No	No	Usual	No	No	No	Rare	Rare	Norm. not req.	50
Blast furnace	Hvy.	Ext. fine to coarse	No	No	No	No	No	No	No	No	No	No	No	Usual	51
Hot strip mills	Light	Fine	No	No	No	No	No	Usual	No	No	No	No	Rare	Norm. not req.	52
Coke screening	Med. to hvy.	Med. to coarse	No	No	Rare	No	Occ.	Occ.	No	No	No	Rare	Occ.	Norm. not req.	53
Materials handling	Med. to hvy.	Fine to med.	No	No	Rare	No	Rare	Rare	Usual	No	No	Rare	Freq.	Norm. not req.	54

Table 2. Laboratory test determinations

Contaminant or process gas	Concentration		Additive	Water rate	Efficiency			Notes
	ppm (wt)	ppm (vol)			One- stage	Two- stage	Three- stage	
Sulfuric acid (H ₂ SO ₄)	130	---	None	S H	97. + 99.9	99.4 100	99.7 100	1
	75	---	None	S H	99.3 ---	100 ---	100 ---	2
Hydrochloric acid (HCl)	105	85	None	S H	94.6 98.1	97.9 99. +	99.4 99.9 +	2
	50	40	None	S H	93.6 100	98.1 100	99. + 100	2
Perchloric acid (HClO ₄)	45	---	None	S	90.1	96.7	99.0	3
Acetic acid (CH ₃ COOH)	1000	---	None	S	69.7	93.0	---	2
				H	84.6	97.7	99.9	
Nitric acid (HNO ₃)	190	---	None	S	93.3	---	---	1
Ammonia (NH ₃)	85	32	H ₂ SO ₄ HPO ₄	S	90.3	95.4	95.7	4
				S	82.1	91.6	92.9	
Chlorine (Cl ₂)	150	35	NaOH	S	52.4	77.0	77.0	4
Ethylenediamine (NH ₂ CH ₂ CH ₂ NH ₂)	225	110	None	S	93.5	98.3	99.1	5
				H	93.7	98.4	99.4	

NOTES:

1. For normal concentration similar to those shown, more than one stage is not required.
2. For very high process concentrations, multiple staging may be necessary.
3. Perchloric acid requires special handling. See VS-205 *Industrial Ventilation*, 10th edition, and use all (including pads) type 316 stainless steel COLAG.
4. The use of an additive is required. Consult home office for recommendations.
5. Use efficiency figures for other members of amine group.

WATER RATES:

- (S) Standard water rate is approximately 5 gph/ft² pad area or .14 GMP/1,000 cfm.
(H) High water rate is approximately 18 gph/ft² pad area or .53 GMP/1,000 cfm.

CONVERSION FACTOR:

To convert to, mg/m³, multiply ppm (wt) by 1.19,
gr/ft³, multiply ppm (wt) by .00053.

Table 3. Example of process-oriented data

Process	Type	Nature of contaminant which may be released to atmosphere	Materials of construction	Eff. range, by weight
Electro-plating fluoborate	Cadmium	Fluoborate salts	PVC	-
	Copper	Copper fluoborate	PVC	-
	Indium	Fluoborate salts	PVC	-
	Lead	Lead fluoborate	PVC	-
	Lead & tin	Lead fluoborate	PVC	-
	Tin	Stannous fluoborate	PVC	-
	Zinc	Fluoborate mist	PVC	-
Electro-plating cyanide	Brass & bronze	Cyanide mist & ammonia gas	All 300 Series S. S.	(6)
	Bright zinc	Cyanide & alkaline mist	All 300 Series S. S.	85 - 90
	Copper	Cyanide & alkaline mist	All 300 Series S. S.	-
	Gold	Cyanide mist	All 300 Series S. S.	-
	Indium	Cyanide & alkaline mist	All 300 Series S. S.	-
	Tin zinc alloy	Cyanide & alkaline mist	All 300 Series S. S.	-
	White alloy	Cyanide & alkaline mist	All 300 Series S. S.	-
	Zinc	Cyanide & alkaline mist	All 300 Series S. S.	-
Electro-plating acid	Chromium	Chromic acid mist	PVC or 316 S. S.	95 - 98
	Copper	Acid mist	PVC	88 - 94
	Iron	Hydrochloric acid mist	PVC	-
	Nickel	Hydrofluoric acid mist	-	88 - 94
	Tin	Halide mist	-	-
	Zinc	Zinc chloride mist	PVC or 316 S.S.	-
Stripping coatings	Anodized aluminum or magnesium	Chromic acid mist	PVC 316 S. S.	95 - 98
	Black oxide steel	Hydrogen chloride	PVC	85 - 90
	Brass & bronze	Alkaline, cyanide mist	PVC or S. S.	(6)
	Cadmium	Alkaline, cyanide mist	All 300 Series PVC or S. S.	(6)
	Cadmium	Hydrogen chloride mist	All 300 Series PVC	85 - 90
	Chromium	Alkaline mist	PVC or S. S.	-
	Chromium	Hydrogen chloride mist	All 300 Series PVC	85 - 90
	Chromium	Acid mist	PVC	85 - 90
	Copper	Alkaline, cyanide mist	PVC or S. S.	-
	Copper	Cyanide mist	All 300 Series PVC	(6)
	Copper	Nitrogen oxide	PVC	(6)
	Copper	Alkaline mist	PVC or S. S.	75 - 80
	Gold	Alkaline mist	All 300 Series PVC or S. S.	(6)

Table 4. The relative adsorptive ability of AAF Activated Carbon Filters for a partial list of compounds

Code: E—Excellent. High capacity. Each pound of activated carbon will adsorb an average of 331/3 percent of its weight in odor.
 G—Good. Satisfactory capacity—approximate average of 18.7 percent of its weight.
 F—Fair. Not highly adsorbable.
 P—Poor. Not suitable.

Compound	Compound	Compound	Compound
Acetaldehyde (F)	Cyclohexanol (E)	Hydrogen cyanide (G)	Paint and redecorating odors (E)
Acetic acid (E)	Cyclohexanone (E)	Hydrogen fluoride (F)	Palmitic acid (E)
Acetic anhydride (E)	Cyclohexene (E)	Hydrogen iodide (G)	Paradichlorobenzene (E)
Acetone (G)	Decane (E)	Hydrogen selenide (F)	Pentane (G)
Acetylene (P)	Dibromoethane (E)	Hydrogen sulfide (G)	Pentanone (E)
Acrolein (G)	Dichlorobenzene (E)	Incense (E)	Pentylene (G)
Acrylic acid (E)	Dichlorodifluoromethane (E)	Indole (E)	Pentyne (G)
Acrylonitrile (E)	Dichloroethane (E)	Iodine (E)	Perchloroethylene (E)
Alcoholic beverages (E)	Dichloroethylene (E)	Iodoform (E)	Perfumes, cosmetics (E)
Amines (F)	Dichloroethyl ether (E)	Irritants (E)	Phenol (E)
Ammonia (F)	Dichloromonofluoromethane (G)	Isophorone (E)	Phosgene (G)
Amyl acetate (E)	Dichloronitroethane (E)	Isoprene (G)	Pitch (E)
Amyl alcohol (E)	Dichloropropane (E)	Isopropyl acetate (E)	Poison gases (G)
Amyl ether (E)	Dichlorotetrafluoroethane (E)	Isopropyl alcohol (E)	Pollen (G)
Aniline (E)	Diesel fumes (E)	Isopropyl ether (E)	Popcorn and candy (E)
Asphalt fumes (E)	Diethylamine (G)	Kerosene (E)	Poultry odors (E)
Automobile exhaust (G)	Diethyl ketone (E)	Kitchen odors (E)	Propane (F)
Benzene (E)	Dimethylaniline (E)	Lactic acid (E)	Propionaldehyde (G)
Body odors (E)	Dimethylsulfate (E)	Menthol (E)	Propionic acid (E)
Borane (G)	Dioxane (E)	Mercaptans (E)	Propyl acetate (E)
Bromine (E)	Dipropyl ketone (E)	Methane (P)	Propyl alcohol (E)
Burned flesh (E)	Ethane (P)	Methyl acetate (G)	Propyl chloride (E)
Burned food (E)	Ether (G)	Methyl acrylate (E)	Propyl ether (E)
Butadiene (G)	Ethyl acetate (E)	Methyl alcohol (G)	Propyl mercaptan (E)
Butane (F)	Ethyl acrylate (E)	Methyl bromide (G)	Propylene (F)
Butanone (E)	Ethyl alcohol (E)	Methyl butyl ketone (E)	Propyne (F)
Butyl acetate (E)	Ethyl amine (G)	Methyl cellosolve (E)	Putrefying substances (G)
Butyl alcohol (E)	Ethyl benze (E)	Methyl cellosolve acetate (E)	Putrescine (E)
Butyl cellosolve (E)	Ethyl bromide (E)	Methyl chloride (G)	Pyridine (E)
Butyl chloride (E)	Ethyl chloride (G)	Methyl chloroform (E)	Resins (E)
Butyl ether (E)	Ethyl ether (G)	Methyl ether (G)	Rubber (E)
Butylene (F)	Ethyl formate (G)	Methyl ethyl ketone (E)	Sauerkraut (E)
Butyne (F)	Ethyl mercaptan (G)	Methyl formate (G)	Sewer odors (E)
Butyraldehyde (G)	Ethyl silicate (E)	Methyl isobutyl ketone (E)	Skatole (E)
Butyric acid (E)	Ethylene (P)	Methyl mercaptan (E)	Slaughtering odors (G)
Camphor (E)	Ethylene chlorhydrin (E)	Methylcyclohexane (E)	Smog (E)
Caprylic acid (E)	Ethylene dichloride (E)	Methylcyclohexanol (E)	Sour milks (E)
Carbolic acid (E)	Ethylene oxide (G)	Methylcyclohexanone (E)	Stoddard solvent (E)
Carbon disulfide (E)	Essential oils (E)	Methylene chloride (E)	Styrene monomer (E)
Carbon dioxide (P)	Eucalyptole (E)	Monochlorobenzene (P)	Sulfur dioxide (F)
Carbon monoxide (P)	Fertilizer (E)	Monofluorotrichloromethane (E)	Sulfur trioxide (G)
Carbon tetrachloride (E)	Film processing odors (G)	Naphthalene (E)	Sulfuric acid (E)
Cellosolve (E)	Fish odors (E)	Naphthalene (E)	Tetrachloroethane (E)
Cellosolve acetate (E)	Floral scents (E)	Nitric acid (G)	Tetrachloroethylene (E)
Cheese (E)	Fluorotrichloromethane (G)	Nitro benzenes (E)	Tobacco smoke odor (E)
Chlorine (G)	Formaldehyde (F)	Nitroethane (E)	Toilet odors (E)
Chlorobenzene (E)	Formic acid (G)	Nitrogen dioxide (F)	Toluene (E)
Chlorobutadiene (E)	Gangrene (E)	Nitroglycerine (E)	Toluidine (E)
Chloroform (E)	Garlic (E)	Nitromethane (E)	Trichloroethylene (E)
Chloronitropropane (E)	Gasoline (E)	Nitropropane (E)	Trichloroethane (E)
Chloropicrin (E)	Heptane (E)	Nitrotoluene (E)	Turpentine (E)
Citrus and other fruits (E)	Heptylene (E)	Nonane (E)	Urea (F)
Cleaning compounds (E)	Hexane (G)	Octalene (E)	Uric acid (E)
Coal smoke (G)	Hexylene (G)	Octane (E)	Valeric acid (E)
Creosote (E)	Hexyne (G)	Onions (E)	Valeraldehyde (E)
Cresol (E)	Hydrogen (P)	Organic chemicals (E)	Varnish fumes (E)
Crotonaldehyde (E)	Hydrogen bromide (G)	Ozone (E)	Vinyl chloride (G)
Cyclohexane (E)	Hydrogen chloride (F)	Packing house odors (E)	Xylene (E)

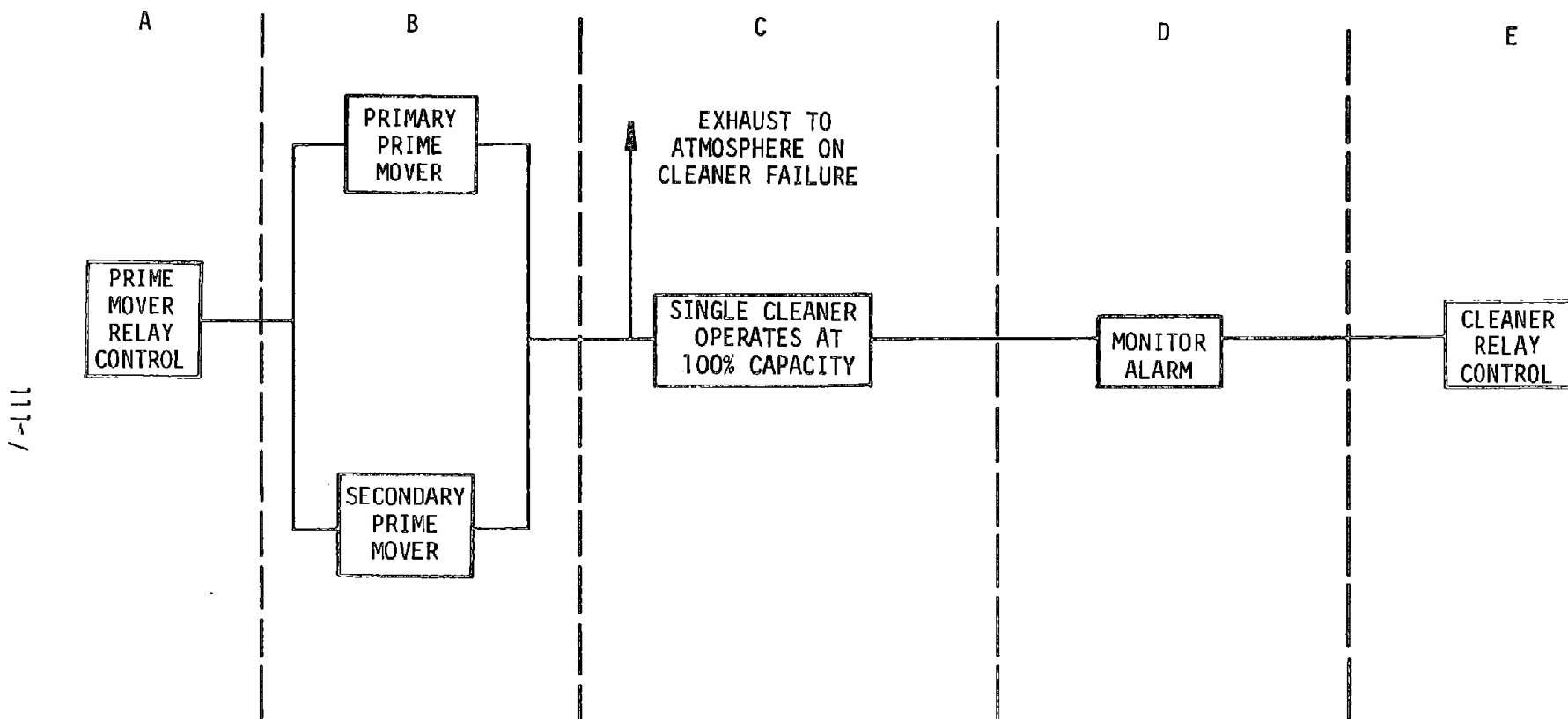


Figure 3. Single cleaner with no excess cleaning capacity - Exhaust to atmosphere.

used in conjunction with duplicate fans. In case the monitor senses a cleaner failure, air is exhausted to atmosphere instead of being returned to the space.

A similar arrangement can be made paralleling duplicate 100-percent cleaners for full redundancy. In this system, air is routed through a secondary cleaner in case of primary cleaner failure. If, for some reason, this does not provide satisfactory cleaning, the sensor again aborts the air to atmosphere.

Figure 4 represents the use of multiple-section cleaners having a total of more than 100 percent capacity and used in parallel arrangement. Once again, when sufficient sections fail so that the effluent air does not meet sensor setting, air is exhausted to atmosphere rather than returned to the space. The use of partial redundancy by parallel arrangement is my preference over the use of a secondary full capacity cleaner. When all sections are operational, better cleaning is obtained; in any event energy requirements are lower, safety is maintained in case of sectional failures, maintenance is required less often and for smaller increments, controls usually are more simple because less change in air pattern is required, and capital investment should be lower.

Figure 5 shows similar sections arranged in series--higher system pressure drops usually eliminate this arrangement. Both monitoring and control systems must be selected to meet the requirements of the particular process involved and the contaminants found. Simplicity should be the keynote in their selection since it is the most important factor in both reliability and operating life. They should, however, provide a visual indication of the operating mode and both audio and visual indications of any system failure with manual disalarm. If possible, they should also be installed on a "fail-safe" basis so that in event of their failure all air is exhausted to atmosphere.

The selection of all components and system arrangements must be primarily concerned with the guarantee of safety and comfort in the involved space. Thus, even though fail-safe measures are included, design should establish manual sampling to verify meeting minimum performance standards. The frequency of this manual sampling will vary with various systems depending upon the allowable TLV, the built-in system redundancy and the monitoring and control system. Suffice to say that any such manual sampling should be simple and avoid the time loss of laboratory analysis. The personal respirator may be one solution. Simplicity will be greatly affected, however, by the contaminant--particularly whether it is a gas, vapor, or a particulate.

Thus far we have concerned ourselves solely with the selection of system components and their arrangement. While this is by far the most important consideration, we cannot overlook other factors contributing toward energy conservation. Ductwork should be sized for minimal pressure drops consistent with length of run, quantity of air handled, and space occupied. Even more important in the conservation of energy is selection of the fan to operate in the high-efficiency range of its curve. Increases in energy requirements from either of these sources are important in any system. This importance is increased in systems where cooling is included. Here any increased energy usage is reflected in extra heat that the cooling system must remove.

Finally, a most important but often overlooked factor towards a successful system is the provision for and establishment of an adequate preventive maintenance program. We have already mentioned selection of components with this in

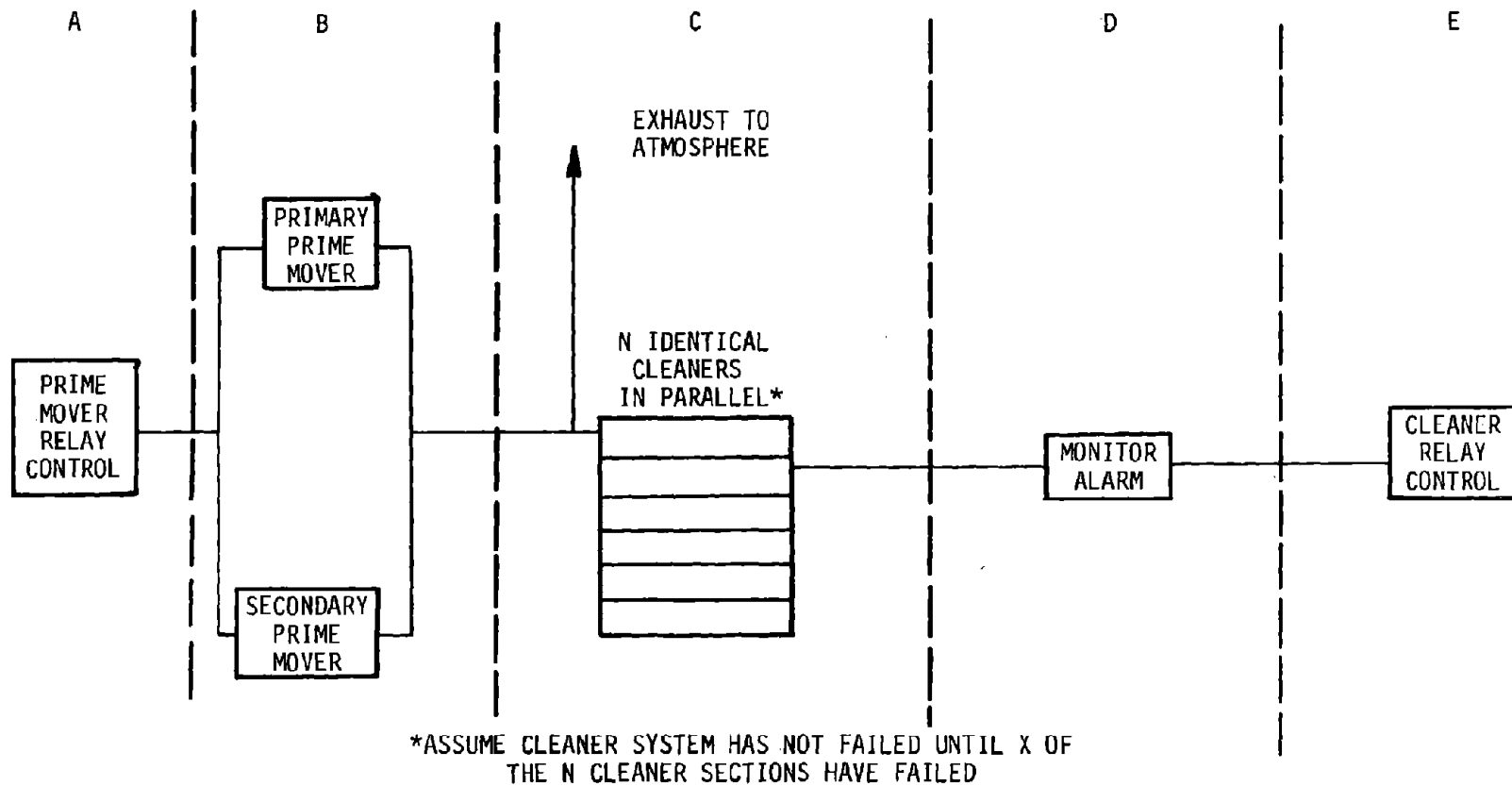


Figure 4. Single cleaner with excess cleaning capacity in parallel.

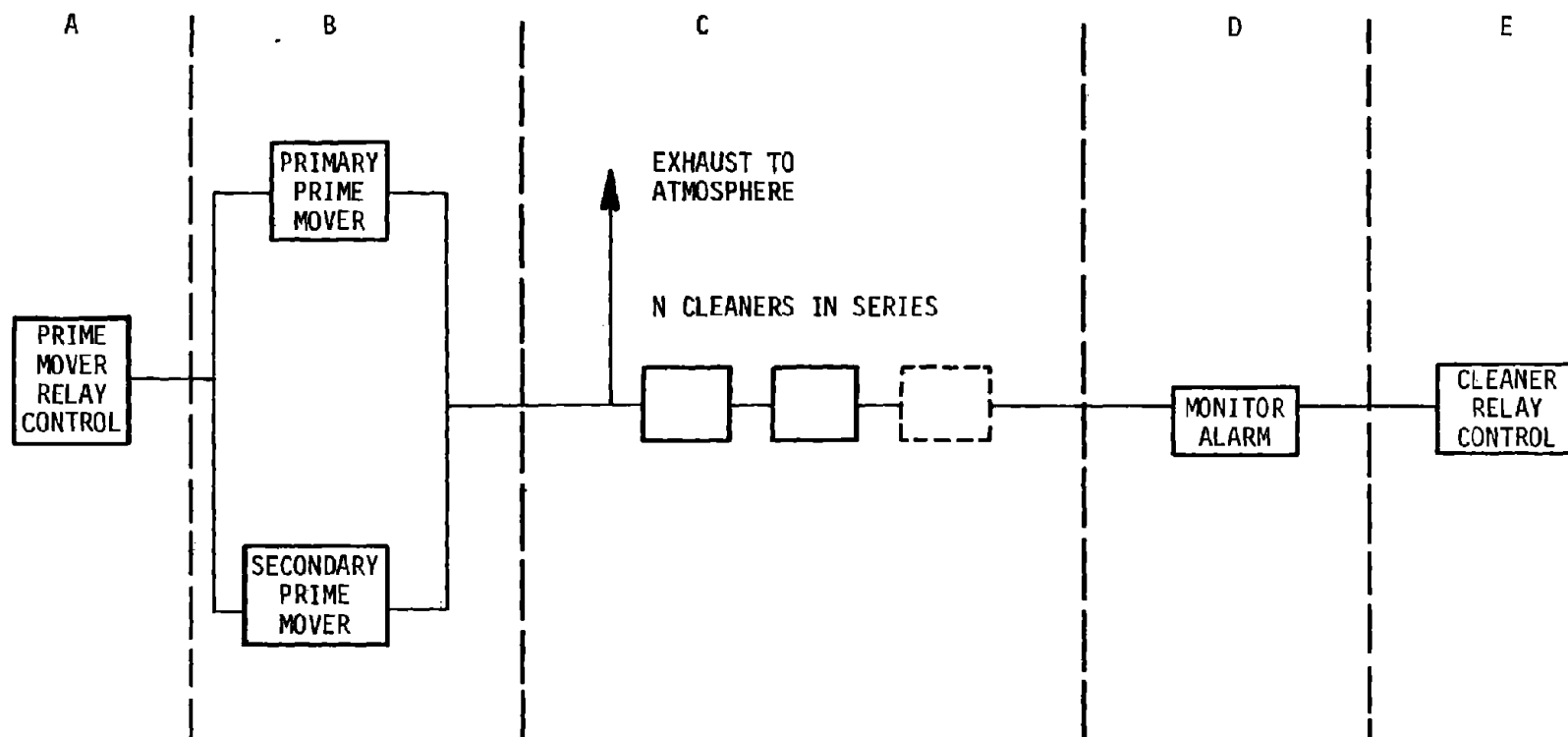


Figure 5. Cleaners in series with excess cleaning capacity.

mind. But a well-designed system must include reliable instrumentation to allow implementation. Thus, instrumentation should include the means of measuring and logging--either automatically or manually--contaminant concentration, pressure drops across various components, power inputs to all electrical apparatus, and fluid temperatures where they are pertinent. The maintenance schedule should also establish maximum values of the logged data at which corrective maintenance action is indicated.

In conclusion, each Recirculation Exhaust Air System must be designed based upon the contaminants developed in the industrial process involved. While the present state-of-the-art does not include a standardized and pre-tested design to answer all problems, sufficient data are available to allow a conservative approach with all potentially recirculatable compounds. Both the seriousness of the energy crisis and the anticipated future high cost of energy dictate that industry take immediate action to voluntarily reduce energy consumption in all reasonable ways. Let us take action, including recirculation if it is practical, while there is still time.

DISCUSSION

MR. KNOWLTON J. CAPLAN (Industrial Health Engineering Associates, Inc., Hopkins, Minnesota): I have two comments to add to Mr. Stotz's remarks.

One is that if we make the assumption that the adequate safe collection of particulate contaminants is the most likely recirculation candidate on the immediate horizon, then you can wind up with a pretty good fit between recirculation for some problems and heat recovery for others. It is an unfortunate fact of life that all of the reasonably efficient heat recovery systems that I know about are not usually applicable to particulate contaminant systems because the fin tubes or the thermol wheels or whatever you are using for heat recovery are fouled by the particulate. That is not true, however, of gaseous contaminants in airstreams that are reasonably clean of particulate. Conversely, at least in my opinion, the efficient cleaning of gases and vapors is a more chancy affair than it is for a particulate.

So there is an opportunity here for openmindedness and using, as he said, the most applicable technique for the different problems. Heat recovery would be usually a quite workable approach for gas streams that are clean of particulate but contaminated with gases and vapors. And vice versa for particulate; probably recirculation would be the best.

The second comment I would like to make is that there are recurring hints or statements made to the effect that the additional energy required for cleaning air to the point where you can recirculate it is an energy cost, and I would like to point out that that is not quite that simple. Let's make a reasonable assumption that the additional pressure drop of the additional cleaners are represented by some round number like 50 percent overall efficiency on the fan, so that half of the energy--the heat of compression of pushing the gas through the additional resistance of the cleaner--is recovered and goes back in the return airstream. In many circumstances, also, if the motors can be put in a fan house, etc., the wasted energy--that is, the inefficiency of the fan motor and drive system--converts itself into heat, which can also be recovered. So that many

circumstances represent a loss of very little energy. It turns out that it may be a little more expensive energy than burning fuel oil and the likes in that you are paying in effect for electric heat, but it is not a net loss.

MR. ROBERT B. STOTZ (R. B. Stotz, P.E., Inc., Panama City, Florida): Cap, I certainly agree with everything you said in the first part of your statement. In the second part, I think it is dependent upon the actual application itself. My background, in case some of you don't know it, has been largely with Chrysler Corporation and I have been involved in most of their new buildings in the HVAC portion of them, and in those plants we were not looking for heat. In all cases we had more than sufficient heat in the plant area itself. For example, in the styling complex the heat that we recovered was not used in the styling area itself, where the exhaust system was, but rather in office and administrative areas, and it was transferred to another section. In general that has been my experience. We had a matter of trying to overcome heat and therefore there was more loss during the cooling season than there was gain in the heating season. Now that may not be true in many of the applications that you're looking at. I think you have to look at them individually and see just where they are located.

We had a comment here yesterday about lowering the temperature in plants, and in some plants this is fine. The latest plant of Chrysler that I was involved in was an assembly plant in Windsor, Ontario, and there we installed no heating equipment with the exception of five small unit heaters, one located over each door for use during the weekend. During normal operating periods enough heat was generated in the plant so that we needed no heat, and therefore lowering the temperature would only have involved operating our cooling equipment for a longer period of time. So I think you have to look at the individual application to determine whether the energy is something that you just use in another way, as you have stated; certainly if you have a need for additional heat this extra resistance will give you a buildup of heat.

CHAIRMAN HUGHES: Cap spoke of recirculation of particulates because of the availability of technology and said that perhaps the gases and vapors would be more appropriate for heat recovery, which I agree with. For industrial processes does anybody have a general feel for what portion of those would be involved with particulates, what proportion with gases or vapors, and within the gases and vapors what proportion of those would have exhaust air of sufficient temperature to be suitable for heat recovery? I'd like a general breakdown. Does anyone have any feel for that?

MR. STOTZ: Let me put it this way: It depends on the type of heat recovery that you use. Again, we have mentioned heat wheels. We have mentioned the heat pipe system. My leaning is towards the refrigeration type of heat recovery for several reasons:

Number one, in the heat recovery wheel, the maximum temperature that you can get is somewhat lower than the temperature you're passing over the wheel in your exhaust stream. This is not true of refrigeration heat recovery. You can take 70° air and you can translate this into a 115° water for heating other air. Therefore I lean towards the refrigeration type because you can raise the level of heat.

So I'm saying, really, that your exhaust from a chemical process, from laboratory hoods, even though it might not be at 70°, can be recaptured at a higher level, and therefore I think it depends on the type of heat recovery equipment as to what you can recapture.

Your bottom level of your refrigeration system is your water temperature, which normally is going to run somewhere in the neighborhood of 40° to 45°, whereas if you have a heat recovery wheel and you've got 0° air on the outside, you can recover, based on that zero. But again, I believe that your percentage gained, and your coefficient of performance is greater on the refrigeration cycle.

MR. GUY CUSUMANO (Hoffman Dust Control, Manalapan, New Jersey): I've noticed substantial amount of information that in many cases we are not looking for heat recovery. We don't need a whole lot of heat because our industrial processes are already generating so much heat within the plant, that our feeling is that getting rid of some of the heat with a ventilation system would make the plant a more liveable place. How about cold recovery?

MR. STOTZ: Again, as I mentioned, with the heat tubes or with heat recovery wheels, you can recover cooling.

MR. CUSUMANO: What about during the summer?

MR. STOTZ: Well, you would during the summertime. In other words, your heat tubes in the exhaust airstream would be able to provide some cooling between your indoor temperature of 76° and the 95° or 100° outside air coming in, so you would have some capability. It's rather limited help, so that it is questionable whether it is practical to use it. That was my comment in the talk here.

MR. CUSUMANO: Once you have added the heat built up by the fan it is even warmer than 76°. You have 76° and you add 12° with the fan; you have 88° something outside.

MR. STOTZ: That's right. It's very questionable.

DR. LANGNER: I would like to comment on your opening statements as far as standardization on laboratory hoods, about the difference between one industry wanting 50 feet and the university that wants 150 feet. I hope you will allow this latitude because it depends upon what material is being used in the hood and also on the safety factor required. In the university with the untrained students with all types of chemicals, they may very well need 150 feet per minute. Industry, using a more toxic material, could very well get by with 50 feet and still provide adequate safety. Another industry using another material may need the 100 linear feet to provide adequate safety to the employee. It depends upon how it is used. We use the term hazard--the likelihood of injury under the condition of use--and we must keep that in mind in all of our work.

MR. STOTZ: Certainly I've got to agree with you on this. However, the amazing thing to me was that the industry in which I would have expected the most toxicity was that which limited its coverage to 50 feet per minute, and those manufacturers that were using 90 and 100 certainly were not nearly as toxic. My only comment is that I think in certain cases maybe we're being a little bit overcautious. The university results were that in any laboratory

building of theirs, they used 100 percent outside air. It was a one-time-through proposition, you lost all of the energy that you put into treating the air.

MR. CAPLAN: I know this is not a meeting on lab hoods, but just to make a mountain out of a molehill, you aren't even talking about the supply-air hoods and all of the magic arrows and all of the twists of sheet metal that you find in the catalogs.

Another approach to that whole problem, instead of saying 50 is the number or 150 is the number, or that such and such a percentage of compensating air is tolerable, is a completely different approach, which a different committee of ASHRAE is working on.

MR. STOTZ: Agreed.

MR. CAPLAN: A challenge-type performance test, hopefully standardized to reasonably represent a challenge to the hood, finds that the hood controls the challenge, okay; and if it doesn't control the challenge, not okay. (And it doesn't make any difference how the salesman drew the educated arrows or what the percentage of compensating air is.

MR. STOTZ: Cap, immediately after this forum we had a joint meeting with several sections to decide what should be done.

CHAIRMAN HUGHES: I would like to clarify a point on your comment on the use of heat recovery in gases. In the area of processes which have gas temperatures that would be appropriate for recirculation, if you recirculate it you wouldn't want to have to cool also.

MR. STOTZ: No, that's not necessarily true.

CHAIRMAN HUGHES: If a person had a system suitable for recirculation, could he utilize heat recovery from the refrigeration system with less cost than would be required to put in a recirculation system? What are the economic tradeoffs?

MR. STOTZ: I think you would have to look at the individual application. There is no way you can set an exact figure. And again, you would have to look at what percent of air we are talking about trying to recirculate, what the outside conditions are that you would get it under if you did not recirculate, and what the conditions are that you would get from your cleaner. Undoubtly your temperatures would be higher. It's possible the humidity would be higher, but they still might be considerably lower than the outside air you would use as makeup air, so I think it is an individual application problem.

MAJ. RONALD D. BURNETT (Hg USAF/SGPA, Washington, D.C.): This concerns your comments regarding the possibility of reducing the air velocities and also staying in line with Mr. Caplan's comments. In the field, I've run into several situations where if you would look at the design criteria--and these are open-surface tanks--it would recommend something like a 100 to 125 feet per minute. In the actual field application you may only have 50, but air samples indicate that you are getting adequate control. Is anybody looking at these design parameters?

MR. CAPLAN: Yes.

MR. STOTZ: I think that is a part of what Cap was talking about where there are certain technical committees in ASHRAE that is looking at all of this now.

MR. BURNETT: You're looking at more?

MR. CAPLAN: Are these big plating rooms?

MR. BURNETT: A row of big cleaning tanks.

MR. CAPLAN: Do you want a speech on that?

CHAIRMAN HUGHES: Why don't you make a very limited comment on it. I think it is an appropriate question.

MR. CAPLAN: One problem with ventilation standards and one reason why those of us who have been burned on this same kind of a question keep wanting to go back to the proof of the pudding, is the contamination level. You set up a criterion for ventilation of an open tank, come up with a reasonably-based number; you get a room full of open tanks with ventilation, and a halfway decent makeup air distribution, and you have two other things working for you. One is that all of the air in the room is moving down towards these tanks, so we have a slang term we call "defense in depth." If you have one tank and any current carries contaminant 1 or 2 feet away, it gets into the room air. When you have a room full of tanks, the entire room airflow is toward those hoods; it starts to get away, then it doesn't get away and it gets turned around and it goes back in the hood.

The other factor that is working for you is tremendous amount of dilution. It is a recognized fact that sometimes you can get by with half the quoted standard ventilation rate if you have a lot of it, big air volumes, and reasonably good distribution. It's awfully hard to write that into a standard.

FOUNDRY OPERATIONS

George E. Tubich*

Abstract

The effectiveness of any exhaust system in controlling airborne contaminants is dependent on a proper air balance between exhaust and supply. Many areas in this country are being severely effected by natural gas allocations that prevent utilization of gas for air supply units. This is being further aggravated by the current energy policy feud. Recirculation may alleviate some of these problems.

The foundry industry is considered a heavy industry in regard to materials and tonnage handled per day. Few realize that in most foundries the tonnage of air exhausted each day far exceeds that tonnage of materials, methods, and processes. Silica dust is by far the major airborne contaminant. Thermal decomposition of a wide variety of organic additives can liberate significant quantities of carbon monoxide and other irritating gases.

Approximately 75 percent of all foundries employ less than 100 workers. Routine maintenance has been a perennial problem. Developing preventative maintenance programs for collectors and/or monitoring will present its challenges.

I think the foundry industry will certainly look with favor upon the concept of recirculation. In the past years, those of us who were concerned with protection of the health of the worker had a chore just to convince management to put in local exhaust ventilation. When we thought we had made so many inroads in this, we then had a bigger chore, to tell them they needed makeup air. Now we are confronted with the energy problem and all of its ramifications, and we are looking again now to the potential of recirculation.

The first thing I am concerned with is the use of the different foundry materials. The American Foundryman Society has a committee on occupational health. We are in the process of cataloging the different materials involved by operations; so far we've gotten through about three of them, and the list is by no way complete. In just molding and core making, 142 different materials are used, and in melting, 68 raw materials and supplies--ranging from A to Z, aluminum to zircon--are involved. In pattern making, there are 18 materials. So it appeared logical for me to go to this beautiful table Bill made up of 6 groups, and by the time I got half way through comparing my foundry list with the groups, I gave up. I said this job can't be done.

There were 14 materials in group 6; 16 in group 5 of nonrecirculatables; in the 2 to 4 groups, there were 45 and 53, respectively; and in group 1 there were 16. This amounted to about a hundred compounds that I went through out of a total of 228, and I just thought I wasn't going to get anywhere. Then I was stopped by the report which said that silica out of a foundry is not to be recirculated.

The foundry industry uses some 8 to 10 million tons of silica sand a year. There are some other materials that they refer to as nonsilica aggregate, all being zircon, chromite, and olivine, but this only amounts to about a quarter

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of a million tons. So our big problem is the silica dust. Personally I feel that if we can control the silica dust in the foundry we've gone a long way in all of the problems of the foundry, and I was certainly encouraged to have Cap bring up this point of the recirculation of silica dust. I think it can be done. I think Cap was maybe a little too kind talking about the failure, and how long it took to develop silicosis or have an effect from the silica dust. I recall he said something like 10 to 15 years. Well, I would say it is more like 20 to 25 years. So the collector could be off for 2 weeks and I don't think it would make much difference. It's going to be dirty, but there will be no immediate health effect.

The foundry industry is important to our economy, but it is going to pose some problems in attempts to work out recirculation. There are some 4,000 foundries in the country employing something like 300,000 people. It's the fifth largest basic industry, although 75 percent of foundries employ less than 100 people and many of them are still largely family owned. Now I'm using this figure of 75 percent or less than a hundred, but I think all industry in general follows the pattern like this. I think that regarding the 75 percent figure for all industries, they have a break point at 250 employees.

Our big problem is to try to help that small plant. Talking about preventive maintenance programs in the small foundry maintenance of production equipment is a tremendous chore. To think of preventive maintenance only for production equipment is kind of a rare bird, and then try to throw in preventive maintenance program for ventilation equipment--it's impossible. Some of these plants only have one maintenance person and it would be impossible for him to do all of these. As we are thinking about our program, it's got to be pretty foolproof and pretty simple so that we can help the small plants.

Cost was also discussed yesterday. This is going to be a very important thing when considering the whole; there is the cost of installation, the maintenance cost, and the monitoring cost. In some cases there is perhaps going to be need of upgrading the maintenance people to handle some of these systems. We heard yesterday about continuous monitoring. Each plant is going to have to be looked at individually, whatever its combination of materials are. There is going to be need for help from the suppliers of raw materials and equipment, from the official agencies, and consultants. A preventative maintenance checklist should be developed for each basic collector system. This could act as a guide for the small plant in required maintenance procedures. This is discussed in SRI's publication, reference IV, page 104.

The big problem in the foundries is that you get a terrific number of decomposition products. Molding and core making require 142 materials; in the iron foundry, they are pouring at 2,600°; they have many organic type additives in the molding sand, or they may be using a resin system for binding. The two significant decomposition products, I feel, are carbon monoxide and, with the resins, phenols. The AFS is considering several research projects now; that probably is going to be a big help to all of us in that they are going to try to identify more clearly what all of these compounds are that are coming out of the molds, and what effect they have on the health of the people. It will be a basis for us in looking at recirculation.

Most foundries are open buildings, which are disposed to cross contamination. You have ventilation in one place and some operation in another, and you've got one big open room. What are you going to try to monitor your control system to? Then each foundry will operate in a different way. I'm involved with a company that has four small foundries, all less than 50 employees. They

are all making essentially the same casting, manganese steel with the same range of about 50 to 100 pounds. One foundry is using silica sand with the furane binder. The other foundry is using olivine in a green sand system, with bentonite as a binder. The other foundry is using olivine urethane binder, and the fourth foundry is using olivine with phenol no-bake. so here are four foundries, all making the same thing, that are going to present four different problems.

In one of these foundries, which uses 100 percent olivine, the free silica content is less than one-half percent. It's a nuisance material. We can recirculate it and it turns out they have MDI as a binder. This is group 6. I think there is a great need to look over these groups. Currently there is some work going on in Cincinnati by NIOSH in the toxicology lab (they are in the second phase of it) where in animal experimentation, they have taken sand and coated half of it with the MDI resin and left the other half uncoated, and injected this in the animals, and the MDI actually inhibited the reaction of silicosis. We've got it in group 6 now, though, so there is a great need to look closely at all of these values; just because they are in group 6 doesn't mean automatically that they are out of the picture.

This work is going on. There is going to be some burnoff of the resin in the actual foundry operation. Air samples have been taken and this will be repeated to see how much reduction the MDI still has made in the inhibiting of silicosis. Similar work has been reported in Germany on the shell resins, finding that these also inhibit the reaction of silicosis.

Despite Cap's talking about that great ventilation manual, I think there is one thing that is missing in there--that is that I haven't instructed the foundry designer on something about the principles of ventilation. Somehow it seems that every foundry I go to the roof is covered with ceiling fans. One of these foundries that I was talking about is 6 months old, has got a building 100' x 200' and exhausting 200,000 cfm through ceiling ventilation. This is an example of an opportunity some of us have regarding this problem of recirculation--just reverse some of these fans and blow the air back into the plant. I think this can be done in certain selected areas.

John and I were working on a foundry, where I think they were exhausting a million cfm through ceiling fans, and we recirculated 300,000--we just reversed the fan blades and threw air in over the heat treat department. I look at this whole problem as a material handling problem. Foundries are handling more air in an 8-hour day than all of the tonnage of the castings and the sand, so to me this is a material handling problem and I think we need to give it attention as we are handling any other material. And I feel we will come up with some answers.

I hope we are not led astray by all of the things that we may have to do in considering recirculation. So let's keep the problem in context.

DISCUSSION

MR. JAMES C. BARRETT (Department of Public Health, Lansing, Michigan): George, if we can provide systems for recirculating venting these materials, what is your view? Is it optimistic or pessimistic on continuing maintenance of the systems so that they stay at somewhere near design performance?

MR. TUBICH: Well, I changed my whole talk a little bit in there. I first said when David called me about this meeting, great, this is just what we need, and my enthusiasm was way up here. Then I got looking down over the whole bit and ended up down here. I don't know. I have been associated with foundries so long that I think the maintenance bit is going to be a tremendous chore. We may have a recirculation system that is working beautifully for the first optimum period, but after that, I don't know. Then there are too many different gases that are involved. I think we can handle the particulates, but the foundry is going more and more to the chemical systems and these are going to pose other problems. I'm a little bit discouraged on what I have seen in some foundries in the past. The very first ones that say they need to clean the place up have a poor attitude on maintenance. One of them I think is the classic example. I asked them at one foundry how the dust collector was working. "Great," he said, "the greatest piece of equipment we've ever bought. We haven't had to look at it in 4 years."

So it's going to be a rough one, but I have been with them for 35 years and I don't have much time left, so I think I'll stick with them and try to help them.

MR. JOHN M. KANE (Industrial Consultant, Louisville, Kentucky): George, I have one other comment, not a question. In local exhaust ventilation you don't talk about a system; in the foundry you'll probably have 12 systems. If you're going to monitor each system, and when we think about the cost and complexity of monitoring that was discussed yesterday, let's keep in mind that it is not just one installation. The cost to monitor each one may be another argument for monitoring workspace instead of the effluent.

MR. TUBICH: In these 12 systems there are probably going to be 12 different materials, so you're going to have 12 different monitoring systems; this cost is an important thing to keep in mind.

MR. KANE: The New York study suggests that the average system could be about 8,000 cfm. The reheat value of 8,000 cfm against a very complex, expensive monitoring system would have little economic appeal.

MR. GUY CUSUMANO (Hoffman Dust Control, Manalapan, New Jersey): Speaking to what John just mentioned concerning recirculation, it occurs to me that of the systems that I have seen over the years, the one that was best maintained was one that was put in on a recirculation basis over our objections. The reason it was best maintained is that typically if a maintenance man never gets around to emptying the hopper and you go to see it, you would see more times than not that they are blowing dust outside. When that system coming inside the personnel area starts to spew dust, there are a lot of problems. Somebody will come around and fix the thing, so maybe we have a built-in monitor.

MR. JOHN T. TALTY (NIOSH, Cincinnati, Ohio): Do you think that the workplace monitoring, as opposed to or in addition to effluent monitoring of cleaning devices or recirculation systems, is a good basis for the kind of engineering design that you would like to see in foundries?

MR. TUBICH: Yes, I go along more with the concept of monitoring--you might say essentially the work station--and then your design of the system you are going to put in X cfm to control this molder, or whatever it is, from the particular contaminant. So I lean toward the monitoring of the individual or the area. You may have 15 shell molding machines and you're going to put ventilation on them. You might want to monitor a couple of them to see that you are within the TLV range.

MR. TALTY: It seems to me that it is contrary to good engineering practice to base your design on that kind of monitoring.

MR. TUBICH: Well, no, I don't think so. I mean actually the design is based on providing a healthful place for this guy to work, and this monitoring is just going to be a guide to say whether you are in that area or not. It's more; it's a check of the ventilation design.

MR. KNOWLTON J. CAPLAN (Industrial Health Engineering Associates, Inc., Hopkins, Minnesota): Another advantage to the workplace monitoring is that the re-circulated air is not the only contributor to the contamination at the workplace. There is the performance of the hood itself. There are the miscellaneous uncontrolled sources. There is perhaps malfunction of the general ventilation makeup air system. The workplace monitoring includes other factors of equal or perhaps greater importance than the concentration in the re-circulated air.

MR. TALTY: Just one further comment. I'm not saying you don't need to do that but I am saying it seems to me if you want to properly design a system you have to have some kind of a feel for what it can or cannot do and it can't be just the end result.

MR. TUBICH: Yes, I agree.

MR. ROBERT W. MODRELL (Goodyear Tire and Rubber Company, Akron, Ohio): Whether you identify the monitor or not, because the requirement for monitoring an employee is going to be pretty well established by OSHA regulation, and this will have to be done, too. The employee exposure is going to have to be evaluated, whether or not you evaluate the equipment.

MR. TUBICH: One of these little foundries I'm working with--200,000 cfm exhaust--had the attitude, "let's go out and buy the makeup; we're going to have it perfect." They bought 250,000 cfm makeup air; they can't use it because of a gas shortage.

MR. BARRETT: Again, I just wanted to comment, George, I wanted to be sure we are not talking about workplace monitoring alone. There is still some monitoring that can be done in the ventilation system and should be done, and static pressure measurements, air flow testing, picture, fan belts and pulleys, and so forth. I think the two go together.

MR. TUBICH: And then you are going to have to monitor the system anyway to meet an EPA requirement of what you are kicking outside so you're going to have a duplicate check.

MR. BARRETT: I wanted to be sure we weren't overlooking that.

AN INDUSTRIAL LOOK AT AIR RECIRCULATION

Phelps S. Eshelman*

Abstract

Not too many years ago, it was common practice to throw away all exhaust air and replenish it with makeup air. With the cost of utilities on a steady increase, the cost of operating makeup air systems has become prohibitive. As a result, programs for the recirculation of air have been started. Where possible, exhaust air should be recirculated or the heat removed before it is exhausted. If industry does not start voluntary utility conservation programs, the Government may issue regulations controlling the use of utilities. This could affect production and possibly shut industry down during the colder months.

The upgrading of the employee's environmental working condition has become quite apparent in recent years. We have seen new manufacturing plants being built which are totally air conditioned. In most cases, this is being done not for the product but for the employee's comfort. In fact, we believe that a proper working environment, the cost of operating the equipment, and utility conservation will be big goals for the coming years.

All of us associated with industry are being guided by a new set of rules. Since the Government passed and started enforcing the Occupational Safety and Health Act (more commonly called OSHA), it has, for the first time, set definite in-plant environmental controls. To insure these goals and to provide proper working environments, long-range ventilation programs will be required. Such programs will require the installation of exhaust ventilation systems to control contaminants generated and the installation of supply or makeup air systems to replenish the air being exhausted. However, industry faces a dilemma when it comes to improving the in-plant environment. On one hand, we have continuing programs to improve working conditions, while on the other we are caught in a cost squeeze.

We have gone through various stages in our efforts to improve the in-plant environment. Not too many years ago, the only thing put into buildings to improve man's working environment was some type of heating system. This started with the radiators along the outer edge of the building and improved to the unit heaters hung high in the upper part of the building.

This type of system was adequate until industry started using larger volumes of exhaust to control contaminants. The result was that large volumes of air were being drawn through windows, doors, and openings in the walls, creating unwanted drafts. Soon employees working near the openings became uncomfortable. With the introduction of forced air heaters in homes, man soon started demanding a better working environment.

One of the worst conditions resulting from the large volume of exhaust was the severe vacuum it produced in the building. Besides the unwanted

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cold drafts, exhaust systems were derated and contaminants were not being controlled. Engineers soon found the solution to the problem and the concept of providing makeup air was started.

This type of system, for the first time, started delivering air evenly to the work areas and controlling the in-plant environment on a year-round basis. It also started for the first time to provide the makeup air required to keep the exhaust systems operating properly.

When exhaust systems were installed in the past, little or no attention was paid to the cost of replenishing the air being exhausted. This was primarily due to the cost of tempering the makeup air, which in the past has been cheaper than trying to recirculate air or reclaim the heat from the exhaust air. Today this is not longer the case. With the cost of utilities steadily increasing, the cost of operating makeup air systems has become one of the most expensive operating costs in many industrial installations.

If makeup air systems are reduced or eliminated and buildings allowed to operate under a negative pressure, it will put an increased load on existing exhaust fans, causing them to operate at a reduced capacity. During the winter months, this may create some undesirable working conditions by not properly controlling contaminants and increasing unwanted cold drafts. To keep the long-range programs for environmental control active, recirculation of exhaust air must be considered.

When starting any energy conservation program for air recirculation, a step-by-step procedure should be developed and followed very closely. In order to make a program of this nature successful, the first thing that must happen is to get the backing of top management. Without this, it will be difficult, if not impossible, to get a program started. To get this backing, a preliminary survey should be made of the plant to determine which systems should be considered and the potential savings. This program should then be presented to management, explaining that monies will be required to purchase equipment, rearrange systems, and even to redesign and reinstall systems in order to conserve utilities. Once they agree that a program of this nature will work, a successful project can be started and carried out to completion.

For years we have installed cooling towers to recirculate water. We would not think of building a new powerhouse without a cooling tower to recirculate the water used to cool bearings and so forth. In a sense, steam is recirculated, since condensate is usually returned to the powerhouse for regeneration. In many areas we have done a good job of conserving utilities, while on the other hand we are exhausting millions of Btu's that could be reused.

In the initial planning, a complete survey should be made of the plant, including the roof. The roof survey is necessary to determine the accessibility of stacks and the availability of space to install new equipment.

Before starting a program of recirculation, a survey of existing systems within the building should also be conducted, to be sure they are handling the minimum amount of air required to control contaminants generated. If systems are found to be operating above designed parameters, corrections should be made to adjust the air volumes.

In the past, many exhaust systems were installed merely because equipment was available, with little or no attention being paid to the volumes of air being handled. In the initial phase of an air recirculation program, such systems should be reengineered and reinstalled, if necessary, to reduce the volume of air being handled. The plan should also include a calculated difference in the exhaust and supply quantities, to be sure the building is kept in a balanced or slightly positive condition.

The use of general exhaust ventilation systems, which require larger quantities of air than local exhaust systems, should be kept to a minimum and eliminated where possible. Where general exhaust systems are currently being used, such areas should be carefully studied to see if it would be possible to use local ventilation. Substituting with such systems will reduce both the volume of exhaust air being used to control the contaminants generated and also the volume of makeup air. Along with the general exhaust system, each individual operation should be carefully surveyed to determine if a different type of ventilation system could be used to reduce the volume of air being exhausted. One such example would be on plating or open-surface tanks, where push-pull ventilation could be used.

When using push-pull ventilation on open-surface tanks, the volume of air required to control the contaminants can be reduced by approximately 50 percent over conventional exhaust systems. This method uses a small volume of supply or push air discharged through slots or nozzles along one side of the tank, or on wider tanks, through a header along the center of the tank, opposite the exhaust systems. This allows the supply air to push the contaminants toward the control of the exhaust hoods. By doing this, the volume of air required to control the contaminant can be reduced. When using such a system, care must be taken to be sure that interferences between the push air and exhaust hoods are kept to a minimum. If this is not controlled, fumes can be blown past the exhaust hoods and into the work areas.

Another method of using less air to control the contaminants is with a system known as the low-volume, high-velocity exhaust method (LVHV). The low-volume, high-velocity exhaust system is designed to capture contaminants at the point of origination and has been quite successful throughout industry. When using such a system, a hood or other device is installed around the tool or operation to confine the contaminant and capture it before it becomes airborne and is allowed to get into the general airstream. An example of this would be a hood around a portable grinding tool. The low-volume, high-velocity exhaust system may use 100 cubic feet of air per minute (cfm) with a slot velocity of 10,000 to 20,000 feet per minute for each grinder, where the conventional exhaust hood for a grinding operation may use 150 to 200 cfm per square foot of hood opening.

In any energy conservation or air recirculation program, the use of such systems and others to reduce the volumes of air being exhausted must be considered. In the original or initial phase of the program, any system that can be redesigned to reduce the volume of air being handled should be investigated.

Although the wet and dry bulb temperatures and the effects of air motion are generally understood by engineers, radiant heat or high-energy radiation is generally misunderstood by many of them. When starting a pro-

gram of air recirculation, radiant heat must be controlled; otherwise, temperatures in the work areas around hot operations cannot be properly controlled. Unlike convected heat, radiant energy cannot be controlled with dilution ventilation.

Radiant heat, which is an infrared energy, is similar to light rays, and it travels in a straight line until it is absorbed or reflected. In any utility program, the use of radiant heat shielding will be necessary in order to protect the employees. By proper selection and placement of the shielding, the heat can be reflected away from the workers and back into the process.

Once every effort has been made to reduce the volumes of air required to control the contaminants, then consideration should be given to recirculation. In a number of States, codes have been enacted which restrict the recirculation of air from operations. Many codes state that air cannot be recirculated which contains greater than 10 percent of the Threshold Limit Value (TLV) of the contaminant being handled. From an industrial hygiene point of view, we believe this is a good limit since it will protect the health of the employees and reduce the possibility of contaminant buildup in the general working areas.

When it has been determined that a system contains less than the limit established by Federal or local codes, the air can be recirculated directly back into the working areas. When installing such systems, it is usually required that a damper arrangement also be installed, so that the air can be dumped to the exterior of the building should something happen and the air become contaminated above the established limit.

If the air being exhausted from either a local or general exhaust system is from a clean hot operation--for example, a glass manufacturing operation--it many times can be recirculated without any heat reclaim equipment. Such systems usually require a damper arrangement and additional fans. With this arrangement, the hot air can be diverted during the summer months and mixed with outside air during the winter months before it is delivered back into the work areas. Instead of exhausting the air to the atmosphere during the summer months, every effort should be made to use it to preheat or dry parts in a productive operation. Designers should in all cases try to develop air recirculation equipment or systems that operate on a year-round basis.

When air is dumped directly back into the plant from an exhaust system, care should be taken to prevent the creation of unwanted drafts which will effect the capture function of the exhaust hoods. At times it may be desirable to discharge this air back into adjacent areas and draw it through the work area where the exhaust systems are located.

When exhaust systems are handling a contaminant, every effort should be made to clean the effluent and return it to the work area. In a study recently completed by the Southwest Research Institute for NIOSH, approximately 500 specific chemical substances were examined to determine if they could be cleaned before being recirculated back into the work areas. The report divided the chemicals into five separate groups. The study indicates that one group is not suitable for recirculation and should not be considered. Also, items which have a ceiling value or are highly toxic usually

are not desirable for recirculation. As mentioned previously, it is crucial to clean the effluent so that it does not contain greater than 10 percent of the TLV. Instrumentation is being developed to scan ductwork and measure the contaminants in the effluent to be sure that it is within tolerable limits. When handling contaminants, it is essential that a method be incorporated so the effluent can be dumped to the atmosphere if the cleaning mechanism fails.

In areas where heat and contaminants are generated and it is not desirable to clean the effluent, every effort should be made to reuse the heated air on operations where recirculation can be used without contaminating the air being provided for employees. An example of this might be heat taken from a quench operation or heat treating operation, where the air could be recirculated back to preheat the parts before they enter the ovens. In areas where the operation is confined to a hood, it might be possible to introduce raw outside air instead of exhausting treated building air.

The method of removing the heat from the air before it is finally exhausted can be used in many areas. It may often be necessary to change or substitute operations in order to get the most benefit from recirculation of air containing contaminants and heat. Contaminated air should never be recirculated into areas where personnel can be exposed. If such recirculation is employed, for example in an oven, and it is necessary to enter the area for any reason, a purge cycle or personal protective equipment should be required before personnel are allowed to enter the contaminated area.

Before using heat exchangers to remove the heat, we believe every effort should be made to 1) recirculate clean air back directly into the plant; 2) clean the effluent with an appropriate air-cleaning device and recirculate; or 3) recirculate contaminated air back over the process. After all attempts have been made to use the air directly, then consideration should be given to the use of some type of heat transfer mechanism. This might be the conventional heat wheel, a runaround liquid system, an air-to-air recovery system, or it may be as sophisticated as a waste-heat boiler. These are just a few examples of heat recovery equipment.

Each system should be studied separately and the equipment that will give the greatest return should be selected. We believe that before any air is dumped to the atmosphere, every effort should be made to remove all the heat possible and reuse it at some operations within the plant. For example, in the winter months there is no reason to operate a cooling tower. Instead, the hot water might be passed through coils and the incoming air preheated. By doing this, the heat would be removed from the water and transferred through the coil to preheat the incoming air. Also, on high-heat-generating operations where it is not desirable to dump the air back into the operation, the heat could be transferred to a liquid and pumped to other parts of the building. There the heat could be transferred for use either in heating incoming air or in processes requiring the additional heat. In these transfer processes, one is limited only by his imagination.

In any metal working operation in which heat is generated, there is a potential savings if the exhaust system can be reclaimed in some manner or the heat removed from it before it is exhausted to the atmosphere. As

mentioned previously, heat reclaim or air recirculation usually was not considered in the past because it was cheaper to supply makeup air than it was to install heat recovery equipment. Today we are in a whole new ballgame. With natural gas supplies being depleted each year and the cost of utilities to operate the plant on a steady incline, the cost of replenishing the makeup air becomes very expensive. If heat recovery or energy conservation programs are not started, we may soon find that we may not have necessary utilities to keep industries operating. If such programs are not started on a voluntary basis, the government may intervene and put mandatory controls on industry requiring such programs.

As we have seen in the past, the government usually does not fully understand all the requirements and will put such restrictions on industry that programs of this nature will be expensive if not impossible to meet. I believe it would be better for all of industry if it would start a voluntary program of energy conservation and avoid a mandatory government program.

Every effort should be made to lay out a good utility conservation program for air recirculation in all industrial operations, and to get management's support in order to be sure the program will be carried out to its fullest. If this is done, then there is no reason to believe that industry will not have the utilities required to keep it operating for many years.

DISCUSSION

MR. WILLIAM J. ASTLEFORD (Southwest Research Institute, San Antonio, Texas): You alluded to the fact that the particulates that were contained in Group 3 were not suitable for recirculation. I don't believe that is entirely the case. Those particulates that are contained in that group may have failed to produce a documented odor or irritant threshold as determined by our literature survey, and that may be the only factor that was involved in their inclusion in that group. They are not necessarily excluded from recirculation.

MR. ESHELMAN: Well, I got the wrong concept from reading your report, because when I read that report, the way it was laid out, I got the idea you people were saying no, you do not touch this group.

MR. ASTLEFORD: I have had a feeling that other people here in the past 2 days have had that impression also, and I thought that I had cleared up that point yesterday, when we discussed the five toxicity criteria.

MR. ESHELMAN: I'm probably going to say something and step on some toes, but this is how I feel about it. When a report of this nature is written and if people in industry get this idea that you're saying that these contaminants over here should not be considered, sooner or later somebody picks it up, and--a lot of times I don't think people in research organizations fully understand how industry has to operate, and that once something is put into print we are going to have to live by it sooner or later, and this....

MR. ASTLEFORD: The point that I was trying to make is clearly stated in the report as to what the qualifications were for those particulates that are in Group 3. They are not necessarily eliminated per se from potential recirculation.

MR. ESHELMAN: As I say, I got the wrong concept from reading your report.

THE RECIRCULATION OF EXHAUST AIR

R. R. Langner and G. J. Roush*

Abstract

The decision to use recirculated air should be made for each individual operation. The final decision should be based on data gathered under use conditions. The SwRI proposed grouping of chemicals has little merit for determining if recirculation of exhaust air is a feasible engineering approach for conserving energy and the protection of employee health. Data gathered in a vinyl chloride copolymer film extrusion plant demonstrates that acceptable workroom concentrations can be maintained with 90 percent recirculation of air. Energy savings of \$30,000 per year are achieved.

I have been asked to represent industry's view. My comments are those of an industrial hygienist and probably represent a near consensus of industry's views. Industry welcomes guidance and aid from any and all sources. Likewise, it opposes excessive regulation and unrealistic standards. We request performance standards which can be met by selecting alternate methods available for individual plant situations.

The rationale used in the final report of Contract No. CDC-99-74-96, SwRI (Southwest Research Institute) Project No. 02-4011, "Development of Criteria for the Recirculation of Exhaust Air," by William J. Astleford, must be challenged as being unrealistic. SwRI accepted the philosophy prevalent today that no risk is permissible in the work environment and that the ACGIH TLV guideline listing, which has become the legal permissible exposure level under OSHA, is a no-risk level. The statement "... These criteria must ensure that, as a result of recirculation, the contaminant concentration anywhere in the workplace does not exceed the threshold limit values ..." clearly demonstrates a lack of understanding of both the ACGIH definition of TLV's and the OSHA legal definition. In both cases the concentration of contaminant is the 8-hour time-weighted average (TWA) exposure to the employee. The workplace concentration may well exceed this value if the employee limits the time spent in the area of high concentration.

In grouping the chemicals, the consequence of chronic overexposure has been given little or no consideration. For example, carbon tetrachloride, ethylene dibromide, and methyl-2-butyl ketone are in Group 1, which allows recirculation, whereas chlorobromomethane, chloropicrin, chloroprene, and dichlorodifluoromethane (Freon 12) are in Group 2. Calcium carbonate (limestone) and cellulose (paper fiber) are placed in Group 3 along with Diazinon, Dibrom, Dieldrin, and glycerine. Groups 2 and 3 may be recirculated with "... suitable monitoring and cleaning devices." Judgment, based on experience, is absent in such ratings. The use of monitoring equipment or redundant air handling devices on nuisance materials, such as glycerine, would be a wasteful use of capital and other resources.

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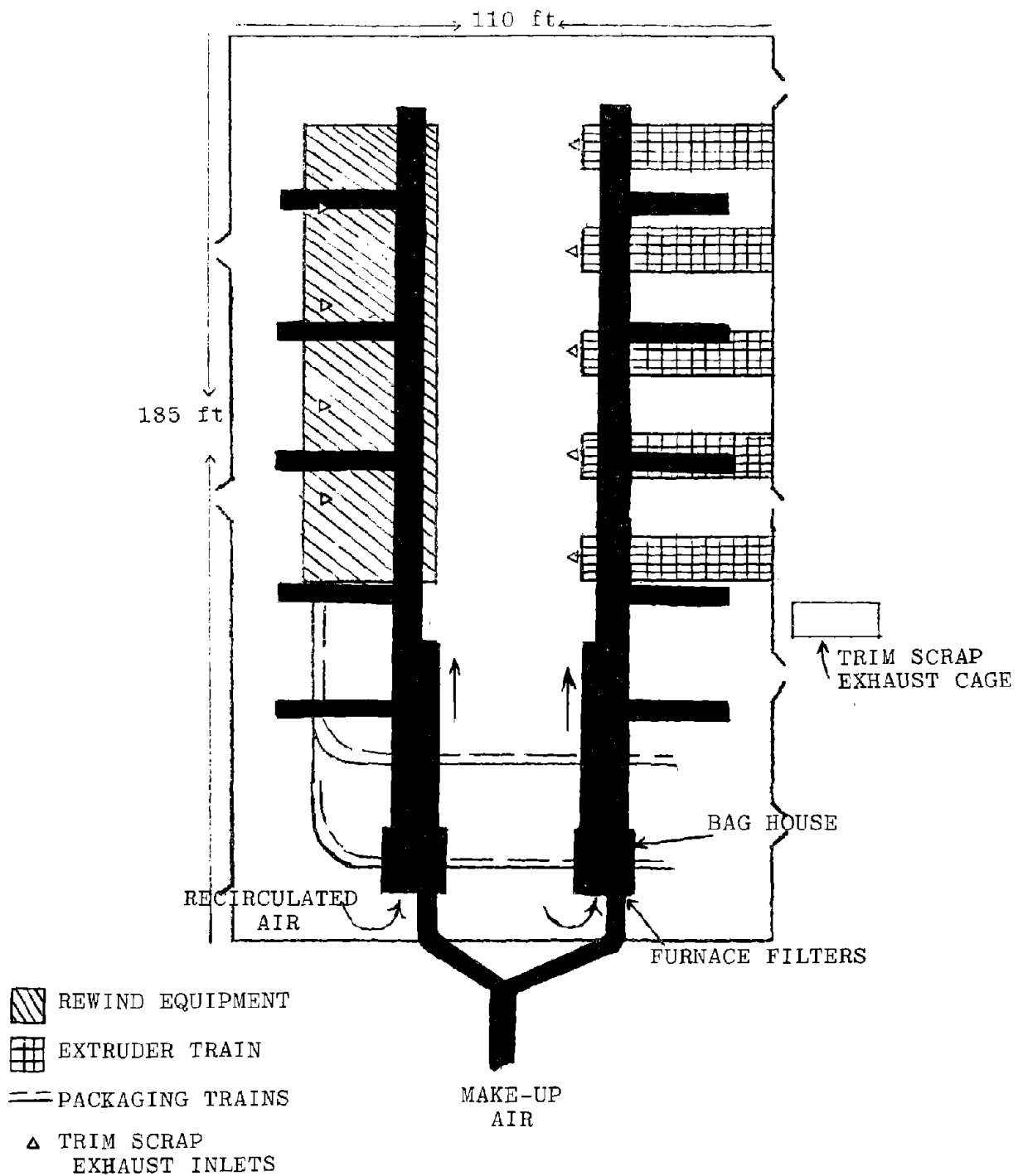


Figure 1. Main operating area of a copolymer film extrusion plant (350,000 cubic feet of air space).

Rather than continue the criticism of the SwRI report, it is pertinent to examine data from an actual plant which used a Group 6 material in its operation. The process to be described is the extrusion, rewind, and packaging operation of a copolymer film plant. Residual vinyl chloride is present in trace amounts in the copolymer and trace amounts could be expected in the workplace. The area contains five extruders and rewind machines, which feed into a single packaging operation. The sealed boxes leave the area on a conveyor to the warehouse for shipping.

Figure 1 is a drawing that shows the location of the various pieces of equipment. The plant operates 24 hours a day, 7 days a week. Employees rotate their assignments each day. Their time is spent in the extruder area, the rewind area, and the packaging station.

The area of concern contains 350,000 ft³ of tempered air. The air supply system was measured in detail. The airflow in the combined ducts is 66,000 cfm. Approximately 10 percent--6,750 cfm--outside makeup air is introduced. Another 7 percent--4,550 cfm--of air is recycled from the warehouse area. The air scrubber system consists of a coarse furnace filter followed by a bagfilter to remove the small particulate matter. Particulate free air is essential in a film operation. Energy savings, using \$2.18/1,000 ft³ of natural gas, amount to \$30,240/year for this operation.

The amount of contaminant released during extrusion was also measured. Table 1 shows the amount of vinyl chloride and vinylidene chloride released per extruder. These values were determined by measuring the air inside the extruded tube after 5 hours of continuous operation, assuming that an equal quantity was released from the exterior surface of the tube. Due to the low levels found inside the tube, migration through the film was assumed to be insignificant.

Table 2 presents the workroom area concentrations as found at various sites and inside the main ventilation duct. These measurements were obtained using a portable gas chromatograph, which allows immediate onsite analysis and eliminates the errors common to adsorption and desorption techniques.

We are all in agreement that worker health is the goal of standards. To determine if the health of these employees was being safeguarded, the operators were asked to wear personal sampling devices that collect the air contaminants on activated charcoal. After completion of the workers' 8-hour shifts, the carbon was desorbed with cold carbon disulfide and analyzed by gas chromatography. Table 3 presents the data obtained from such studies on several different days. Although detectable amounts of vinyl chloride

Table 1. Chemical vapors released at the extruder in a copolymer extrusion film plant

	mg released pound of resin extruded	mg/hour released
Vinyl chloride	0.003	1.6
Vinylidene chloride	0.037	20.4

Table 2. Work-area concentrations measured (ppm v/v air)
in a copolymer film extrusion plant

Work area sampled	Vinyl chloride	Vinylidene chloride
Extruder	ND	ND
Rewinders	ND	ND
North end of operating area	ND	ND
South end of operating area	ND	ND
Main ventilation duct	ND	ND
Maximum sensitivity of gas chromatograph at analytical conditions used, ppm v/v	0.1	0.1

Table 3. Results of personal samples taken in a copolymer extrusion film plant

Operator number	Job description	Date sampled	Conc. (ppm v/v)	
			Vinyl chloride	Vinylidene chloride
1	Film train operator	12/23/74	0.1	0.3
2	Film train operator	12/23/74	0.1	ND
3	Film train operator	12/31/74	ND	ND
4	Film train operator	12/31/74	ND	ND
5	Film train operator	01/24/75	ND	ND
6	Film train operator	01/24/75	ND	ND
7	Packaging train operator	02/07/75	0.2	ND
8	Packaging train operator	02/07/75	0.2	ND
9	Packaging train operator	02/14/75	ND	ND
10	Packaging train operator	02/14/75	ND	ND
11	Packaging train operator	02/21/75	ND	ND
12	Packaging train operator	02/21/75	0.1	ND
13	Utility man	02/28/75	ND	ND
14	Utility man	03/07/75	ND	--
15	Foreman	02/28/75	ND	ND
16	Foreman	03/07/75	ND	0.9
Maximum sensitivity of gas chromatograph at analytical conditions used, ppm v/v			0.1	0.1

and vinylidene chloride were found on occasion, detectable quantities were not found on most days. However, levels found were markedly below standards.

What does this study demonstrate?

(1) Given a performance standard--i.e., 1 ppm, 8-hour TWA, with a 15-minute peak of 5 ppm--this plant has devised methods to control exposure which far surpass the desired legal goal.

(2) Continuous monitoring systems and redundant systems are not necessary if management is prepared to shut down before exposures exceed acceptable levels.

(3) Energy savings can be achieved by allowing industry to innovate and apply available technology to solve problems.

(4) Most important of all, it is not realistic to issue generalized statements or criteria concerning acceptable operating procedures. Give industry a performance standard, and it will meet the standard by available methods that are feasible for the processes of a given plant. Industry's problems are best solved on a case-by-case basis, not with rigid standards.

In summary, this study has demonstrated that recirculated exhaust air is an acceptable engineering tool to conserve energy, and that industry, given the opportunity to use alternate approaches, can achieve the desired performance results and maintain an acceptable work environment.

DISCUSSION

MR. KNOWLTON J. CAPLAN (Industrial Health Engineering Associates, Hopkins, Minnesota): I have wrestled with this N.D. notation myself. How would you handle it when you have taken samples of varying lengths of time? The sensitivity of your analytic method may be a number, like .1 mg or 2 mg, or whatever, but when you translate that back into the variable air volumes that you have sampled in your table, you have a different footnote for every N.D. in the table. How do you cope with that?

DR. LANGNER: In our in-plant reports we have another column and list the level of sensitivity, dependent upon the amount of air that has been drawn through the sample, because you are very right, the sensitivity will vary with the amount of air that has been sampled.

MR. WILLIAM J. ASTLEFORD (Southwest Research Institute, San Antonio, Texas): Ralph, could you comment on the control methods that you used to achieve these results?

DR. LANGNER: Yes, I would be happy to. There are many different regulatory agencies today. I think we have some 23 in existence today, which helps us operate our plants. The solution to this particular problem is actually multifaceted. FDA has certain regulations for films, such as this, which goes into food use. OSHA has certain regulations, the 1 ppm, and so on. For example, in the resin manufacturing plant, we have 25 people who must wear respirators to meet the OSHA standard. And let me assure you they are not happy doing that. To solve the FDA problem, to solve the OSHA problem in the rest of the plant, the best solution was to reduce the vinyl chloride in the polymer to a level

whereby the resin dryer operator, the packager, all of the rest of the people associated with this, and the many purchasers of our resin product would not have to worry about the vinyl chloride problem from the regulatory agency standpoint. The solution was to put energy back into the process where the original resin was made, and remove the vinyl chloride at that particular step.

As the data showed, there is a small trace carryover; this is why we ask for latitude, so that we can solve the problems by the best method possible for the total system.

MR. ROBERT W. MODRELL (Goodyear Tire and Rubber Company, Akron, Ohio): Do you have any figures on the vinyl content of the resins you were using?

DR. LANGNER: I know the vinyl chloride content of the resins which we produce are below detection by the analytic procedures available today--approximately 1 to 2 parts per million in the resin.

MR. MODRELL: This resin mentioned here released 3,000 mg of resin; was that comparable, say 1 or 2 ppm?

DR. LANGNER: Yes, in the resin.

MR. MODRELL: What was the ratio of recirculated air?

DR. LANGNER: This was 90 percent recirculated.

My good friend from Goodyear is also in the PVC business and I'm sure he is very interested in this type of thing. Here again is another case where industry certainly does not mind sharing this type of health data. Any way we can help one another in matters of health, we're more than willing to do so.

MR. BARRETT: Just to clarify what I thought I saw in the slide, you had a number of little exhaust systems shown at the extruders and the reels. Did those go directly to the outside?

DR. LANGNER: No, those went over to the reclaim station for reclaiming the film, so actually that was exhausted back into the warehouse and then part of the warehouse air gets recirculated back into the system.

MR. BARRETT: It's all part of the same?

DR. LANGNER: Yes; the warehouse opens to the outside for loading the trucks and boxcars. I thought Mr. Kane did an excellent job yesterday of indicating that when you have large doors you have a tremendous amount of makeup ventilation.

MR. CAPLAN: Was your ventilation design based upon these emissions rates of vinyl chloride and some kind of a dilution calculation, or how did you arrive at that?

DR. LANGNER: No. I'm not really sure how this was done. This type of operation has been in existence for 25 years, so that there was a lot of data for the design, but the design was not based on these data. These data were Johnny-come-lately.

MR. CAPLAN: Sort of evolved?

DR. LANGNER: Right. This is the type of check we make on the system on a routine basis and it is not as regular as we would like.

MR. JAMES C. WOODLING (Goodyear Tire and Rubber Company, Akron, Ohio): The fact that you are recirculating 90 percent of it raises the question in my mind, why are you ventilating at all?

DR. LANGNER: Because with the design of the building, there is no way we can prevent it.

MR. WOODLING: Well, rather than put it duct work and individual process pull-off points, why is it that you are not putting in 10 percent makeup air and exhausting it all from the other corner? Wouldn't you accomplish essentially the same thing?

DR. LANGNER: I think our data today would show that probably the makeup air really wouldn't be required under the present operating condition--present operating condition being that there is nothing in the warehouse; the product goes straight from the production line into the truck, so that we have a lot of open space. The building was designed and put into operation with the concept that a lot of these doors would be closed, where in fact they are not.

MR. ROGER L. WABEKE (Ford Motor Company, Dearborn, Michigan): I have two questions. Is your frequency of employee monitoring greater than that required by the OSHA standard at point of recirculation? Secondly, it wasn't clear if there was a monitoring probe in the return ducts.

DR. LANGNER: We do not have continuous monitors in this particular plant because our repeated monitoring has demonstrated that this would not be a practical expenditure.
Now what was your first question?

MR. WABEKE: Was the frequency of employee monitoring greater than OSHA standard?

DR. LANGNER: Because of the findings here, this particular operation does not come under the OSHA standard. We are well below the 1/2 ppm which the regulation calls for, so that this does not require the frequent monitoring that the resin-producing plant would. In the resin-producing plant we have continuous area monitoring and then we also have continuous personnel monitoring--we try to catch each job classification at least once a month.

MR. RICHARD J. COOMES (The Proctor & Gamble Company, Cincinnati, Ohio): Ralph, just as a point of curiosity, have you had any employee relations problems over the concept of recirculating the air?

DR. LANGNER: No, we have not. Our biggest employee relations problem has been on forcing the men to wear respirators when they didn't feel it was necessary.

MR. JOHN T. TALTY (NIOSH, Cincinnati, Ohio): Would you say that recirculation of exhaust air is a trend in your industry?

DR. LANGNER: Very definitely, because of the energy savings. Keep in mind that in the chemical industry the trend is for outdoor plants, so that

you don't get into this problem. Another trend which is being widely used today is to use small, tempered, control rooms where the man spends most of his time, and then when he leaves the tempered control room, he puts on the protective gear for the area into which he is going. This is the real advantage of the continuous air monitor. The employee knows what is in the area before he ever enters in it, so he can go properly prepared, protected, so that he doesn't have to be exposed. Of course the OSHA standards requires us to take measurements as if the man were not protected.

MR. THOMAS J. CIVIC (Bethlehem Steel Corporation, Bethlehem, Pennsylvania): What are your feelings about publishing a rigid listing of contaminants recommended for recirculation and those not recommended for recirculation?

DR. LANGNER: I have lots of strong feelings. I'm known as the Barry Goldwater of Michigan. I think you have detected that I believe very strongly in letting industries solve their problems, but I do insist that industries solve their problems and not walk away from them. I picked the particular example discussed in my presentation because I wanted to show that it is possible to take known carcinogens and, with other alternate methods, to use recirculated air. Phelps mentioned earlier that management has to be behind you. We are a very fortunate company because we have a very aggressive management as far as health and safety matters are concerned. We have a very aggressive State Health Department and Labor Department. We are very supportive of their effort. We are very proud of the people we have in our State and I am making that statement after just having a State Labor Inspector spend three months in our Midland Michigan plant. He found many things. We are going to receive several citations. I'm still very proud; all this says is that another set of eyes looking at the situation sees things a little differently. We have had visits by several of the State Health Inspectors. We have had the State Health Inspector in on several occasions, dealing again with our carcinogens, and again I have nothing but compliments for the way in which these people conduct themselves. Most of your speakers today are graduates of the Michigan Department of Health and I think it attests to the type of situation which we have there. In fact, I was kidding Jim that after his speech, I have a feeling that he probably did more to move industry into Michigan than any other type of speech. This is great. As I say, we welcome aid from any source.

MR. WOODLING: Dr. Langner, would you be willing to comment on the comment that you had made relative to the necessity of using respirators in operations. As I understand it, OSHA respirators are only allowed to be used where engineering techniques, available status of the art will not permit, or where there is no known technique available to reduce the sources of contaminant. Have you been able to convince OSHA that you haven't been able to do this?

DR. LANGNER: No, we have not been able to convince OSHA and we have no alternative. You go in for a variance if you have a method that is

equal to or better than OSHA's. But there is no way that you can convince any person that if the law says you will wear a respirator when you are above a certain level, that it is equal or equivalent if it is above that level, and that you have data to prove it. There is no choice.

MR. WOODLING: Respirators are essentially a temporary measure, aren't they?

DR. LANGNER: Yes. Personally, I agree with the concept that engineering controls should be used wherever feasible, and that is where we get into the trouble, determining what is feasible for the particular application. The standards which are being discussed at present, where they allow the use of respirator 1 hour per week, is totally unrealistic because, as you know, in our plants we have many operations where a man must go through an area to check something, more than once a week, and yet it would be very expensive to engineer out the problem. I encourage all of you people from industry to work with the NIOSH people, work with the OSHA people, and work with your EPA people. We have them in our plants quite frequently, and I encourage you to get them in your plants likewise.

MR. ROBERT G. CONFER (Exxon Corporation, Linden, New Jersey): You remove the vinyl chloride from the polymer that you make, but this is done by stripping, I presume. If every batch that you make isn't the same, the efficiency of vinyl chloride removal might vary from batch to batch. You're processing this, you're measuring vinyl chloride concentration after the fact, you don't know what the concentration was.

DR. LANGNER: Right.

MR. CONFER: Have you established a program to continuously monitor vinyl chloride in the work area?

DR. LANGNER: In the work area we have this type of monitoring.

MR. CONFER: No, I meant in the area that you referred to where you have recirculation.

DR. LANGNER: Yes.

MR. CONFER: You'll have a continuing program for monitoring?

DR. LANGNER: No, in this area we do not, because in our quality assurance program in the resin plant, before the product ever leaves the polymerization area, we have already done our check to make sure that the vinyl chloride is down to the level to meet the specifications. Therefore, we know from experience that vinyl chloride will not be a problem in the film extrusion plant. And more importantly, we also know that it is not going to be a problem in our customer's plants. The small plant is a real problem to industry. They are our customers. We recognize that they cannot afford and do not have available enough industrial hygienists and safety engineers, so we do everything we can under what we call our Product Stewardship Program to help our customer. Half of my group of 19 industrial hygienists spend this time in the customer plants helping our customers, because if they get in trouble, there goes our market. We actually furnish to our customers industrial hygiene help.

RECAPITULATION AND FUTURE DIRECTION

Robert D. Mahon*

Mr. Hughes has asked me to address two questions. The first question is the recapitulation of the seminar. In a half hour I'm not naive enough to believe that I can say what you gentlemen have said in the last 2 days. Then the second task is to talk about the future direction of NIOSH in the area of the recirculation of exhaust air.

Prior to addressing these two questions I feel it is in order for me to say something about the background of what happened before we came here yesterday. I am encouraged in this approach by the comments that many of you have made during this seminar, and those that I have heard during breaks and other times away from the meeting. As most of you know, all too often in the past we have polluted the air by just dumping outside the plant what we didn't want inside. Slowly but surely a lot of us have come to the realization that dilution is not the solution to pollution.

I remember in 1962 while I was serving with Dr. Allen Brandt on the National Association of Manufacturers' Health and Safety Committee, he made the statement that it had been calculated at Bethlehem Steel that for every ton of steel manufactured, a ton of carbon monoxide was exhausted outside of the plant. This was a pretty frightening thought, and it took a long time for people on the committee to recognize that what Dr. Brandt said was true. It has also taken a lot of engineers a long time to even accept the idea that there is such a discipline as environmental engineering. But as our plant managements have become more enlightened, and as quality assurance personnel have said that they want more reliability, we have changed. The space program also gave a great impetus to cleaning up our products and processes. Consequently engineers have been given the responsibility of coming up with an answer to how to clean up the pollutants that are generated in manufacturing processes.

NIOSH was faced with the necessity of addressing the problem, just as you gentlemen were, and just as you react when faced with a new problem, we look for analogous situations. Many of the situations that have been referenced in the last few days have direct application to what our obligation is now. For instance, some years ago we were faced with the problem of scaling in our steam generating boilers. How did we get rid of the nonsoluble salts in the water and steam cycle in our boilers? We were able to do it by adding chemicals to keep the nonsoluble salts in solution and engineering a system so that we had to introduce only a minimal amount of makeup water. These actions made it possible for us to conserve the life of boilers, piping, and auxiliary equipment.

Several of you have mentioned other actions pertaining to the use of closed systems, for example, cooling towers. Another analogous situation that comes to my mind are the coolants used on machine cutting tools. I am sure a lot of you remember one problem we used to have with them--dermatitis. This problem has now been pretty well engineered out of most processes. So we have precedents on which to base our approach to new problems.

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How did NIOSH address the problems associated with the recirculation of exhaust air? The engineering branch has a procedure where when it is asked to come up with a solution to a problem, it prepares what is called an RFC, request for contract. It is a 10-point document in which we try to call out the tasks that we want the contractor to address. After the RFC is approved throughout the organization, then we advertise for proposals--the RFP, request for proposal.

When Mr. Hughes was given the responsibility of preparing an RFC to address the problems associated with the recirculation of exhaust air, that is exactly what he did. As a result there was developed a criteria for the recirculation of exhaust air, and the contractor has talked to you about his report during the last 2 days.

I would like to call attention to a couple of things relative to the contractor's report. It is more or less boiler plate in NIOSH to include in the preface the following text: "The conclusions and recommendations contained in this report represent the opinion of the contractor and do not necessarily constitute NIOSH endorsement." I think it is important that you keep this in mind because many of you have expressed some anxiety about anything that NIOSH publishes becoming a regulation. Certainly this (holds up report) has been published as a final report. It has not been widely distributed and is certainly not intended to be used as a standard or regulation.

The other thing that I think that you should keep in mind is that in the RFP that went to the contractor, NIOSH included what is called the schedule of work, and that is what the contractor must address. I think that maybe some of you have been a little harsh in your criticism of the contractor because he did exactly what NIOSH asked him to do. We asked for certain things. We might have asked for certain things that it was naive to ask for, but the fact remains that there was a schedule of work which defined the tasks that were considered important to us in our research effort.

With that background review out of the way, I will now address task 1--a recapitulation of the seminar. I think that this task can be pretty much patterned along the scientific steps to problem solving. As engineers and scientists, we all learned a long time ago that the first thing that must be done is identify the problem.

The second step is to look for all possible solutions and third you select what you consider to be the best solution. Fourth, sell that solution, fifth, install the solution, and sixth, follow up.

In connection with the definition of the problem, when Dr. Harris opened the seminar he identified the problem as follows: he said that, number 1, NIOSH wanted to know how can we recirculate exhaust air, and number 2, how can the contaminants in exhaust air be removed.

He also gave us another guideline. He said that under the Occupational Safety and Health Act we are required to comply with the preamble of the act, which says, "to assure safe and healthful working conditions for working men and women." This act is where NIOSH gets authorization for funds with which to operate. This is the Bible, so to speak, that was given to us by the Congress.

In listening to Bill Astleford review the solutions that he arrived at during his research, and listening to Mr. Eshelman, Dr. Langner, Knowlton Caplan, speakers from the floor, and Mr. Barrett, Mr. Tubich, Mr. Hogland, Mr. Kane,

Mr. Decker, Mr. Parker, and Mr. Stotz, it seemed to me that what Jim Barrett said yesterday came into perspective. Jim talked about perspective, the parallel lines. I agree with Bill; it is possible for parallel lines to converge under certain conditions and I think that we did see a convergence during this seminar. We did see a convergence on the fact that when all the disciplines are joined together to solve the problem, we could arrive at a solution that would protect the health and safety of the worker. I feel there was general agreement on that point.

We then discussed the various disciplines and interfaces associated with the tasks.

I think that we need to put these parameters into perspective. In the chemical area, for instance, just to name a few, we talked about Threshold Limit Values (TLV's). We talked about time-weighted averages (TWA's). We talked about maximum allowable concentrations (MAC's). We talked about ceiling values (CV's). We talked about X levels. We talked about dose effect. We talked about carcinogens. And on many occasions we talked about mixed contaminants and how to clean up the exhaust air that contains them, because I think we all recognize that this can be a very troublesome area. We talked about the regulatory agencies, specifically OSHA and FEA. Dr. Langner advised us that Dow Chemical has 23 regulatory agencies that are assisting it in running its plants. That is quite a few.

It was also mentioned that there are other partners in this endeavor: organized labor groups; the public; the people outside of the plants. There are also employees that are not represented by organized labor. The insurance carriers also have a great deal of interest in our deliberations. So there are a lot of people who are interested, outside as well as inside the plant.

We have also talked about economics and feasibility. Much was said about the cost effectiveness of the recirculation of exhaust air. We talked about design and about various cleaning methodologies, both theoretical and practical; about such things as parallel and series filters, adsorbents and absorbents. We talked about specific substances in the atmosphere. We talked more about the particulates than we did about the gases and vapors. We talked about new state-of-the-art developments, the cue dot. Maybe to some of you it is not new, but to others it may be--the heat wheel, the heat pumps, various heat recovery systems, solar energy, fossil power vs. nuclear. We talked about the research that entails building model plants, building prototypes, building pilot plants, and such things as reliability, redundancy, reengineering. We talked about some of the things that other groups are doing, ASHRAE, for example. Some of the energy indices that have been developed. Several of you have touched on the voluntary compliance aspect, how you can do your thing the best way, and you do not need the assistance or the surveillance of outside interested parties. We have discussed performance standards, consensus standards, and specification standards. In summary, these are some of the parameters within which we as scientists and engineers must operate in making a selection of the best solution to the problem.

At this point, I've got a little good news and a little bad news. In doing a recapitulation I find that there is one thing that I believe we unanimously agreed upon. There will never be complete agreement on what is the one best universal solution to the recirculation of exhaust air.

However, on the positive side, the good news, I felt that there was agreement that exhaust air can be cleaned up and it could be recirculated. Also there was unanimous agreement that we can and must conserve energy by the recirculation of exhaust air.

And finally, that there is agreement that it is much more economical to design a system on the drawing board for the recirculation of exhaust air than to go back and reengineer after the plant, the process, or system is in place.

Rather interestingly, Mr. Talty just gave me a copy of the Environmental News. This is a news release that was specified, by EPA, for release at 11:00 a.m. Monday, October 20. They quote Mr. Russell Train, speaking in Cleveland to the International Pollution Engineering Exposition and Congress. Perhaps some of you attended that meeting. He said, "But the commonly held concept to change has generally been confined to traditional add-on devices, such as end-of-pipe-line or top-of-stack technology. While such add-ons often are necessary for protection of public health, welfare, and environment, more basic changes in the process of an industry offer a greater potential for accomplishing these same purposes."

What I think he is saying is that the things that many of us participated in the past, for example, we put the stack up a little higher, or we increased the rpm on the exhaust fan, we moved an operation, or we changed our schedule so that the people were working with a particular solvent or a particular plating compound when the density of the plant was at its lowest and perhaps that is the way many of us continue to operate, is not good enough. What I hear him saying is, let's get back to the drawing boards, let's do the things we know can be done at the drawing board. I think that we all agree that is a much more economical approach. In fact, one of our speakers actually quoted the figures of savings that he had observed in doing it at the drawing board as opposed to doing it after the job is in place and had to be reengineered.

The best solution, the third step in the scientific steps to problem solving, requires us to look at the past, the present, and the future; what have we been doing in the past, what are we doing now, or what is someone else doing now, and what can be done in the future.

At this point I need to admonish you, as many of the speakers have done during the last 2 days, that we cannot look at a particular final report or a ventilation manual as a panacea. We cannot look at a formula or a TLV and expect it to exactly prescribe what we have to do. There are too many other variables. For instance, if you have a plating room that is operating under a negative pressure and the rest of the plant is under positive pressure and even if you put a big sign on the door of the plating room saying "Keep These Doors Closed;" what happens when it gets hot? The doors are left open because the rest of the plant is air conditioned and the plating room is not. The plating room employees want cool air where they are working. The design of the ventilation system for the plating operation is negated. Instead of having the fumes from your nitric acid bath being pulled down and out, they may be drifting over to a cyanide cleaning operation.

Several of you have mentioned the importance of maintenance. I think one of the best examples that comes to my mind is in a plant where I once worked. We built a laboratory and went to great expense to install electrostatic precipitators. I received complaints that they were getting a high level of ozone

and I found upon investigation that they were absolutely right. We found that the maintenance people had allowed the grids to load up. Arcing was occurring and generating a high concentration of ozone. When you start talking about so many thousands of hours of fault-free operation, and then you hear someone else say, "We had the installation in for 3 months and never could get it to work." I think it points out to us that we have to be careful in accepting anything as a panacea.

Now we come to step four in the scientific steps to problem solving. That is the selling of the solution. We must get top management's support. Several of you have said this. How do you get top management's support? Many of you have illustrated sound arguments, the dollar savings that accrue from the recirculation of exhaust air. That's good. Also you need to have the support of the employees. If you do not have the support of the employees, the example that was mentioned yesterday with the white wall will occur. Exhaust from grinders and discoloration of the white wall are psychological or related human factors that can and will shut down a plant. It isn't necessarily the physiological effects of a contaminant, but also the psychological effects that influence the individual worker. We must not overlook this fact in our approach to the problem.

Now we come to the fifth step in the scientific approach to problem solving; that is the installation of the solution. This is really the easiest part, because if you have done a good job until, now, the installation is not too difficult. Many of our speakers have told us how to perform this task.

The last step, the sixth, is followup. This is the step where we have heard from this podium about many of the failures--for instance, the foundry man who says, "Oh, we've got a beautiful bag system." Why is it so beautiful? "It has sat up there on the roof for 4 years and we've never had to touch it." Or there is the example I just used of the electrostatic precipitator. I could go on and mention others we've been told about, monitoring for instance.

Perhaps I should recapitulate some of your comments on monitoring. There has been some concern voiced about the keeping of records. Those of you going home today have records to keep. You know where you have been as a result of those records, and hopefully those records will help you to know where you are going. That same thing applies to the followup of anything that we do in our recirculation of exhaust air. All too often engineers are criticized because a well-designed installation is not operable. Why isn't it operable? Because all too often after the solution has been sold and management agreed to spend all of the money necessary to install it, no PM records are kept and it's not maintained. There is no followup and you know what happens. There is an old saying, "You must inspect what you expect."

This brings me to the second task Mr. Hughes assigned me. That is: future direction.

If we think of the universe of problems and the universe of solutions as two concentric circles, in the center we know a great deal, but around the outside there is a great deal that is unknown "the UNK's" as they are called in the aerospace industry.

The future direction is a learning process; we must relate the known to the unknown. So how does NIOSH proceed? There is a research philosophy

followed in NIOSH, as I'm sure it is in most of your companies. We obtain the information that is already known. We do this by means of a literature search. We generally find out the state-of-the-art by working through contractors. When we have gathered the available information, such as we have done in this document, we then do a gaps analysis. That's what we have been doing here. We are looking for the gaps. We are drawing on the hundreds of years of experience that are represented in this room. As a result of the transactions that have taken place here, Mr. Hughes will determine what gaps exist. He will then follow the same procedure as before; he will prepare an RFC, a 10-point document, in which he will call out those gaps that he feels need to be addressed. After the RFC has been approved throughout NIOSH, an RFP will then be prepared.

The future direction or the objectives as we see them now, and as Mr. Talty, Mr. Hughes, and I discussed them at lunch today, are three parallel lines:

Number one, we want to identify the criteria necessary to the safe and healthful recirculation of exhaust air.

Number two, we need to quantify the product of these criteria.

And third, the final product must be design and performance criteria supported by reliable data. Hopefully the three parallel lines will converge in a single document.

There has been some concern voiced about what we will do with this information. Our target is to have the contract information back by June of 1977. We intend, subsequent to that date, to have another seminar such as we have been having here the last 2 days. That will help us in the promulgation of a final NIOSH technical publication.

I was pleased that Dr. Langner offered to share his companies' data with NIOSH. We hope that many others of you will do the same thing. The data and the knowledge that you have accumulated will be most helpful. It will help us arrive at a better solution to our mutual problems.

NIOSH personnel are going to visit some plants now. Last week Mr. Hughes and I went to a screw machine shop with 70 screw machines in a very small area, and looked at the air ventilation system, and gathered research data. We were not there as a regulatory agency. We were there to fulfill the research function that NIOSH has been charged with under the Occupational Safety and Health Act.

In closing, I would like to say thanks to each one of the persons who participated in this seminar. We do want you to know that NIOSH appreciates your participation and we will look forward to further cooperation with you in the future.

CLOSING REMARKS

CHAIRMAN HUGHES: Before closing, Jim Barrett would like to inform you of an upcoming ACGIH topical symposium to be held in Cincinnati.

MR. JAMES C. BARRETT (Department of Public Health, Lansing, Michigan): I don't know if you heard about it or not, but it came to mind when Dr. Langner talked this morning. ACGIH is sponsoring a meeting; the subject of the meeting is monitoring and medical surveillance of the workplace, and it will be held here in Cincinnati December 8th and 9th, right down the street at the Netherland Hilton. If you would like I will make sure that everyone here on the registration list receives a copy of the announcement. I think it very apropos to the subject we are talking about, as Dr. Langner illustrated, as well as to the overall subject of occupational health standards. That is my commercial message. Thank you.

CHAIRMAN HUGHES: In closing the symposium, I would like to personally thank everybody who attended and participated, and I think from my own standpoint, and NIOSH's standpoint, this has been a very fruitful effort. In discussions with you, I think that most of you feel that it has been beneficial to you too.

I would like also to give a special thanks to our contractor who set this meeting up--Research Triangle Institute, in particular Dave Bacon and Frank Ayer who have been keeping things going smoothly. I think you have done a very good job and I thank you, and again I thank all of the participants.

PART TWO

DEVELOPMENT OF CRITERIA FOR THE RECIRCULATION OF EXHAUST AIR

by

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The conclusions and recommendations contained in this report represent the opinion of the contractor and do not necessarily constitute NIOSH endorsement.

The criteria presented in this report are conceptual and are not to be considered as final criteria for the recirculation of exhaust air.

PART TWO

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ABSTRACT

This report describes a study to develop technical performance criteria for recirculated exhaust air systems. These criteria reflect contaminant toxicity, the requirements for air monitoring and air cleaning equipment, reliability analyses of fail-safe systems, and theoretical modeling of system performance.

Based on contaminant toxicity, 356 of the 514 compounds that are listed in the body of the 1973 ACGIH TLV table are potentially recirculatable. Carcinogenic compounds and compounds with ceiling concentrations are to be excluded from recirculation systems. Air monitoring equipment should be on-line, automatic and specific for individual contaminants. Reliability analyses indicate that recirculation systems that incorporate backup or redundant air cleaning equipment have a lower probability of failure for all operating times than systems without backup. Systems without backup air cleaners should contain provision for exhaust bypass to the atmosphere in the event of an air cleaner or monitor failure.

Analytical recirculation models were developed to predict the transient response of workroom concentration as a function of contaminant generation rate, room volume, general and recirculated air flows, and the air cleaner and local exhaust hood capture efficiencies. The effect of air cleaner failure and by pass of exhaust air to the atmosphere were also modeled.

Recommendations for further research are provided.

I. INTRODUCTION

Historically, contaminant laden air from industrial processes has been discharged to the atmosphere. In recent years, air cleaning or pollution control devices have been employed in order to meet ambient air quality* and stationary source emission standards⁺. Even though the effluent concentration downstream of these cleaning devices may comply with existing emission standards, the heated or cooled makeup air that is needed to replace the exhaust is ultimately discharged to the atmosphere as an expendable item. Due to the high initial cost of the conditioning equipment for the makeup air, the increasing costs of energy and, in many cases, the unavailability of energy to operate the conditioning equipment in new installations, many industries are actively seeking exhaust systems that will clean the air and recirculate it directly to the workplace with a corresponding reduction in energy consumption. While this is a highly desirable approach, especially in view of the energy crisis, there are no established technical design or operational criteria for such systems.

The application of recirculated exhaust air systems to industrial processes is a relatively new and unexplored technique. The broad objective of this research program, therefore, has been to develop technical criteria for air recirculation systems which will provide adequate safeguards for worker protection. More specifically, these criteria must ensure that, as a result of recirculation, the contaminant concentration anywhere in the workplace does not exceed the Threshold Limit Values (TLV's) specified by the American Conference of Governmental Industrial Hygienists (ACGIH)[±].

*"National Primary and Secondary Ambient Air Quality Standards," Federal Register, Vol. 36, No. 84, Part II, April 30, 1971.

⁺"Standards of Performance of New Stationary Sources," Federal Register, Vol. 36, No. 247, December 23, 1971. Including subsequent modification and expansion.

[±]Threshold Limit Values for Chemical Substances in the Workroom Air, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1973.

To achieve these objectives, the research effort was partitioned into four major areas of inquiry:

- (1) Determination and Categorization of Recirculatable Contaminants

Relatively few specific contaminants are covered by the federal air pollution standards. On the other hand, the ACGIH-TLV table specifies the acceptable occupational exposure concentration for approximately 500 specific chemical substances that may be found in the industrial workplace. Because of the size of the TLV list, each contaminant was considered individually. The decision to recirculate or not to recirculate was based on the chemical, physical and toxicological properties of each contaminant. All determinations were, therefore, industry and process-independent. Additive and synergistic effects resulting from recirculation of multiple contaminants were excluded from this study.

- (2) State-Of-The-Art Of Commercially Available Air Cleaning Equipment

The objectives of this task were two-fold. First, manufacturer's published brochures on air cleaning devices were solicited for the purpose of determining which devices were appropriate for removal of specific contaminants, and second, a review of user experience was conducted with specific cleaning devices in order to acquire a data base for analysis of system reliability and quality assurance.

- (3) Reliability and Fail-Safe Provisions for Recirculated Exhaust Air Systems

This task effort involved the reliability analysis of recirculated exhaust air systems with and without redundancy or backup. Control system logic and automatic contaminant sampling systems were also considered.

- (4) Analytical Models of Recirculation Systems

Theoretical models of exhaust air recirculation systems were developed, including the effects of partial bypass and air cleaner failure. The parameters that influence the magnitude of the mixing factor were defined by a steady-state diffusion model.

Each of these four areas is analyzed in a separate section of this report. To aid the reader, pertinent literature references appear at the end of each major task effort.

II. DETERMINATION AND CATEGORIZATION OF RECIRCULATABLE CONTAMINANTS

II. 1 Basis I: Chemical, Physical and Toxicological Properties

The Threshold Limit Value (TLV) Table for 1973, which is published by the American Conference of Governmental Industrial Hygienists (ACGIH), Reference II. 1 (see also Federal Register reference in Section I), contains in excess of 500 chemical substances that may be present in industrial workroom air. Because recirculated exhaust air systems and the development of appropriate performance criteria are still in the neophyte stage, a process or industry-oriented approach to contaminant selection was not indicated. Therefore, each contaminant was considered as a separate entity. Consequently, additive or synergistic effects resulting from recirculation of multiple contaminants were excluded from this study.

Figure II.1 summarizes the results of the determinations that were made under Basis I. At this point the reader may wish to refer to Appendix A. This appendix indicates which specific contaminants from the TLV table are contained Groups 1 through 6. The criteria for group categorization are described below.

Beginning with the entire TLV table, Group 6 was constructed. This group, which contains 94 contaminants, is composed of human and experimental carcinogens, compounds which have a specified maximum allowable concentration (MAC) or ceiling value, and synonym duplicates. Synonym duplicates are contaminants which appear under more than one chemical or trade name in the TLV table. The carcinogenic and MAC contaminants in the TLV table were excluded from further consideration as potentially recirculatable compounds because of proven or otherwise experimentally determined adverse health effects. The carcinogenic compounds in this group are compatible with the recent list that was published by the Occupational Safety and Health Administration, Reference II.2. Synonym duplicates that did not carry a carcinogenic or MAC label joined the remaining contaminants and were subjected to the criteria that ultimately led to Groups 1 through 5. The rationale for contaminant assignment to Group 6 is contained in Appendix B.

At this point, an extensive literature search was conducted in

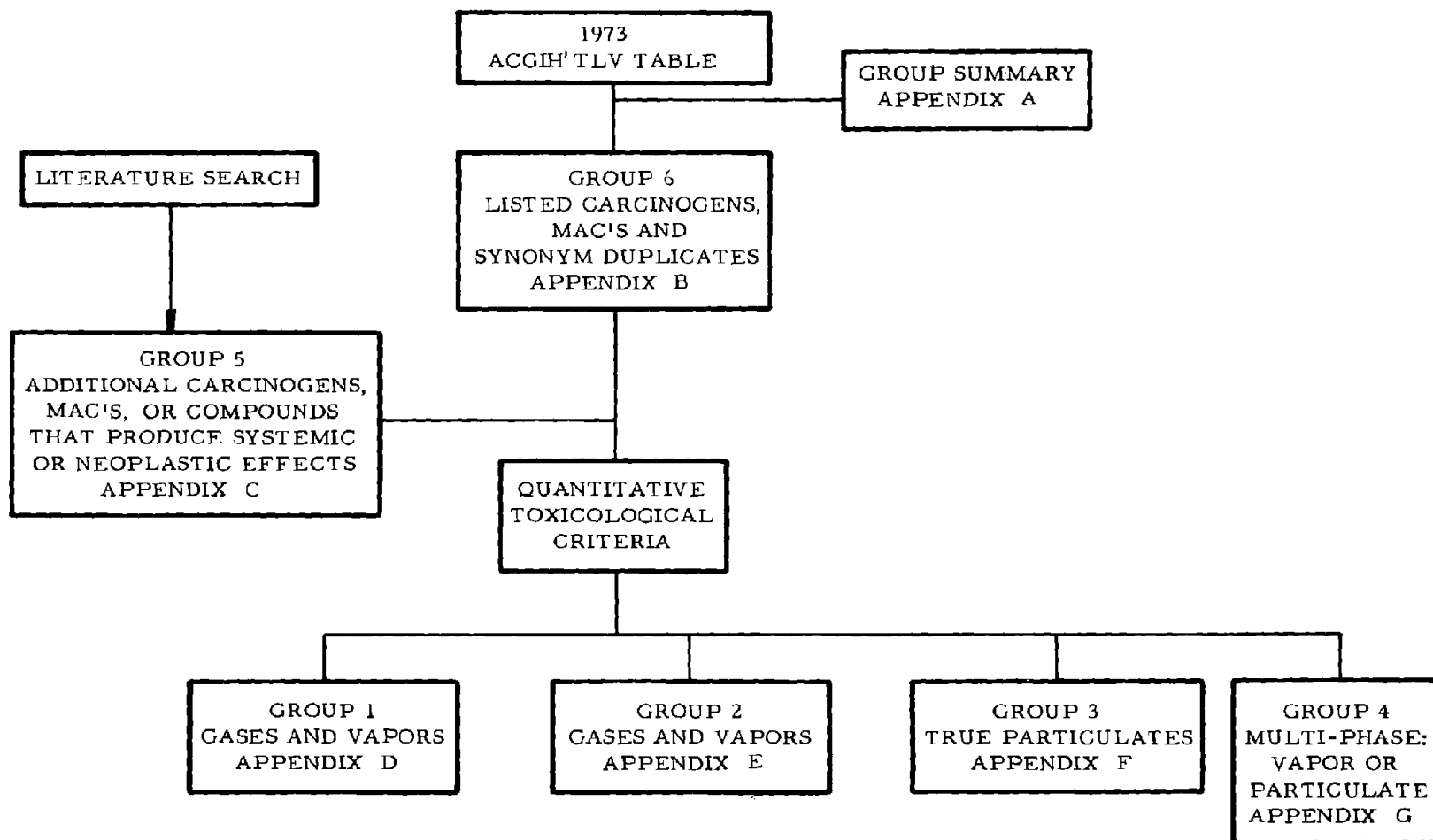


Figure II.1 Toxicological Partitioning of the 1973 ACGIH TLV Table

order to gather the chemical, physical and toxicological data with which to judge a contaminants suitability or unsuitability for recirculation. Much of the needed data was obtained from Reference II.3 through II.21. In some cases, specific properties such as odor and irritant thresholds have not been documented in the literature. Based on these data and quantitative toxicological criteria, Groups 1 through 5 were generated.

Group 5, which contains 64 contaminants, is not recommended for recirculation. The results of the literature search and documentation indicate that the contaminants in this group possess one or more of the following unfavorable qualities.

- (1) They are experimental carcinogens that are not contained in the TLV table.
- (2) An MAC or ceiling concentration is suggested in the literature but is not reflected in the TLV table.
- (3) Neoplastic effects can be produced experimentally.
- (4) Systemic effects are produced at concentrations that fall within the excursion factor for the appropriate TLV, i.e.,

$$C_s < EF(TLV)$$

where EF is the excursion factor that is appropriate to a particular TLV range. The excursion factor is the permissible deviation in concentration above the TLV, and numerical values have been defined in Reference II.1.

The rationale for contaminant assignment to Group 5 is contained in Appendix C.

The contaminants that passed the Group 5 decision level were then subjected to five quantitative toxicological criteria that could be stated as mathematical inequalities. These criteria were designed to maximize worker protection in industrial environments that employ recirculation systems. The criteria are as follows:

- (1) $C_o < TLV$
- (2) $C_i \leq TLV$
- (3) $C_s > TLV$
- (4) $C_s > C_o$
- (5) $C_s > C_i$

where C indicates a threshold concentration, and the subscripts i, s, o denote irritant, systemic and odor properties, respectively. These five conditions were applied to each contaminant, and if all inequalities were satisfied the contaminant was placed in Group 1. By definition, those contaminants in Group 1 also satisfy the inequality

$$C_s > TLV(EF)$$

The majority of the compounds in Group 1 are gases and vapors. Pending availability of air cleaners and concentration monitors, Group 1 is a logical choice for recirculation because of the existence of odor and irritant early warning properties as well as manageable systemic properties. Care should be exercised not to rely solely on an odor or irritant property because of the potential for desensitization. These properties can serve as a valuable adjunct to a fail-safe recirculation system. The rationale for assignment to Group 1, which contains 128 contaminants, is given in Appendix D.

The remaining contaminants that did not satisfy all of the toxicological criteria are presented in Groups 2, 3 and 4, which contain 116, 103 and 9 compounds, respectively. These groups represent natural categories that reflect the dominant physical state of the contaminant, i.e., true particulates, gases and vapors, and multi-phase compounds that can exist as either particulates or vapors. Appendices E, F, and G contain the rationale for Groups 2, 3, and 4, respectively. The contaminants in Groups 2, 3, and 4 are not necessarily excluded from recirculation applications. They were placed in these groups because they failed to satisfy one or more of the toxicological criteria. A decision to recirculate must be based on the availability of suitable monitoring and cleaning devices. The next two sections explore, as far as was possible, the requirements for and availability of these devices.

The results of these toxicological determinations apply only to the compounds that are listed in the body of the ACGIH-TLV table and to the nuisance particulates in Appendix E of Reference II. 1. Recirculatability of mineral dusts were determined separately, and the results are as follows.

Crystalline and amorphous forms of silica do not appear to be suitable for recirculation. References II.3, II.7 and the Accident Prevention Manual for Industrial Applications indicate that three of the crystalline forms of silica (quartz, cristobalite and tridymite) have fibrogenic potential leading to cumulative and irreversible silicosis. Amorphous silica (diatomaceous earth) has been used to experimentally induce silicosis at concentrations significantly below the current TLV. Fused quartz has been shown to contain microscopic free quartz crystals that do have fibrogenic potential.

Under the category of silicates, asbestos, mica, fibrous talc and tremolite are not recommended for use in recirculation systems. Asbestos is a human carcinogen. Exposure to mica can potentially produce pneumoconiosis. From the literature, the null concentration (concentration that did not produce pneumoconiosis) is approximately one-sixth of the present TLV, and the incidence rate increases for concentrations that approach the TLV. Until more definitive data is available, the present difference between the null level and the TLV indicates that a conservative decision be made regarding its use in a recirculation system. Fibrous talc and tremolite contain asbestiform fibers and exposure to these silicates is conducive to the production of pneumoconiosis and the formation of lung lesions that are indistinguishable from those in cases of asbestosis.

II.2 Basis II: Air Cleaning Devices

The compounds in Groups 1, 2, 3 and 4 were reviewed next with the objective of recommending cleaning devices or unit processes for effective contaminant control.

It was readily apparent that the true particulates (Group 3) were the only group that lacked sufficient information with which to make an air cleaner recommendation. The chemical and physical properties of this group are known, but the missing element is the particle size distribution, which is heavily dependent on the industrial process that generates the contaminant. A knowledge of the particle size distribution is a mandatory prerequisite to air cleaner recommendation. There are four basic classes of particulate air cleaners:

- (1) Electrostatic Precipitators
- (2) Fabric Filters
- (3) Wet Collectors
- (4) Dry Centrifugal Collectors

Any of these basic classes of collectors may have as many as six subclasses which are applicable to specific particle size ranges. It is recommended that the reader consult Reference II.22 for more detailed information. For these reasons, cleaner recommendations for Group 3 were neither possible nor warranted but must be deferred to a definitive, process oriented study.

With the exclusion of true particulates, air cleaner recommendations were possible for the gases and vapors in Groups 1 and 2 and those multi-phase

contaminants in Group 4 that can be present in the vapor state. The following classes of air cleaners are suitable for gas and vapor collection.

- (1) Absorbers - a wet collector in which a gas or vapor solute is soluble in a liquid solvent.
- (2) Adsorbers - activated carbon, molecular sieve or silica gel.
- (3) Catalytic Oxidizers
- (4) Direct Combustors and Thermal Oxidizers

For the following energy and contamination considerations, use of combustors (after burners) and oxidizers are not recommended for contaminant removal in recirculation systems.

- (1) Direct combustors and thermal oxidizers
 - a. Recirculation of combustor effluent in the most efficient operation results in the accumulation of asphyxiants and the depletion of oxygen.
 - b. Improper operation could cause combustion by-products to be recirculated that would be more hazardous than the original contaminants.
 - c. Combustion processes are intrinsically energy intensive.
- (2) Catalytic Oxidizers
 - a. These devices generally operate at elevated temperatures and require an auxiliary energy input.
 - b. Combustion products accumulate causing a build-up of asphyxiants. Improper operation could cause partially oxidized, hazardous emissions to be returned to the workplace.
 - c. Poisoning or fouling of the catalyst could occur suddenly, thus rendering it ineffective for further contaminant removal.

In addition, these two processes are exothermic and would require energy intensive equipment to temper the exhaust air prior to recirculation.

The following discussion provides the basis for recommending either an absorption or adsorption process to remove contaminant Groups 1, 2 and 4 from the recirculated exhaust air.

Adsorption Processes

The ability of a gas or vapor to be adsorbed by a particular adsorbent at a given temperature and pressure depends on the nature of the adsorbed gas. Unfortunately, there are no simple, quantitative relationships that express adsorbability as a function of intrinsic adsorbate properties. However, certain generalized relationships have been observed between adsorbed gases and their physical properties.

Early discoveries were made which showed that the most condensable gases were adsorbed in greatest amounts by an adsorbent. These observations, were correlated with boiling point and critical temperature, and it was noted that the volume of gas adsorbed on a given quantity of adsorbent increases as the boiling point increases (Reference II.23 and II.24). A similar relationship between adsorbed gases and their respective molecular weights shows that, as the molecular weight increases, the capacity for adsorption also increases (References II.25 and II.27).

With the above observed adsorption phenomena in mind, several approaches were taken in order to ascertain with a reasonable degree of accuracy the effectiveness of the adsorption process in removing gaseous or vapor contaminants from recirculating air. It is possible to make preliminary judgements concerning the suitability of an adsorption system for gaseous contaminant removal provided that experimental adsorption data on a large number and wide variety of compounds are available.

Experimental data on approximately 200 substances of widely varying chemical classes have been gathered by a leading manufacturer of activated charcoal (Reference II.28). These data did not reflect the base material of the charcoal or the method of activation. The tabulated substances were indexed using a numerical designation from 1 to 4 in the order of increasing adsorbability. The designations, which are contained in Reference II.28, are interpreted as follows:

<u>Adsorption Index</u>	<u>Adsorbability</u>
1	Poor
2	Fair
3	Good
4	Excellent

Using the adsorption data from this source and the boiling points and molecular weights of the various substances, definite relationships were observed between boiling point, molecular weight and adsorbability on activated charcoal,

as illustrated in Figure II.2. Various sources (Reference II.25 and II.27) have indicated that satisfactory adsorption occurs on activated charcoal for substances having a molecular weight above approximately 30 to 45. This is substantiated by the data shown in Figure II.2. A similar observation is made regarding substances having a boiling point above -80°C .

Activated carbon adsorbs non-polar hydrocarbon vapors in preference to water vapor, while the opposite is the case with silica gel. For this reason, activated carbon is preferred over silica gel for removing contaminants from recirculating room air (References II.23 to II.27). Generalized expressions that attempt to relate the physical and/or chemical properties of the adsorbate to its adsorbability result in spurious conclusions that could lead to the design of an ineffective adsorption system or a system that is substantially overdesigned for the intended service. In the final analysis, only those adsorption characteristics that are supported by well-documented experimental data should be used for the design of an adsorber system. Water vapor, being a large constituent of room air, would tend to displace adsorbed hydrocarbons. This tendency of adsorbed water to displace previously adsorbed gases would be substantially diminished if the gas were water soluble; for example, ammonia or sulfur dioxide. All gas molecules are adsorbed to some degree, regardless of their level of activity, by activated carbon due to the induced dipole effect caused by electrostatic forces at the adsorbent surface (van der Waals forces).

Impregnated charcoals are designed to increase an adsorbent's ability to remove one or more specific gases (Reference II.29). Impregnation is a process by which a chemical treatment of the activated charcoal combines chemical reaction with absorption to fit a particular purification requirement. Most impregnating processes are proprietary methods of charcoal treatment that have been developed by the various manufacturers. The main disadvantage of using impregnated charcoal is that the adsorptive capacity is reduced for contaminants other than those for which it was specifically designed. Also, the impregnated charcoal bed cannot be regenerated in-situ, whereas in-situ regeneration of a non-reactive, activated charcoal is a routine operation.

Absorption Processes

Absorption is the process by which a soluble component of a gaseous mixture is dissolved in a relatively nonvolatile liquid and is thereby selectively removed from the main gas stream. Absorption is effected when the gas stream is brought into intimate contact with the absorbent liquid, usually in a plate or packed tower, or in a spray chamber. Absorption processes are somewhat more complicated than adsorption processes, and they are not as effective, in most cases, in approaching complete removal of contaminant. Absorption processes primarily employ countercurrent flows

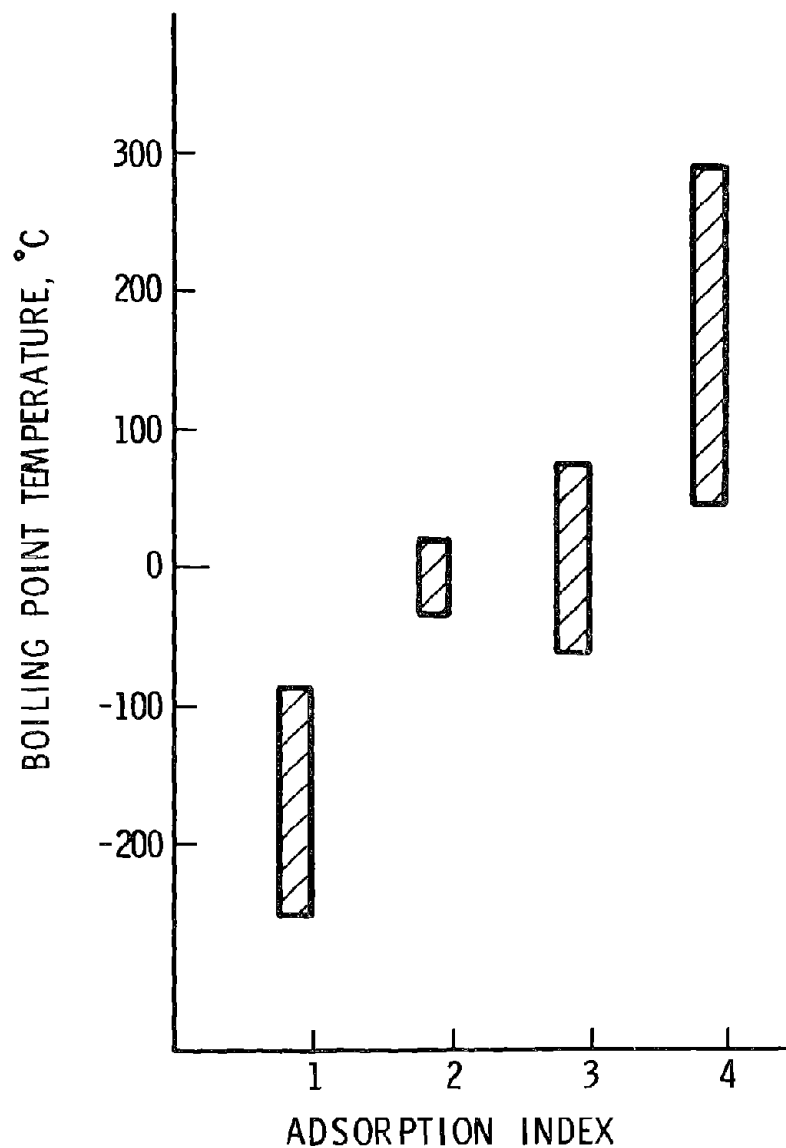
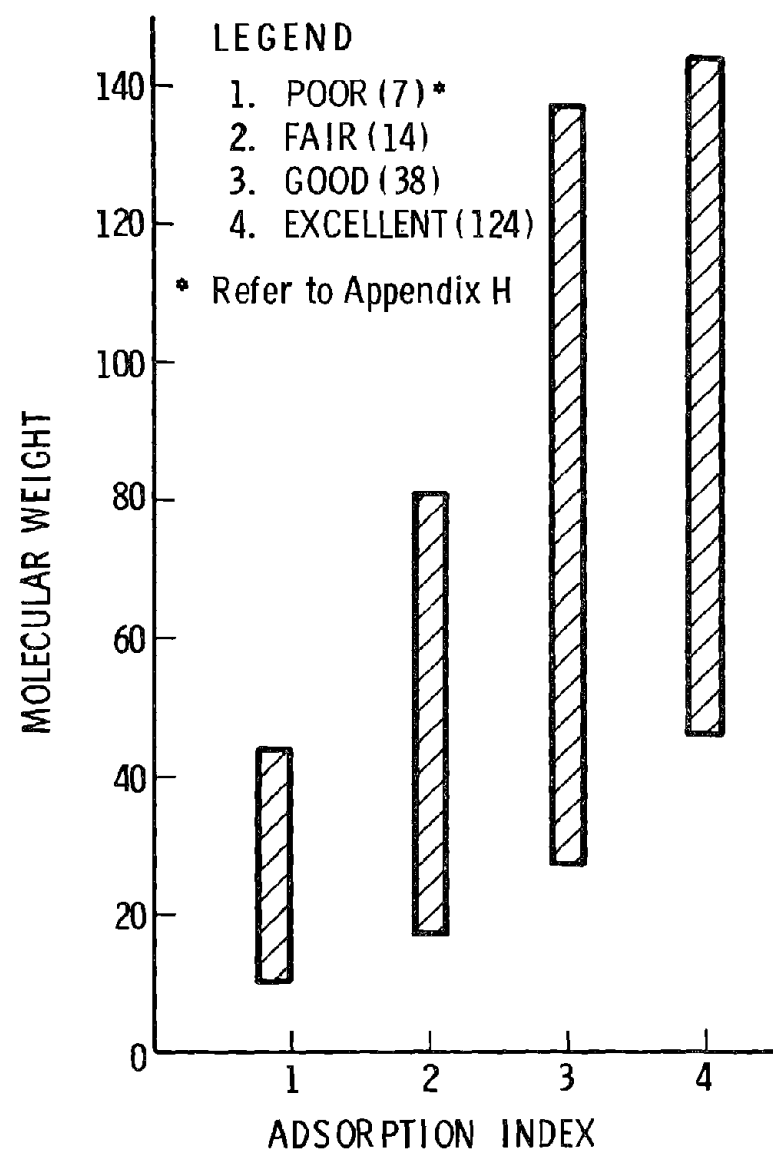


Figure II. 2 Adsorbability of Gases and Vapors as a Function of Molecular Weight and Boiling Point

of carrier gas and liquid, and the departing gas stream is essentially in equilibrium with the entering absorbent. In a straight absorption process, the contaminant-rich liquid (liquor) leaving the absorber must either be stripped of the dissolved contaminant and recirculated or used in a once-through process where contaminant-rich absorbent is disposed of in an environmentally acceptable manner. In the latter case, this is only economically feasible where water is the absorbent. In the former case, reclamation or stripping is feasible if the process-generated contaminant has economic value. Where additives are present in the adsorbent liquid and they react chemically and irreversibly with the solute, the absorbent may be recirculated until the concentration of the reactive additive is reduced to an ineffective level. As a rule, absorbers were not recommended where TLV's were less than 50 to 100 ppm.

The absorption and adsorption processes were evaluated to determine their suitability for removal of the contaminants in Groups 1, 2 and 4. The criteria that were used to judge the adequacy of either cleaning process are shown in Table II.1. Appendix H contains the results of these recommendations, along with a coded entry for each contaminant, e.g., A-1(C). This code refers to the applicable criteria section in Table II.1.

The reader will note that an adsorption process has been recommended for the vast majority of the contaminants. While it is true that certain gaseous contaminants are highly soluble in various non-aqueous solvents, the ultimate user of either of these processes must weigh the economic advantages of the adsorption process against the initial cost of the special solvent and the subsequent cost of solvent reclamation.

The manufacturer's brochures from Section III were then reviewed to obtain an indication of the number of air cleaner manufacturers that stated that their equipment was appropriate for removal of a given contaminant. The results of this screening are also contained in Appendix H.

Regardless of the type of cleaner that is ultimately chosen for contaminant control, performance requirements dictate that it should be capable of cleaning the process exhaust to a concentration that does not exceed the value of C_{in} , the effluent concentration downstream of the air cleaner, that is derived from the mathematical models in Section V of this report. This requirement places limits on the cleaning efficiency that is necessary to ensure that the workroom concentration does not exceed the TLV.

II.3 Basis III: Contaminant Monitoring Equipment

The air cleaner and the contaminant monitor are two of the most important elements in an exhaust air recirculation system. The function

TABLE II.1

RATIONALE FOR AIR CLEANER RECOMMENDATIONS

A. Adsorption

1. Adsorption occurs readily on activated carbon
 - a. Hydrocarbons - active carbon specifically adsorbs hydrocarbon vapor in preference to water vapor, which is always present in room air (References II.23, 24, 25, 26, 27 and 30).
 - b. High boiling point (low vapor pressure) and high molecular weight compounds are readily adsorbed on activated carbon (References II.23, 24, 25 and 27).
 - c. Adsorbent capacity for a given gas or vapor has been experimentally determined (References II.26, 27 and 30).
2. Adsorption occurs readily on silica gel as determined experimentally (References II.23 and 30).
3. Impregnated adsorbent has an adsorption/reaction mechanism that removes the contaminant by chemical alteration (References II.26, 28 and 29).

B. Absorption

Absorption removes the contaminant by dissolving it in an inexpensive nonvolatile liquid.

1. Solvent regeneration (stripping) or disposal of tailings with make-up is indicated in order to maximize absorption efficiency.
2. Absorbent is a solution that reacts chemically with the absorbed contaminant, thus eliminating the need for a solvent recovery in a once-through disposal operation (References II.24, 26 and 27).

of the monitor is to provide an indication of the contaminant concentration in the effluent duct on the discharge side of the air cleaner. System reliability and fail-safe considerations indicate that the monitor should possess the following performance capabilities:

- (1) The monitor should be on-line and automatic which implies that sample acquisition and analysis are performed in-situ. Laboratory analysis of the sample is unacceptable.
- (2) Sampling and analysis should be performed continuously or intermittently. In the latter case, the monitor should be capable of initiating a sample acquisition and analysis cycle every 15 minutes. The results of any given sampling and analysis cycle must, of course, be available for display and further processing before initiation of the next cycle. The 15-minute requirement is consistent with the short-term exposure time for maximum contaminant excursions above the TLV.
- (3) The monitor should be specific for a given contaminant, i.e., interference-free.
- (4) The minimum detectable concentration should be less than the theoretical prediction of C_{in} from Section V of this report.
- (5) A digital display of concentration is required for comparison with a redundant manual sampling of the air cleaner effluent (Section IV of this report).
- (6) An analog output proportional to concentration is required for input to a fail-safe control system (Section IV of this report).

These requirements are rather strict, but they can be justified solely on the basis of employee safety.

Nine major manufacturers of air monitoring equipment were contacted personally and then by letter and each one agreed to indicate whether or not their equipment could meet the above criteria for sampling and analysis of the contaminants in Groups 1, 2, 3 and 4. In the final analysis, only seven of the nine manufacturers chose to respond. The participating manufacturers also indicated the appropriate analysis method, minimum detectable concentration and/or full-scale range.

An additional list of 127 manufacturers of air monitoring equipment was assembled from the buyer's guide that is published in the Journal of the Air Pollution Control Association (APCA). A letter request for normally-distributed, published product information on air monitors was sent to this

group. The response rate was 62 percent. Because of the nature of product brochures, an evaluation of monitor requirements versus availability was not entirely possible for this group. The responses were screened, and applicable information was extracted.

Overall, the sample size for which complete information was available did not lend itself to an objective evaluation of monitor requirements versus availability. Consequently, the results of this inquiry, which are also contained in Appendix H, only indicate the number of monitor manufacturers who stated that their equipment could sample and analyze for the contaminants in Groups 1 through 4 without regard to the six monitor system criteria. These results suggest that the application of air monitoring equipment to recirculation systems is feasible for processes that involve the gases and vapors in contaminant Groups 1 and 2 and to a lesser extent the multiphase media in Group 4. The situation is entirely different for the particulates in Group 3. Based on the technical literature and correspondence and discussions with monitor manufacturers, on-line sampling and analysis equipment that is specific for a given particulate is not commercially available at this time. Several total mass concentration devices are available, but contaminant concentration distribution within the sample weight must be performed by laboratory analysis. Further investigation is needed to determine if the specificity requirement can be relaxed for processes that generate a single particulate or processes where the particulate of interest remains at a fixed percentage of the total emission. The effect of process-related variations in generation rate and the effect of the cleaning cycle of the pollution control device, e.g., fabric filters, on the contaminant makeup in the cleaner effluent duct should be considered.

Appendix H concludes with a categorization of contaminants by chemical class.

II. 4 Summary

The results of this analysis are summarized in Table II.2.

On an overall basis, 67 of 244 or 27 percent of the contaminants in Groups 1 and 2 have both cleaning and monitoring equipment. Similarly, 68 of 356 or 19 percent of all contaminants in Groups 1 through 4 have a cleaner and a monitor.

II. 5 References

- II.1 Threshold Limit Values for Chemical Substances in the Workroom Air, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1973.

TABLE II. 2
AIR CLEANER AND CONTAMINANT MONITOR SUMMARY

	<u>Group 1</u>	<u>Group 2</u>	<u>Group 3</u>	<u>Group 4</u>
Total Number of Contaminants, N	128	116	103	9
Cleaners*	45	27	37	2
Monitors*	127	91	0	3
Cleaners† and Monitors	45	22	0	1
Percent‡	35	19	0	11

*Number of contaminants for which either cleaning or monitoring equipment was indicated.

†Number of contaminants for which both cleaning and monitoring equipment were indicated.

‡Percentage of N with cleaners and monitors by contaminant group.

- II. 2 Federal Register, Vol. 28, No. 85, May 3, 1973.
- II. 3 Documentation of the Threshold Limit Value for Substances in Workroom Air, Third Edition, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1971
- II. 4 Pesticide Official Publication and Condensed Data on Pesticide Chemicals, Association of American Pesticide Control Officials, Inc., College Park, Maryland, 1955 Supplement.
- II. 5 Pesticide Official Publication and Condensed Data on Pesticide Chemicals, Association of American Pesticide Control Officials, Inc., College Park, Maryland, 1956 Supplement.
- II. 6 Pesticide Official Publication and Condensed Data on Pesticide Chemicals, Association of American Pesticide Control Officials, Inc., College Park, Maryland, 1957 Supplement.
- II. 7 Hygienic Guides, American Industrial Hygiene Association, Akron, Ohio, 1955-1972.
- II. 8 The Merck Index, Eighth Edition, Merck & Company, Inc., Rahway, New Jersey, 1968.
- II. 9 The Toxic Substances List, U.S. Department of Health Education and Welfare, 1973.
- II. 10 Luft, Staub-Reinholt, Vol. 32, No. 10, pp. 28-31, 1972.
- II. 11 Fieldnap, A. C., et al., "Warning Agents for Fuel Gases," U. S. Bureau of Mines Monograph No. 4, 1931.
- II. 12 Prentis, A. M., Chemicals in War, McGraw-Hill Book Co., 1973.
- II. 13 The Chemistry of Acrylonitrile, American Cyanamid Company, The Beacon Press, 1951.
- II. 14 The Chemistry of the Ferrocyanides, American Cyanamid Company, The Beacon Press, 1953.
- II. 15 Bennett, H., Concise Chemical and Technical Dictionary, Second Edition, Chemical Publishing Company, Inc., 1962.

- II.16 Clark, George L., The Encyclopedia of Chemistry, Second Edition, Van Nostrand Reinhold Co., 1966.
- II.17 Miller, S. A., Acetylene, Its Properties, Manufacture and Uses, Vol. 1, Academic Press, 1965.
- II.18 Standen, Anthony, Kirk-Othmer Encyclopedia of Chemical Technology. Second Edition, Interscience Publishers, 1963.
- II.19 Strong, Ralph K., Kingzett's Chemical Encyclopedia, Seventh Edition, Van Nostrand Co., Inc., 1946.
- II.20 CRC Handbook of Chemistry and Physics, 54th Edition, CRC Press, 1973.
- II.21 Lange's Handbook of Chemistry, Sixth Edition, Handbook Publishers, Inc., 1946.
- II.22 ASHRAE Guide and Data Book: Fundamentals, Applications and Equipment Volumes, Published by the American Society of Heating, Refrigeration and Air Conditioning Engineers.
- II.23 Mantell, C. L., Absorption, McGraw-Hill Book Company, Inc., 1945.
- II.24 Bloomfield, Bernard D., "Control of Gaseous Pollutants," Heating, Piping, and Air Conditioning, Jan. 1968.
- II.25 Enneking, J. C., "Control of Vapor Emissions by Adsorption," Air Pollution Control - Part II, July 1973.
- II.26 Contamination Control Handbook, NASA SP-5076, 1969.
- II.27 Air Pollution Manual, Part II: Control Equipment, American Industrial Hygiene Association, 1968.
- II.28 Technical Bulletin T642, Barneby-Cheney, Columbus, Ohio.
- II.29 Technical Bulletin T561, Barneby-Cheney, Columbus, Ohio.
- II.30 Perry, J. H., Chemical Engineers Handbook, Second Edition, McGraw-Hill Book Company, Inc., New York 1941.

III. STATE-OF-THE-ART OF COMMERCIALY AVAILABLE AIR CLEANING EQUIPMENT

The two main objectives of this equipment assessment task were to:

- (1) Perform a technical review of the product specifications that are published by manufacturers of air cleaning devices. The ultimate purpose of this review was to select a recommended air cleaner for each contaminant in Groups 1 through 4 and to construct a list of purchasers of cleaning devices for a review of user experience. Insofar as was possible, the air cleaner recommendations that were performed under this task have been presented in Section II.
- (2) Conduct a review of user experience in order to gather performance, failure rate and maintenance data on selected air cleaners for input to a reliability and fail-safe system analysis.

This section contains a definition of contaminant classes, a discussion and categorization of the various types of cleaning devices, and a summary of the acquisition of product data and the review of user experience.

III. 1 Definition of Contaminant Classes

Workroom contaminants may be grouped into six categories that reflect the physical state and, to some extent, the contaminant generation mechanism. The definitions of these categories that are found in the literature vary to some degree. Therefore, in order to maintain a consistent set of definitions, the NIOSH definitions from Reference III. 1 are reproduced below:

Dusts

Dusts are solid particles generated by handling, crushing, grinding, and detonation of organic and inorganic materials such as rock, metal, coal, wood, and many other materials. Dust particles do not diffuse in air in the classical sense, but the finer

particles of diameters < 20 microns are carried with air currents because the settling rate is so low as to be of no practical significance. Dust particles must be about 5 microns or smaller to reach the lungs; larger particles are filtered out in the nasal passages or other parts of the breathing apparatus.

Fumes

Fumes are small, solid particles created by condensation from the gaseous state, generally after volatilization or by chemical reaction such as oxidation. Fumes are usually submicronic in size.

The outstanding characteristic of most fumes is their tendency to flocculate and coalesce. Very small spherical fume particles tend to attach themselves together in long chains or clumps of particles due to Brownian diffusion and electrostatic attraction.

Smoke

Smoke is the aerosol mixture which results from the incomplete combustion of carbonaceous material such as coal, oil, tar and tobacco.

Mists

Mists are suspended liquid droplets generated by condensation from the gaseous to the liquid state or by breaking up a liquid into a dispersion such as by splashing, foaming and atomizing. Fogs are similar to mists but the term is usually reserved for high concentrations of very fine droplets that are more frequently airborne.

Vapors

Vapors are the gaseous forms of substances which are normally in the liquid or solid state and which can be changed to these states either by increasing the pressure or decreasing the temperature alone.

Gases

Gases are normally compressible, formless fluids which occupy the space of an enclosure and which can be changed to the liquid or solid state only by the effect of increased pressure and decreased temperature or both.

The definitions for fumes and vapors are especially noteworthy. While reviewing manufacturer's product brochures, it was frequently observed that a device was purported to be a fume scrubber, but on close inspection of the schematics, the capture mechanism and the list of "scrubbable" contaminants, it was apparent that the device was an absorber for control of vapors. The lay-definition (dictionary) of a fume includes both particulates and vapors. However, the application of a consistent, unambiguous set of definitions is highly desirable.

III.2 Types of Devices and Principles of Operation

Selection of an air cleaning device is influenced by the contaminant class that is to be controlled. The types of cleaners that are frequently applied to contaminant removal are shown in Table III. 1, which is based on the information that is contained in Reference III.2. Dry centrifugal collectors and settling chambers are sometimes grouped under the sub-heading of mechanical collectors. Selection of a dust, fume or smoke collector is affected by the particle size distribution in the process effluent. For this reason, manufacturers of dry particulate collectors require that the potential user furnish the results of a particle size distribution analysis as well as the thermodynamic and fluid dynamic properties of the carrier gas and particulate in the effluent before a system is recommended.

Collection of any one of the six classes of contaminants is governed by one or more of the following ten contaminant collection or destruction mechanisms:

- (1) Gravity
- (2) Centrifugal force
- (3) Inertial impaction
- (4) Direct interception
- (5) Diffusion
- (6) Electrostatic forces
- (7) van der Waals forces
- (8) Capillary condensation
- (9) Catalytic oxidation
- (10) Direct combustion.

TABLE III. 1 CLASSIFICATION OF COLLECTORS

Dust, Fume and Smoke Collectors

- I. Electrostatic Precipitators
- II. Fabric Collectors
 - a. Intermittent-Duty
 - b. Multi-Section, Continuous-Duty, Automatic
 - c. Reverse-Jet, Continuous-Duty
 - d. Reverse-Flow Collapse, Continuous-Duty
- III. Wet Collectors
 - a. Chamber or Spray Tower
 - b. Packed Tower
 - c. Wet Centrifugal
 - d. Wet Dynamic Precipitator
 - e. Orifice Type
 - f. Venturi
- IV. Dry Centrifugal Collectors
 - a. Cyclone Collector
 - b. High Efficiency Centrifugals
 - c. Dry-Type Dynamic Precipitator
 - d. Louver Type
- V. Settling Chambers
- VI. Unit Collectors

Mist Collectors

- I. Packed Tower
- II. Electrostatic Precipitators
- III. Fabric Collectors
- IV. Centrifugal Collectors

Gas and Vapor Collectors

- I. Absorbers (packed towers)
- II. Adsorbers (activated charcoal and molecular sieve)
- III. Thermal Oxidizers
- IV. Direct Combustors
- V. Catalytic Oxidizers

Table III.2 summarizes the mechanisms that are associated with various cleaner categories. The mechanism key corresponds to the above itemized list.

III.3 Technical Review of Manufacturer's Specifications

Using the Thomas Register and the Conover-Mast Purchasing Directory, a list of 180 manufacturers of air cleaning devices was assembled. In constructing this list, an attempt was made to obtain equal corporate representation in the areas of dry particulate, liquid particulate, and gas and vapor collectors. These manufacturers were then contacted by letter to request copies of their published product brochures (marketing catalogs, service bulletins, etc.) that are normally made available to potential clients. Proprietary information was not requested. The letter indicated that the requested information would be used to identify items such as:

- (1) Electromechanical, hydraulic and pneumatic schematics
- (2) Operating instructions
- (3) Power requirements
- (4) Usage restrictions
- (5) Periodic maintenance procedures and recommended schedules
- (6) Purchasers of specific items of equipment
- (7) Test procedures
- (8) The class of cleaner that is appropriate to a specific contaminant
- (9) General performance data.

Seventy-three responses were received. However, the quality of the response was highly variable. To obtain a measure of the quality of the information that was received, each response was graded as either R, for a positive response that contained usable technical information, or NR which constituted a nonusable reply. A reply was considered usable if it included data that was applicable to the task efforts that are described in Sections II and IV of this report. An NR rating was assigned if any of the following criteria was satisfied:

- (1) The brochures did not contain a technical description of the device(s), principle(s) of operation and performance data.

TABLE III.2
CAPTURE MECHANISMS FOR AIR CLEANING
DEVICES

<u>Cleaner of Type</u>	<u>Mechanism(s)</u> [*]
Fabric Collectors	3 + 4 + (5) + (6)
Wet Collectors	(2) + 3 + 4
Dry Centrifugal	2 + 3
Settling Chamber	1
Electrostatic Precipitators	6
Adsorbers	7 + 8
Absorbers	5

^{*}Numbers in parentheses indicate additional mechanisms for specific configurations.

- (2) The brochures pertained to inappropriate equipment because the corporate name had been listed under an incorrect heading in the product catalogs.
- (3) The company no longer manufactures air cleaning equipment or is no longer in business.

Of the 73 responses, 33 or 18.3 percent of the original 180 contained appropriate information; 40 or 22.2 percent of the original 180 requests were unusable. These figures indicate that 59.5 percent of the manufacturers chose not to respond in some fashion.

Simultaneously, a reader service review of wet scrubbers was initiated through the May 1974 issue of Pollution Engineering. The response rate was 61.5 percent (56 of 91). These responses were not graded as in the previous case because in several instances there was duplication of an NR rating, or manufacturers chose not to respond to either request. Air cleaner manufacturers (33 of 180 and 56 of 91) were then categorized according to the type of contaminant and cleaning device that was presented in Table III.1. This classification list will not be reproduced in this report because it was felt that the sample size was not representative of the true state of air cleaner availability.

III.4 Review of User Experience

The object of this review was to obtain performance, maintenance and failure rate data for input the system reliability analysis. The users or purchasers of air cleaning equipment were identified from the responses that were received in Section III.3. Seventeen manufacturers supplied user lists. Where the type of device and application were not noted in the user lists, the manufacturers were recontacted to obtain this necessary information.

Nine user evaluations were to be conducted. With this number of evaluations it was, of course, not possible to include all major cleaner classes for particulates, gases and vapors. Therefore, the plan was to maximize the input to the reliability analysis by restricting the evaluation to systems that were currently being used to remove mists, gases and vapors. This approach is justified because (1) the majority of the contaminants in Groups 1 through 4 (Section II) are gases and vapors, and (2) References III.3, 4 and 5 contain user evaluations for wet scrubbers, electrostatic precipitators and fabric collectors as applied to dry particulate control. Duplication of this effort was not warranted.

Eight users of mist, gas and vapor collectors were contacted by telephone and all verbally agreed to participate. A user of a high efficiency, multi-cyclone was included in the nine evaluations after all users of mist,

gas and vapor collectors had been exhausted. Table III.3 indicates the industrial scope of the user review. Forty telephone contacts were made to obtain nine approvals. Seven organizations chose to fill out a questionnaire, and members of the project team made an on-site visit to two users. Of the seven questionnaires, four were completed to some degree and were returned. Three organizations ultimately chose not to complete the questionnaire.

The questionnaire was constructed in five parts; two parts were:

- I. General - general information regarding the type of cleaner, application and a description of the process.
- II. Properties of Carrier Gas and Contaminants - temperature, pressure, flow rate, gas composition, particle size distribution (if applicable), contaminant concentrations, etc.

These two parts were specially tailored to each type of cleaner that was involved in the review. The remaining three parts were common to all reviews, and they are reproduced in Appendix I. These last three sections deal with the fate of the air cleaner effluent, methods and procedures for monitoring system performance and contaminant concentrations, and equipment failure and maintenance experiences.

The significant results of this review process are as follows:

- (1) The electrostatic precipitator is currently being used in a recirculation mode for the removal of machine tool oil mist. In these cases, however, the effectiveness of the device as measured by the oil concentration in the cleaner effluent has not been determined under operating conditions.
- (2) With the exception of one absorber installation, contaminant removal efficiency is either unknown or is assumed to be unchanged from the value stated by the manufacturer. Accepted stack sampling procedures were used on the absorber effluent, with a laboratory analysis by an ion probe.
- (3) The average off-line time per failure ranged from 30 minutes to 4 hours; the majority of the failures were electrical in nature. An isolated failure of a combustor flame detector was experienced. Typical preventive maintenance actions included weekly lubrication of fan bearings, weekly cleaning of collector plates on precipitators and weekly inspection of absorber spray nozzles for calcium deposits.

TABLE III. 3
AIR CLEANER USER REVIEW

<u>User No.</u>	<u>Type of Cleaner</u>	<u>Process or Contaminant</u>	<u>Status*</u>
1	multi-cyclone	instant coffee powder	Q
2	electrostatic precipitator	machine tool oil mist	Q
3	electrostatic precipitator	machine tool oil mist	V
4	absorber	glass etching with hydrofluoric acid	V
5	absorber	acid mist and organic vapors	Q
6	adsorber	isopropyl alcohol recovery	Q
7	adsorber	paint solvent vapors and mists	Q
8	direct flame combustor	NO _x from acid leaching of steel	Q
9	catalytic oxidizer	acrylic acid, xylene and hydrocarbon vapors from wire coating process	Q

*Q - Questionnaire to be completed by user
V - field visit by project team

- (4) Four of the six air cleaners operate continuously (three shifts per day).
- (5) System parameter monitoring included detectors for fan outage and failure of system power, a gas sensor for adsorber effluent and an ultraviolet flame-out detector. The monitors were not capable of initiating corrective action, although, in one case, a visual signal appeared at failure.
- (6) In general, a negligible amount of information was received on the physical properties of the carrier gas and the contaminant.

Based on this small sampling of industrial contaminant control, it was concluded that the type of information that is required for fail-safe system design is not readily available. This posture is somewhat understandable. From a corporate operations standpoint, monitoring of system performance and accumulation of failure rate data and preventive maintenance actions are nonproductive overhead items even in cases where compliance with stationary source emission standards is mandatory. This information is more apt to be available where it is economically advantageous to recover process effluent.

III. 5 References

- III. 1 The Industrial Environment--Its Evaluation and Control, U.S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, 1973.
- III. 2 Industrial Ventilation Manual, American Conference of Governmental Industrial Hygienists, 13th Edition, 1974.
- III. 3 Wet Scrubber System Study: Volumes I and II, A. P. T., Inc., EPA R2-72-118, CPA 70-95, July 1972.
- III. 4 Electrostatic Precipitator Systems Study: Part I- Fundamentals, Part II - Applications, Bibliography and Final Report, PHS CPA 22-69-73, March October 1970.
- III. 5 Fabric Filter Systems Study: Volumes I, II, III and IV, GCA Corporation, CPA 22-69-38, December 1970.

IV. RELIABILITY, MAINTENANCE, FAIL-SAFE, CONTROL AND SAMPLING PROVISIONS FOR RECIRCULATED EXHAUST AIR SYSTEMS

Worker safety should be the dominant consideration in the design of a recirculated exhaust air system for industrial applications. The design must, therefore, be fail-safe in the sense that it minimizes the probability of excessive exposure to workroom contaminants caused by failure of a major system component or subsystem. In this section, two recirculation models are developed, and each model is analyzed for system reliability. The requirements for monitoring and automatic control systems are investigated.

It should be noted that both recirculation models incorporate redundant or backup prime air movers. This level of redundancy is not normally encountered in practical applications because the blower-motor combination is a highly reliable device. The backup blower concept serves two purposes. First, it demonstrates the versatility of the reliability analysis, and second, the loss of air moving capability in a one-blower system would require total process shutdown.

IV. 1 Reliability, Maintenance and Fail-Safe Considerations

IV. 1. 1 Physical Models of Recirculation Systems

Two basic recirculation systems have been devised and evaluated:

- Case I. This model incorporates a redundant or backup air cleaner in parallel with the primary cleaner. The inlet and exhaust air flows are manifolded into a common duct system.
- Case II. Where redundant air cleaners are not feasible because of economic or space limitations, provision has been made for bypass of contaminated air to the atmosphere in the event of an air cleaner failure.

Both systems are instrumented with sensors and monitors for analysis of fail-safe operations. These models, which are described below, are oriented

toward contaminant removal from the recirculated airstream. Provisions for temperature and humidity treatment of the recirculated airstream are process-dependent and, therefore, should be considered at another level of investigation. The models have been purposely simplified in order to demonstrate the salient features of a recirculation system.

The physical model for Case I is shown in Figure IV.1. Under normal operating conditions, the contaminated inlet air from either a local exhaust hood or a ceiling vent enters the primary blower duct where it is processed by the primary air cleaner and then returned to the workroom. In the event of a malfunction of the primary blower motor, the backup blower is activated and the inlet air is manifolded through the backup duct. If the primary cleaners fails, the air flow is diverted by a butterfly valve or damper to the backup air cleaner, thus isolating the primary cleaner. The damper is controlled by a drive motor and linkage. The blowers in Figure IV.1 have been placed upstream of the air cleaners. Without loss of generality, they can be placed in the ducting downstream of the cleaner if the cleaner normally operates a negative pressure or if contaminant-induced corrosion of the blower impeller and housing is an important consideration. A contaminant monitor probe is located in the common exhaust duct.

In order to sense a component failure and initiate corrective action, the system must be instrumented with transducers so that specified failure parameters can be monitored continuously. A list of typical sensors may include:

- (1) A sensor to monitor blower-motor and damper drive motor rpm or armature amperage.
- (2) A microswitch or proximity gage to detect closure of the damper valve.
- (3) Performance parameter sensors for the primary and backup air cleaners. Examples include differential pressure transducers for fabric filters, a voltage or amperage sensor for the ionizer section of an electrostatic precipitator, absolute pressure transducers for liquid supply lines on wet scrubbers, etc.

Regardless of the number of performance parameters that are monitored and the type of transducer that is employed, the sensor electrical output for each channel is input to a separate failure control module; the input signal is compared to a set point value that corresponds to an acceptable level of the performance parameter. If the input signal is within specified limits, normal operation continues. If the input signal is out of tolerance, an error signal is generated internally indicating a subsystem failure. At this point, several courses of corrective action can be designed into the system.

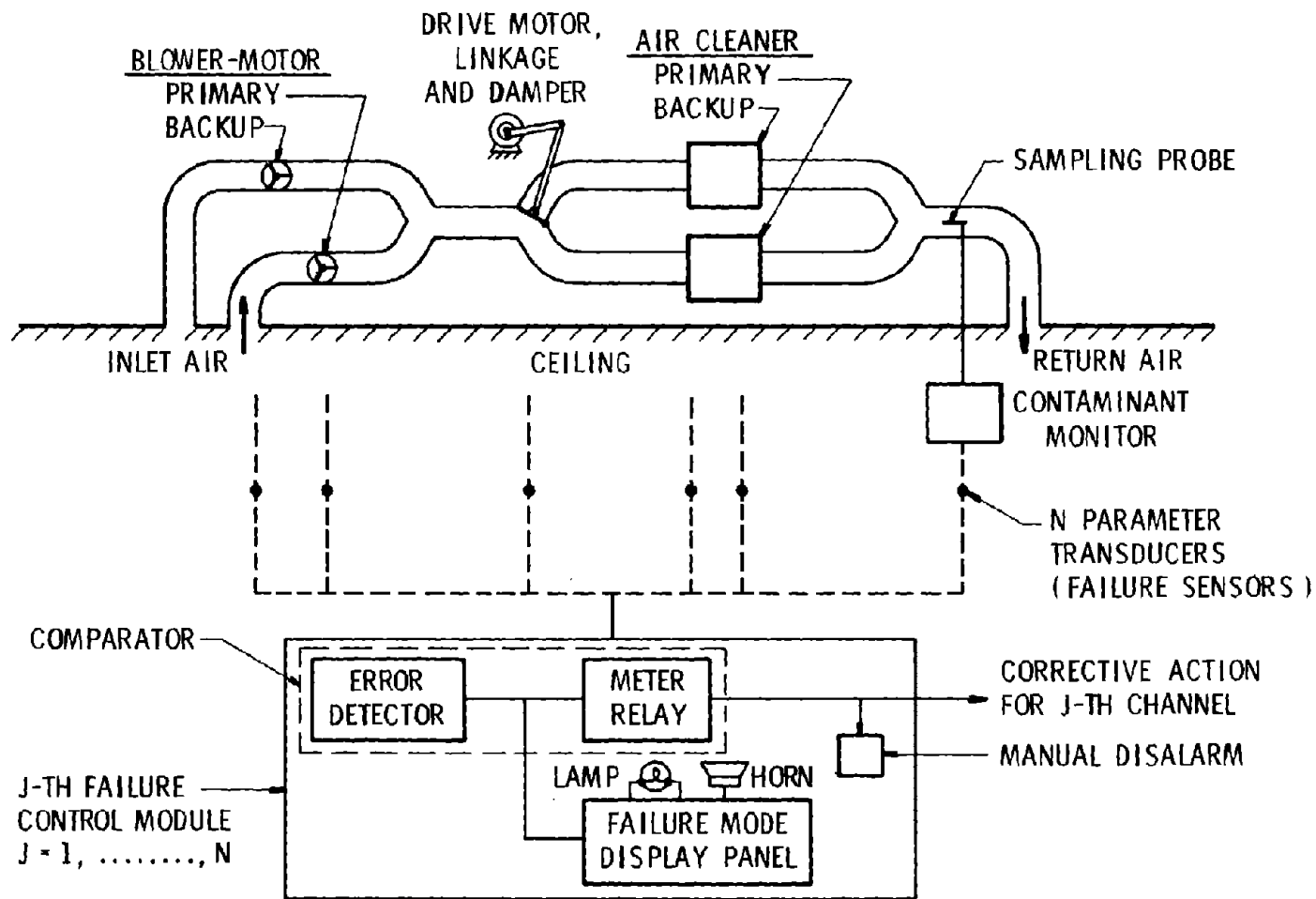


Figure IV.1 Physical Recirculation Model for Case I : Redundant Air Cleaners

- (1) Completely automatic switching to the backup unit with no audio-visual indication of malfunction.
- (2) Backup switching by manual action in response to audio-visual alarms.
- (3) Automatic switching to backup with audio-visual alarm and manual disalarm.

Of the three options, the third course of corrective action is preferred because it is least likely that the failure will go unnoticed (Option 1), and switching delays resulting from a manual interaction with the system (Option 2) will be minimized. The third option is shown in Figure IV.1 where the error signal is input to a meter relay that automatically selects a preprogrammed course of action. An audio-visual alarm is activated in response to the error signal and will remain on, after switching, until it is manually disarmed by an operator. In this manner, the mode of failure can be logged and corrective maintenance actions can be initiated. The ensemble of control modules should be designed to accommodate manual or automatic process shut-down in the event that either a backup unit fails while the primary unit is off-stream for repair, i.e., coincident failure, or the contaminant monitor fails (Section IV.2.2). If the manifold damper fails to close, a manual override of the damper drive mechanism (hand crank) should be provided.

Many on-line contaminant monitors have an integrated failure control module. Whether the module is integrated or remote, the error set-point should coincide with the calibration signal that corresponds to the permissible exhaust duct concentration, C , that is derived in Section V. If this set-point is exceeded, the workroom concentration has violated the contaminant TLV, and the backup air cleaner should be activated.

The essential difference between the model for Case I and the model for Case II, which is shown in Figure IV.2, is that, if an air cleaner failure is detected, either by the transducers on the cleaner or the concentration monitor, the process exhaust is diverted to the atmosphere. In this example, the prime air movers must be located upstream of the bypass damper. Blower selection merits special consideration if corrosive vapors are to be processed.

In Case I, the exhaust air flow rate balances the return air flow rate, and the workroom static pressure is equal to or greater than ambient pressure. However, in Case II, the net flow of air into the room will be negative after the bypass mode is activated and a corresponding negative pressure buildup in the room will occur if some provision is not made to replace air from another source in an amount equalling 90 to 110 percent of the bypass flow rate. Infiltration of ambient air through doors and windows cannot be expected to make up the deficit in flow rate. This situation is easily remedied

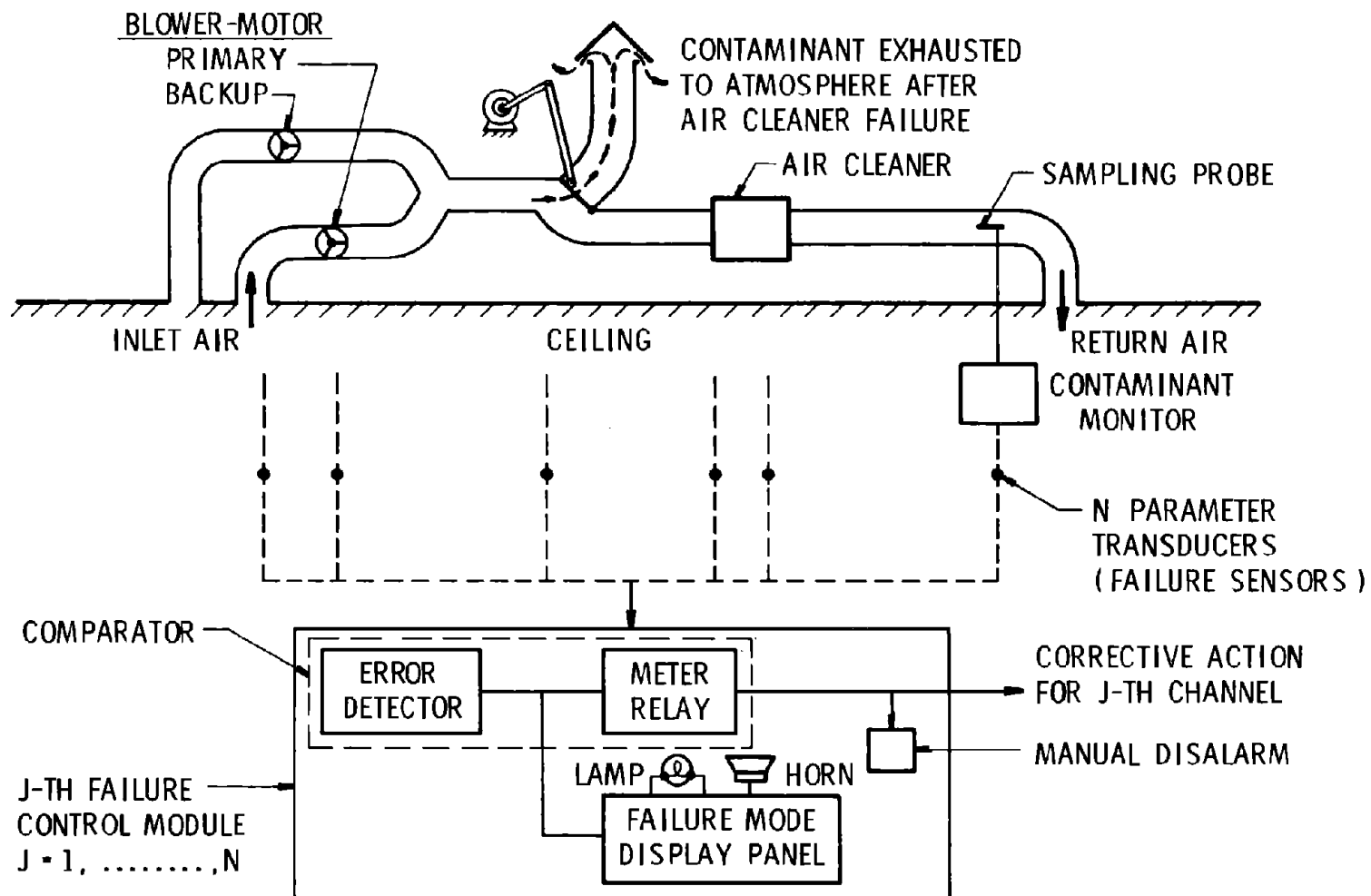


Figure IV.2 Physical Recirculation Model for Case II : Air Cleaning with Bypass

by using the bypass damper closure signal or the air cleaner failure signal to activate a standby makeup air unit (general ventilation blower). If this makeup unit is mounted on the roof, the fan inlet should be remote to the ambient exhaust duct in order to minimize entrainment of contaminant into the workroom.

IV. 1.2 Functional Recirculation Models

Fail-safe operation of recirculating air cleaning systems can be achieved in two fundamental ways:

- (1) Provide separate backup and control systems for critical subsystems or components, or,
- (2) If separate backups are not feasible, exhaust contaminated air to the outside atmosphere when a critical failure occurs in a nonredundant subsystem.

The major consideration in determining how (or if) fail-safe operation will be achieved appears to be primarily economic, i.e., how much will it cost to install and maintain a fail-safe recirculating air cleaning system? Two system parameters which exert a major impact on the economics of fail-safe recirculating air cleaning systems are equipment reliability and system operating maintenance requirements. The following subsections discuss the ramifications of cleaning system equipment reliability and maintenance parameters as they affect overall system operational fail-safe characteristics and effectiveness.

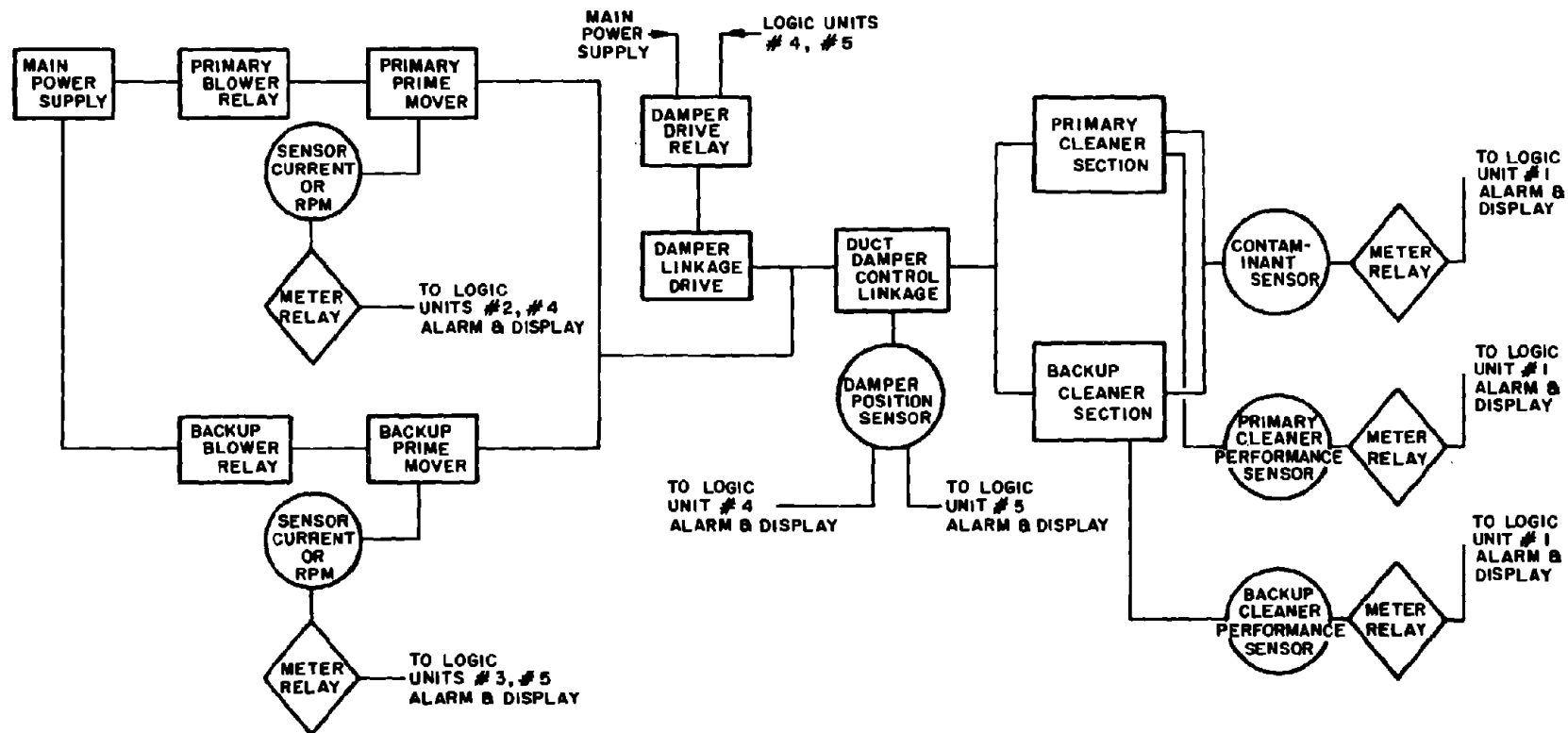
In reviewing published literature, it was found that a very meager amount of information is available concerning the operating reliability and maintenance of air cleaners. Information received from the user questionnaires revealed that the users do not maintain comprehensive records on equipment failures or maintenance requirements. The data that are available lack sufficient detail to be used as a basis for estimating state-of-the-art air cleaner equipment fail-safe performance. No meaningful information on operating reliability or preventive maintenance levels, required or established, was supplied in answers on the questionnaires. It thus became apparent that an organized approach or methodology has not been developed and implemented to collect and document historical data on the operating reliability characteristics and maintenance requirements of air cleaner systems, subsystems or components.

This gap in the availability of air cleaner equipment operating data represents a major stumbling block in analyzing, evaluating and developing criteria for the fail-safe operation of recirculating air cleaning systems for industrial processes. Because of this lack of existing data, and in order to establish a preliminary set of air cleaner fail-safe criteria, it became

necessary to develop an approach based on a set of generic reliability models which could be used to analyze and evaluate the sensitivity of the system fail-safe operation to variations in equipment reliability and maintenance parameters. These generic reliability models are constructed in such a manner that cleaner subsystem or component reliability is the variable or independent parameter. This approach provides the flexibility that is necessary to analyze and evaluate the influence of subsystem and component reliability on the fail-safe characteristics of any type of air cleaning system by relating the specific cleaner type under consideration to one of the generalized reliability models. To provide the necessary background and perspective for further discussion on the development of generalized reliability logic models functional operating block diagrams were initially developed and are shown in Figures IV.3 and IV.4. These functional operating models are based on the cleaning system diagrams in Figures IV.1 and IV.2. The purpose of constructing these models was to indicate the functional operating interactions and relationships among the various subsystems and components that make up a recirculating air cleaning system.

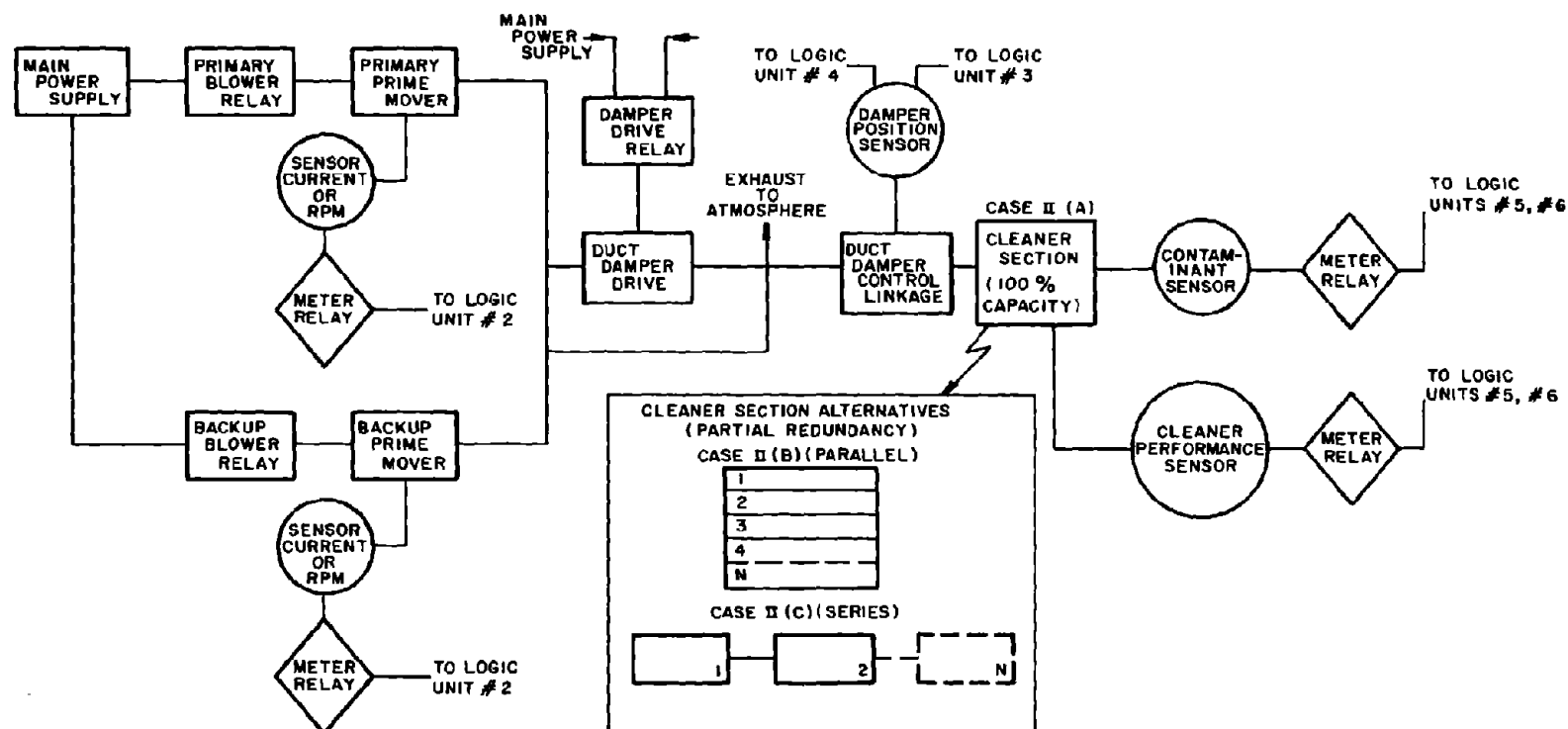
The fail-safe system concept for Case I is based on providing adequate standby or redundant prime movers and cleaner sections, monitoring, warning and control devices, and corrective and preventive maintenance procedures, such that the probability of a subsystem or component failure, which would result in the recirculation of excessive contaminant concentration levels, is negligibly small. As indicated by Figure IV.3, this concept requires at least one standby for each major subsystem or critical component, i.e., two prime movers, two cleaner sections, several parameter sensors, control devices, relay meters, and a display console. Obviously, this approach, for large systems, could become complex and expensive.

The concept for Case II represents a set of cleaning systems that ultimately rely on exhausting contaminated air to the atmosphere in the event of a critical failure. Two alternatives to this basic configuration were developed to add greater flexibility in analyzing specific cleaner types. Referring to Figure IV.4, Case II(A) assumes a single cleaner section operating at 100-percent capacity during peak loading. Cases II(B) and II(C) represent alternative configurations in which the cleaner can be separated into several cleaner subsections that are connected either in parallel or series. These latter two configurations are partially redundant. This partial redundancy is achieved by initially designing the cleaner to handle a given percentage of the peak excess cleaning capacity beyond that which would normally be required based on design calculations. For example, if the required cleaning capability can be achieved with two stages, then adding a third stage would permit failure of one of the the three stages and still leave the system with adequate cleaning capability. If a second stage failed, prior to repair or replacement of the first failed stage, then the cleaner system would be considered inoperative, and the contaminated air would be exhausted to the atmosphere.



NOTE: SEE SECTION IX.2.1 FOR LOGIC UNIT DIAGRAMS

Figure IV.3 Physical Function Block Diagram: Fail-Safe Operation With Backup, Case I



NOTE: SEE SECTION IV.2.1 FOR LOGIC UNIT DIAGRAMS

Figure IV.4 Physical Function Block Diagram: Fail-Safe Operation Without Backup, Case II (A), II (B), II (C)

For the various types of cleaning systems, the possible configurations are almost limitless. However, as is shown, it will be possible to analyze and evaluate the fail-safe characteristics of almost any type cleaner and cleaner configuration by relating its configuration to one of the generic models represented by Case I or the three alternate versions of Case II.

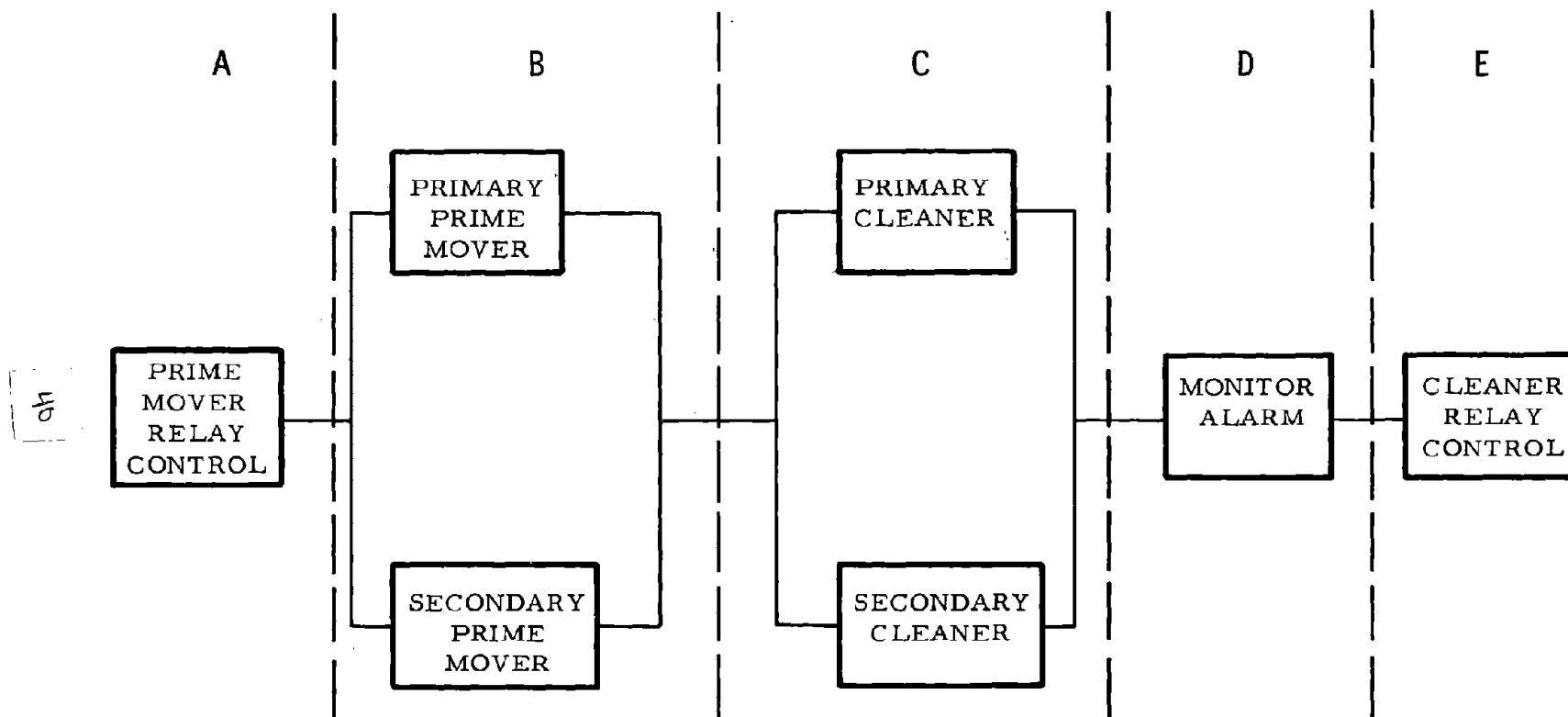
It should be pointed out that the Case II configuration retains the backup prime mover concept. This redundancy is deemed essential because loss of the prime mover, with no backup capability, could be catastrophic for a failure which requires contaminated air to be exhausted to the atmosphere.

IV. 1.3 Generic Reliability Logic Models

This section describes the generic reliability logic diagrams that were derived from the functional operating block diagrams. Reliability logic diagrams are based on breaking down the total cleaning system into a number of distinct functional operating units so that a single reliability number or probability failure distribution can be defined for each subsystem. The overall reliability of the system can then be expressed analytically as a function of the reliability of its individual subsystems. The advantage of this approach is the extreme flexibility that it offers in analyzing the sensitivity of overall system reliability to variations in reliability of the individual subsystems and components.

Figures IV.5(a) and IV.6(a, b, c) show the reliability logic diagrams that were derived from the functional block diagram models of Figures IV.3 and IV.4. Case I, Figure IV.5(a), depicts the single backup (no exhaust to atmosphere) configuration. Case II, Figures IV.6(a, b, c), represent the configurations for exhaust-to-atmosphere with partial redundancy. As previously discussed, there are three variations of the Case II configuration. Case II(A) assumes no partial redundancy with exhaust to atmosphere for any critical cleaner section failure. Case II(B) assumes a cleaner system with excess capacity utilizing several individual cleaner units operating in parallel. Case II(C) assumes excess cleaner capacity with the several individual cleaner units connected in a series configuration. It is shown later that the system reliability characteristics of essentially all cleaner types can be analyzed by relating the particular cleaner configuration to the generalized reliability block diagrams of Case I or one of the three versions of Case II.

Referring to Figure IV.5(a), for purposes of reliability analysis, the system is broken down into its major subsystems (A through E). Each of the major subsystems can then be subdivided into its basic components as shown in Figures IV.5(b) and IV.5(c). Obviously, this latter breakout of each subsystem requires information on component reliabilities which is not always available in sufficient detail. It is thus common practice to use reliability estimates at the level of the major subsystems (A through E).



NOTES :

1. PRIMARY PRIME MOVER AND CLEANER ARE FOR NORMAL OPERATION. SECONDARY SYSTEMS ARE IN STANDBY MODE.
2. RELAY CONTROLS INCLUDE LINKAGE FOR SWITCHING DUCT AIR FLOW.

Figure IV.5(a) Case I : Reliability Logic Diagram - Subsystem Backup

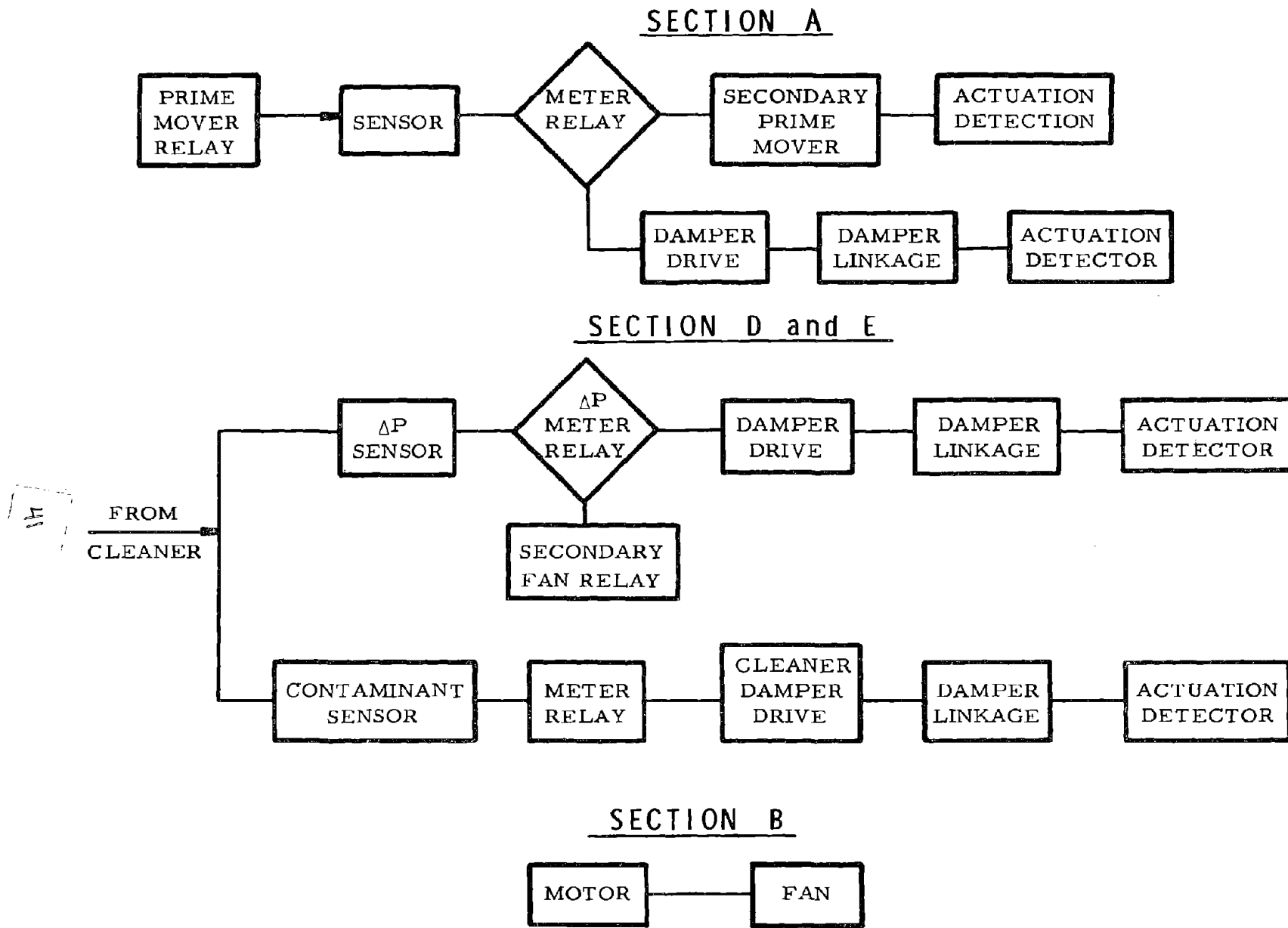
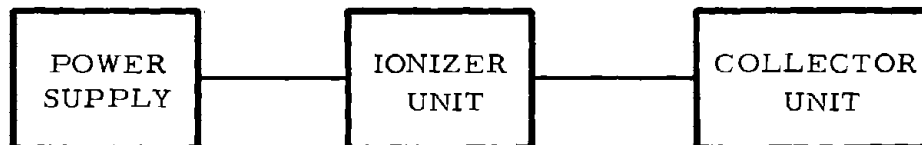


Figure IV.5(b) Case I : Reliability Logic Diagrams for Subsystems A, B, D and E



FABRIC FILTER CLEANER



ELECTROSTATIC PRECIPITATOR CLEANER

Figure IV.5(c) Examples of Reliability Logic Diagrams for Subsystem C

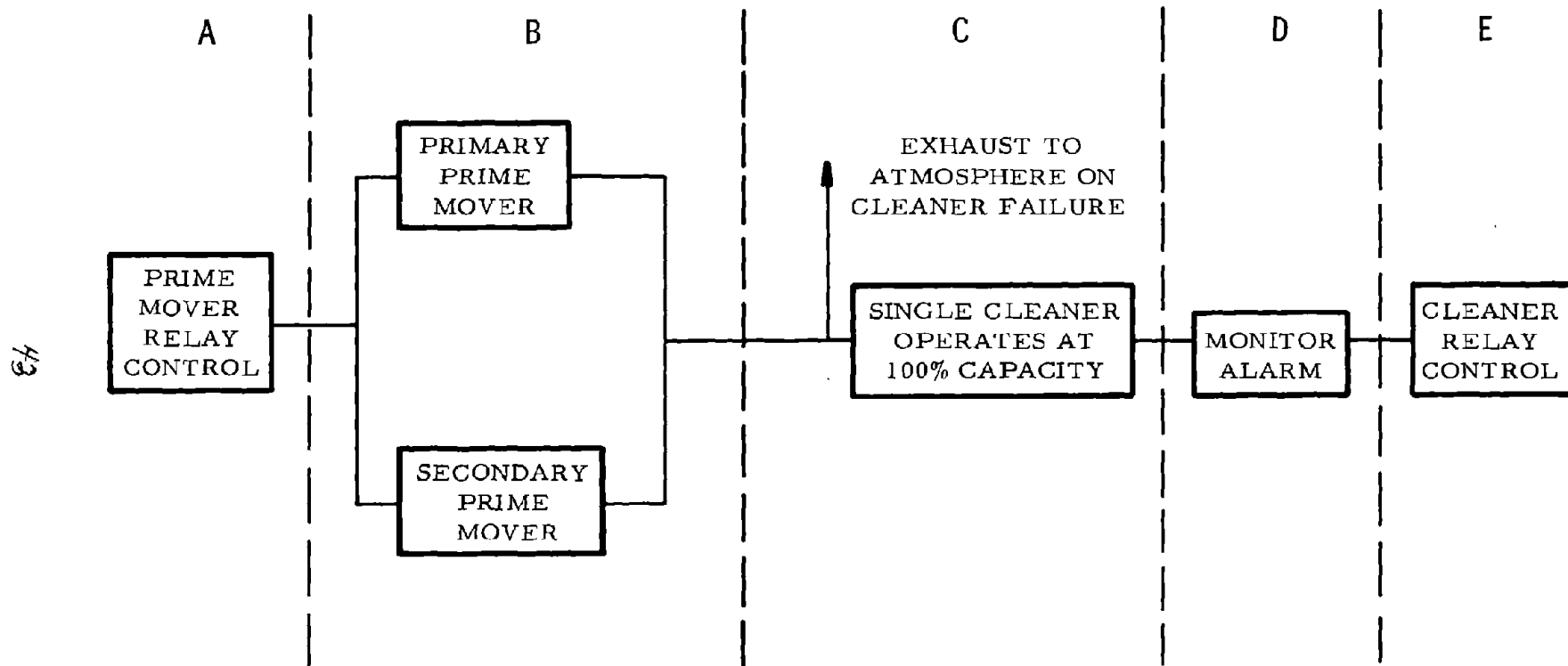


Figure IV.6(a) Case II (A): Single Cleaner With No Excess Cleaning Capacity - Exhaust to Atmosphere

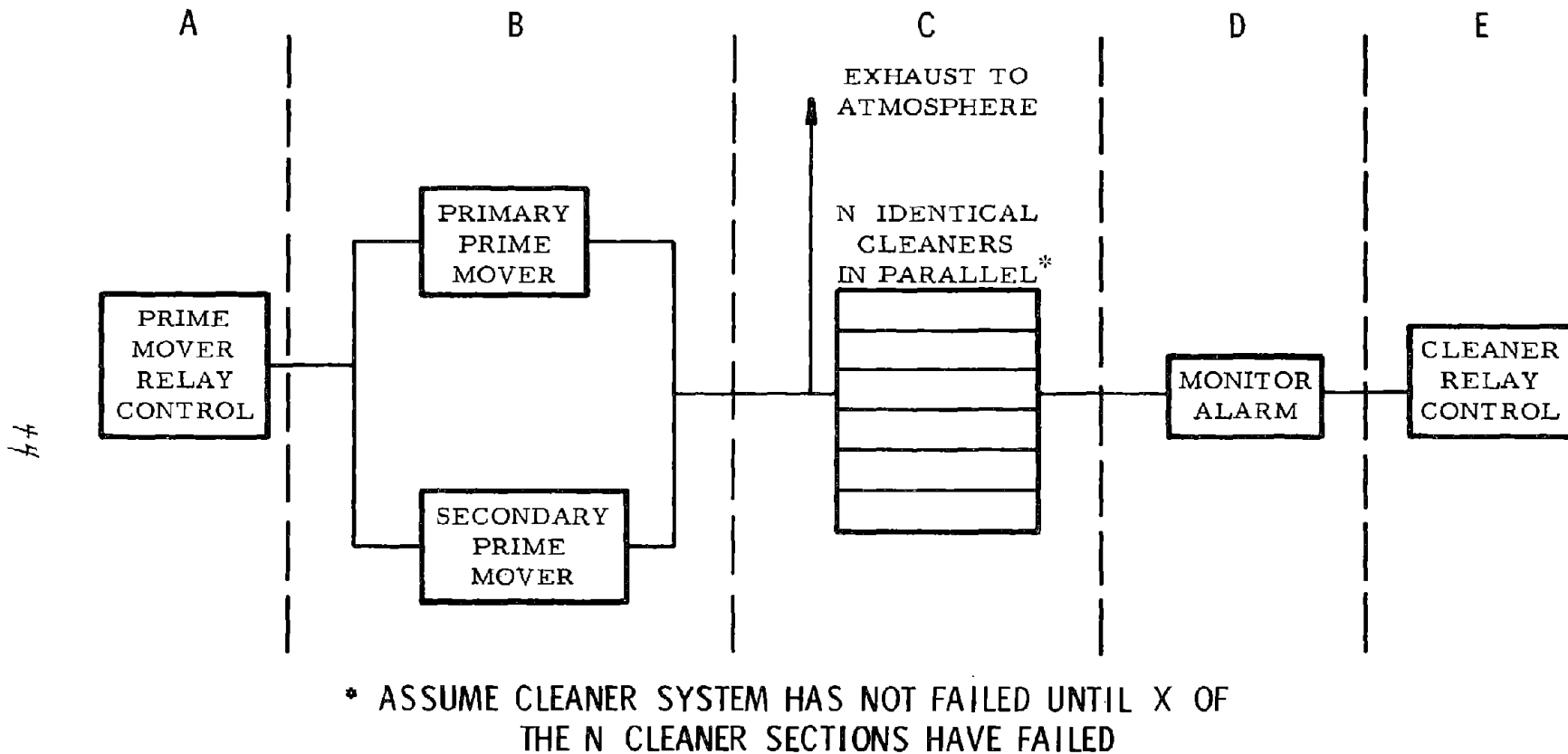


Figure IV.6(b) Case II (B) : Single Cleaner With Excess Cleaning Capacity in Parallel

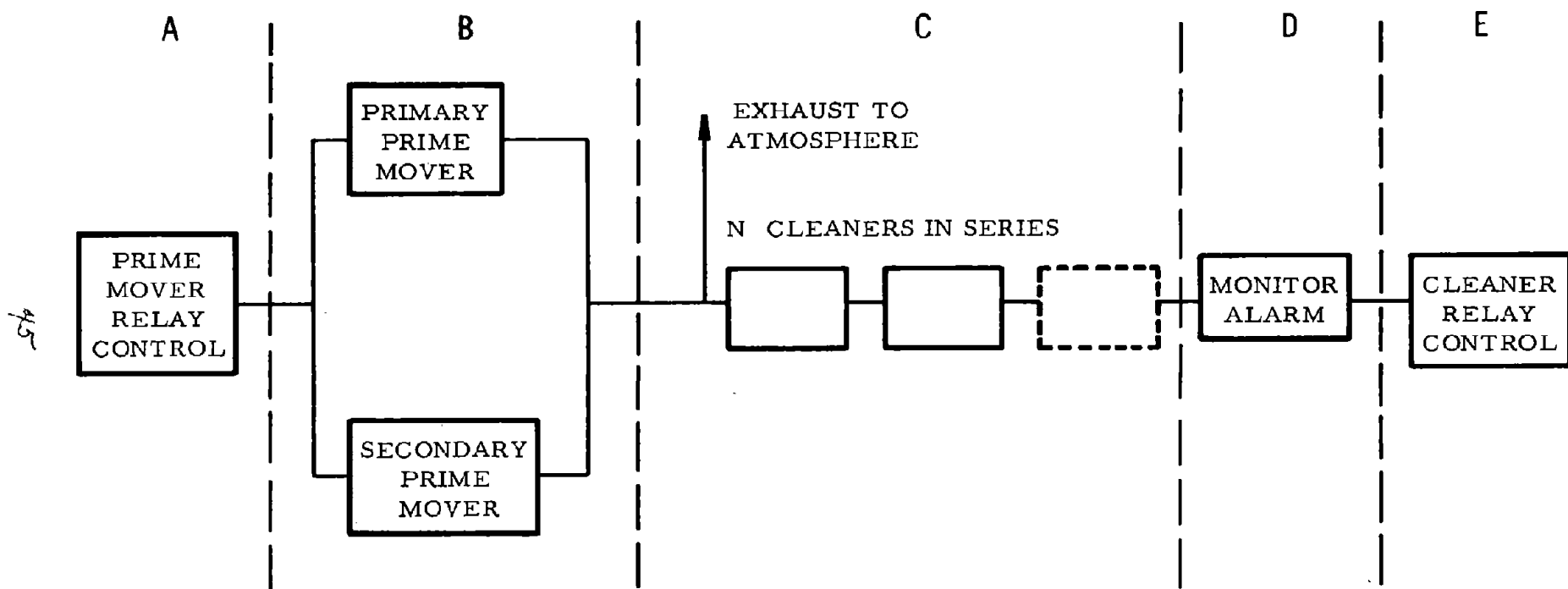


Figure IV.6(c) Case II (C): Cleaners in Series With Excess Cleaning Capacity

Case I - Redundancy with Standby Subsystems

As shown in Figures IV.5(a), this configuration is a combination of single and parallel sections connected together in series. The blower relay control automatically switches to the backup blower in the event that the primary system fails. The cleaner relay control performs the same function for the two parallel cleaner sections when the air cleaner transducers detect a failure in the primary unit. Referring to Figure IV.5(a), the system reliability, R_s , as a function of time, t , can be expressed as the product of the reliability of the individual sections, A through E, connected in series (Reference IV.1). That is,

$$R_s(t) = \prod R_i(t) \quad (IV.1)$$

where $R_i(t)$ is the reliability of the i -th section at time t . Failures of individual sections will be assumed to follow the exponential time-to-failure probability distribution, $R_i(t) = e^{-t/m_i}$, where

m_i = mean time between failure (MTBF) of the i -th section

t = operating time of the i -th section

The exponential distribution is the most widely used and accepted failure distribution when sufficient data is not available with which to establish the true failure distribution. It is further assumed that the reliability of the relay control units are independent of operating time and can be represented by a constant value, k . The value of k will vary depending on the particular relay control unit. This is a reasonable assumption because commercially available relay control units are normally designed to be actuated on the order of 10^6 cycles.

Based on the above assumptions and using Equation IV.1, the system reliability for Case I can be expressed as

$$R_s(t) = e^{-(t/m_b)} (1 + k_a t/m_b) \cdot e^{-(t/m_d)} \cdot e^{-(t/m_c)} (1 + k_e t/m_c) \quad (IV.2)$$

where

$R_s(t)$ = system reliability

t = system operating time

m_b = MTBF of each prime mover

m_c = MTBF of each cleaner unit

m_d = MTBF of the contaminant monitor

k_a = reliability of prime mover relay control

k_e = reliability of cleaner section relay control

The above expression accounts for the fact that the parallel backup prime mover and cleaner units are in standby mode (nonoperating with unit reliability) until the primary unit fails (Reference IV.2).

Case II(A) - Exhaust to Atmosphere

Using the same approach as described in Case I, system reliability for Case II(A), Figure IV.6(a), can be expressed as:

$$R_s(t) = e^{-(t/m_b)} (1 + k_a t/m_b) \cdot k_e e^{-(t/m_c)} \cdot e^{-(t/m_d)} \quad (IV.3)$$

where the terminology is the same in Equation IV.2.

Case II(B) - Partial Redundancy, Exhaust to Atmosphere, Cleaner Subunits in Parallel

The general approach to this case is identical to the previous cases except for Section C, Figure IV.6(b). The constraint on Section C was that the cleaning unit has excess capacity in the sense that an individual cleaner subunit may fail, but the remaining sections have adequate cleaning capability. If the air cleaner is made up of N identical subunits connected in parallel, the criterion for fail-safe operation is that X of the N subunits must be operating. The general expression for this criterion, assuming all subunits are operating, is taken from Reference IV.3:

$$R_c(t) = \sum_{r=x}^N e^{-(rt/m_c)} \binom{N}{r} \left[\sum_{i=1}^{r-x+1} \binom{r}{i-1} (-1)^{i+1} \right] \quad (IV.4)$$

where $\binom{N}{r} = \frac{N!}{r!(N-r)!}$

m_c = MTBF of each cleaner subunit, and i, r are dummy variables.

The variable, r , takes on integer values from x to N .

For illustrative purposes, the above expression has been evaluated assuming that two of the cleaner subunits ($N - x = 2$) may be allowed to fail. Then,

$$R_c(t) = \frac{N(N-1)e^{-\frac{(N-2)t}{m_c}}}{2} + N(N-2)e^{-\frac{(N-1)t}{m_c}} + \left(\frac{N^2 - 3N + 2}{2}\right)e^{-\frac{Nt}{m_c}} \quad (IV.5)$$

Using Equation (IV.1), the system reliability is:

$$R_s(t) = e^{-(t/m_b)} (1 + k_a t/m_b) \cdot k_e e^{-(t/m_d)} \cdot R_c(t) \quad (IV.6)$$

If we assume that $(N - x)$ cleaner subunits are on standby (not operating with unit standby reliability), then Equation (IV.5) becomes:

$$R_c(t) = \sum_{r=0}^x e^{-\frac{Nt}{m_c}} \frac{(Nt/m_c)^r}{r!} \quad (IV.7)$$

The practical implications of the Case II(B) configuration are that the design of the air flow ducting must be such that any failed subunit can be isolated from the main air stream, and each subunit must be accessible for equipment repair without interrupting the cleaning operation. These design requirements may not be feasible for certain types of cleaning systems.

Case II(C) - Partial Redundancy, Exhaust to Atmosphere, Cleaner Subunits in Series

This configuration, Figure IV.6(c), is identical to the previous case except that the cleaner subunits are connected in series. The only practical application of this configuration is a design which allows uninterrupted air

flow if failure occurs in one or more of the series subunits. Bypass ducting would also be required to isolate the failed subunits for repair or replacement while the system remains in operation. If the above requirements can be satisfied, the system reliability can be calculated using Equation (IV.6)

Table IV.1 summarizes the characteristics and reliability equations of the generalized reliability logic diagrams that have been developed in this section.

IV.1.4 System Reliability Sensitivity Analysis

In this section, examples are presented that are based on the reliability expressions developed in Section IV.1.3. General reliability trends are indicated and comparisons are made of the several different fail-safe configurations. Sensitivity of total system reliability to variations in cleaner subsystem and component mean-time-between failure is shown as a function of operating time.

Failure Rate Summary

As previously pointed out, adequate historical reliability data for the cleaner or collector section of the air cleaning system is not available in the published literature. A standard procedure that is often employed in estimating failure rates is to utilize data that has been compiled for a range of similar subsystems or components regardless of the application or the operating environment. Again, because of the uniqueness of air cleaner subsystems, applicable data are not available. However, failure rate data for certain peripheral components in the cleaning system are available and are summarized in Table IV.2. In some cases, a range of failure rates is shown to indicate the impact of operational environment and component type.

Effect of Air Cleaner Redundancy

Figure IV.7 compares system failure probability as a function of operating time for Case I (single backup cleaner section), Case II(A) (no backup cleaner section), and Case II(B) (partial backup cleaner section). In comparing these three configurations, the following assumptions were made. The cleaner section for Case II(B), Section B of Figure IV.3, is assumed to have six identical but separate subunits. Two curves are shown for this case; either four of six or five of six cleaner subunits are required to be operating in order to provide adequate cleaning capability. To make a meaningful comparison, an equivalent MTBF for the cleaner was computed in the following manner:

TABLE IV.1

SUMMARY OF GENERIC RELIABILITY MODELS

Reliability Model	Fail Safe Configuration	System Reliability $R_s(t)$
Case I	Parallel subsystem backup	$R_s(t) = e^{-(t/m_b)} (1 + k_a t/m_b) \cdot e^{-(t/m_d)}$ $\cdot e^{-(t/m_c)} (1 + k_e t/m_c)$
Case II(A)	No cleaner backup, exhaust to atmosphere	$R_s(t) = e^{-(t/m_b)} (1 + k_a t/m_b) \cdot k_e e^{-(t/m_c)} \cdot e^{-(t/m_d)}$
Case II(B)	Partial backup, cleaner subunits in parallel	$R_s(t) = e^{-(t/m_b)} (1 + k_a t/m_b) \cdot k_e e^{-(t/m_c)} \cdot e^{-(t/m_d)}$ $\cdot \sum_{r=x}^N e^{-(rt/m_c)} \binom{N}{r} \left[\sum_{i=1}^{r-x+1} \binom{r}{i=1} (-1)^{i+1} \right]$
Case II(C)	Partial backup, cleaner subunits in series	Same as Case II(B)

TABLE IV.2
SUMMARY OF PERIPHERAL EQUIPMENT FAILURE RATES*

<u>Item</u>	<u>Equipment Type or Environmental Factors</u>	<u>MTBF (Hours)</u>
Motor-Fan (Combination)	Cool Clean Side	60,000
	Hot Dirty Side	35,000
Power Supply	Tube Type	20,000
	Solid State	100,000
Relays	Balanced Armature	0.1×10^6
	Sensite Balanced Armature	0.25×10^6
	Dry Circuit	0.45×10^6
	Thermal	0.3×10^6
	Pneumatic	0.3×10^6

*Based on data contained in References IV.4, 5 and 6.

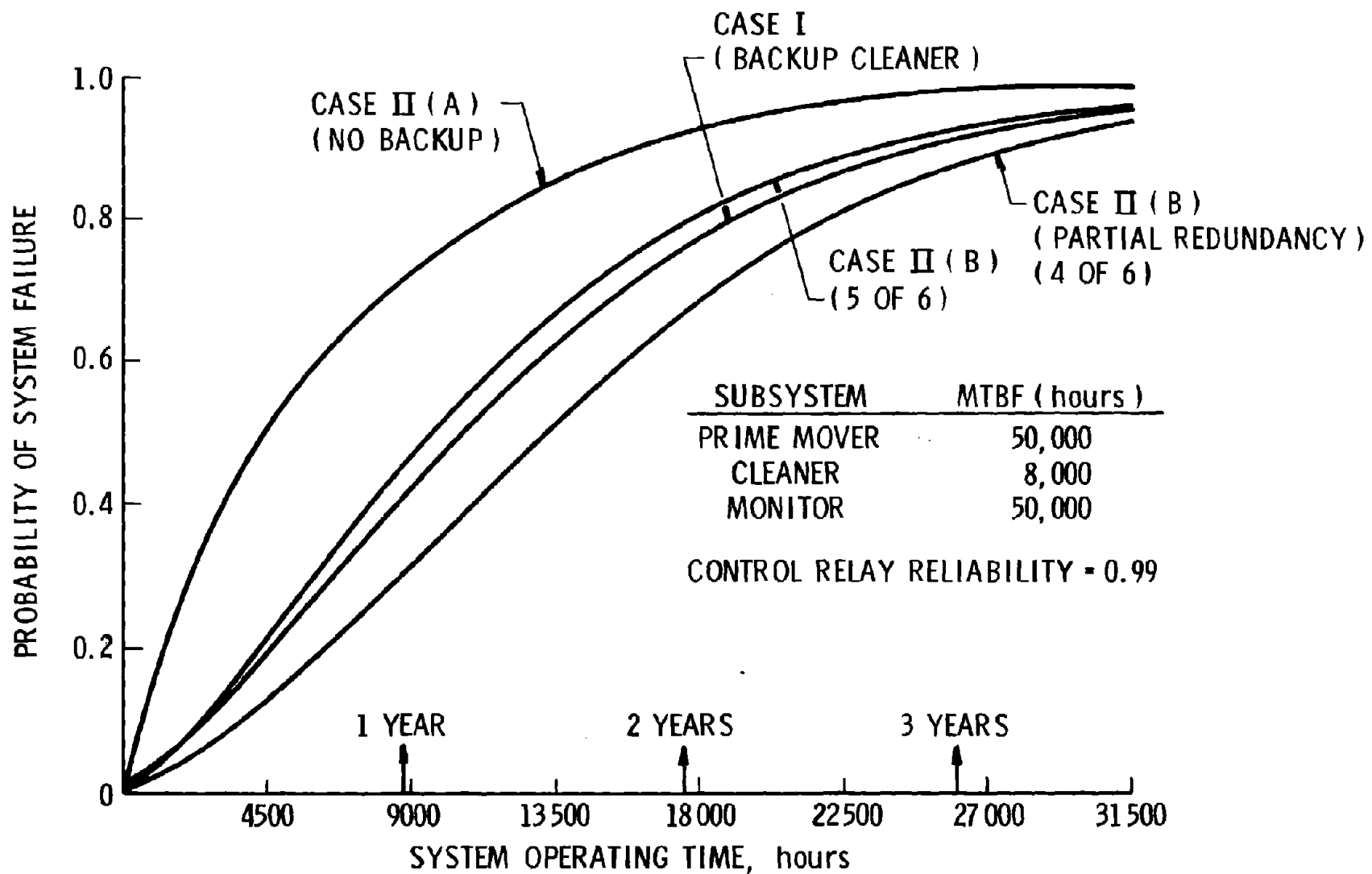


Figure IV.7 System Reliability : Effect of Air Cleaner Redundancy

$$\frac{1}{m_e} = \frac{1}{m_1} + \frac{1}{m_2} + \frac{1}{m_3} \text{ ---- } + \frac{1}{m_N} \quad (\text{IV. 8})$$

where

m_e = equivalent MTBF

$m_1, m_2, \dots, m_N$ = MTBF of individual subunits.

If the MTBF for all N subunits is identical, say m hours, then the equivalent MTBF for the cleaner is

$$m_e = \frac{m}{N} \quad (\text{IV. 9})$$

Referring to Figure IV. 7, it is observed that the partially redundant configuration (four of six subsections operating) has a failure probability less than one-half that of the non-redundant system (0.32 versus 0.72) after a 1-year operating time. Compared to Case I (one identical backup cleaner) the reduction is less significant (0.32 versus 0.42). Assuming that five of the six cleaner sections must be operating, a partially redundant configuration, has a slightly higher failure probability than Case I (one identical backup cleaner).

Effect of Cleaner Section MTBF

Plotting failure sensitivity data in the form shown in Figure IV. 8 is informative because it establishes meaningful upper limit on subsystem MTBF beyond which no significant increase in system reliability is achievable. An attempt to increase the cleaner section MTBF above about 8000 hours for Case II(B) and above 12,000 to 16,000 hours for a Case I serves no useful purpose. In general, a large subsystem MTBF implies a high initial equipment cost as well as a high maintenance cost. Figure IV. 9 shows the same data as Figure IV. 7 for Case I, except that the ordinate is system operating time.

Effect of Monitor MTBF

Figure IV. 10 contains a similar sensitivity plot showing the effect on system reliability of variations in the MTBF of the contaminant monitor. An upper limit on monitor MTBF can be established beyond which further increases do not produce a significant increase in system reliability but would likely result in a disproportionate increase in the initial cost of the monitoring equipment.

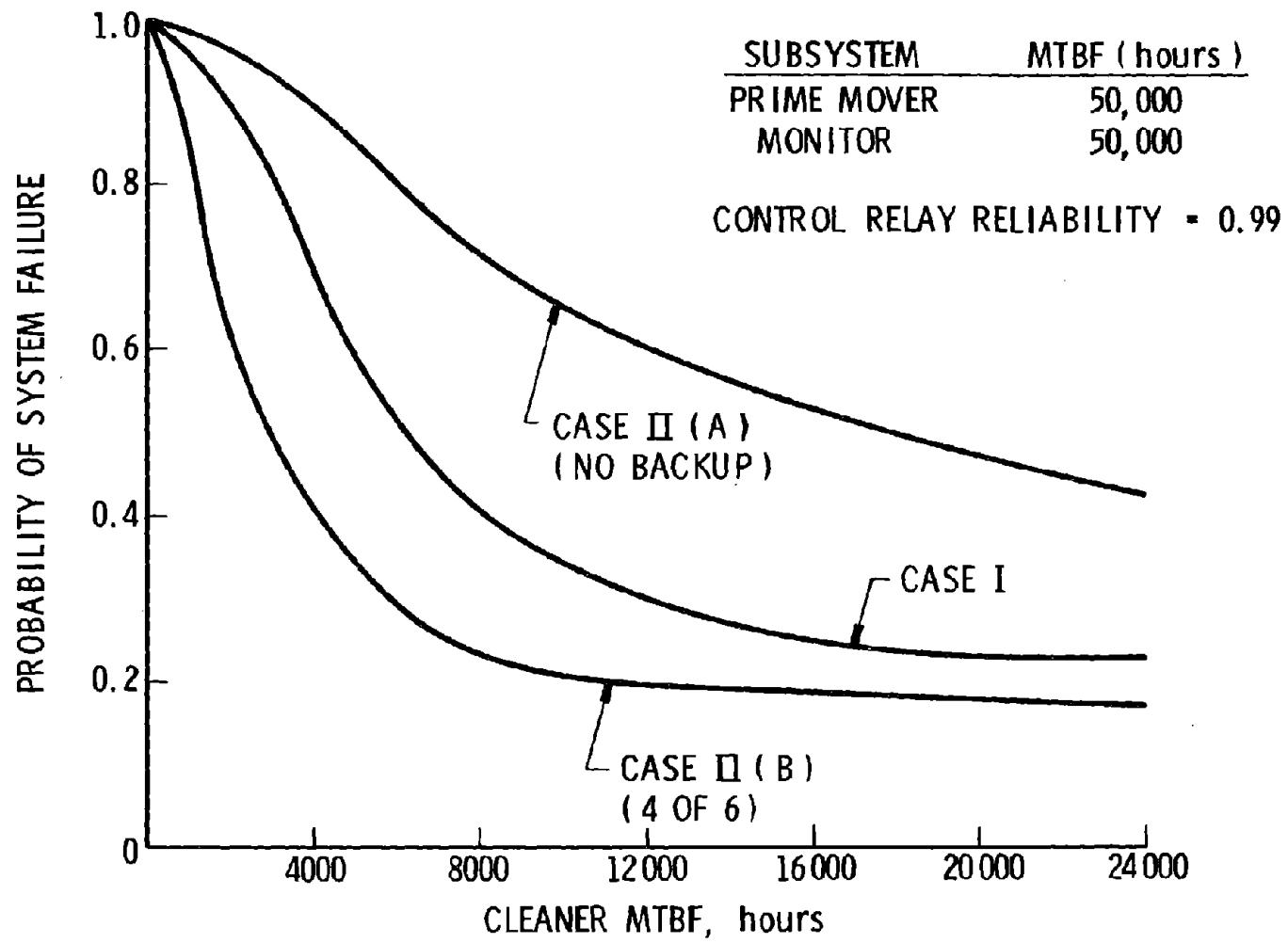


Figure IV.8 System Reliability: Effect of Air Cleaner MTBF for a One-Year Operating Interval (8,760 hours)

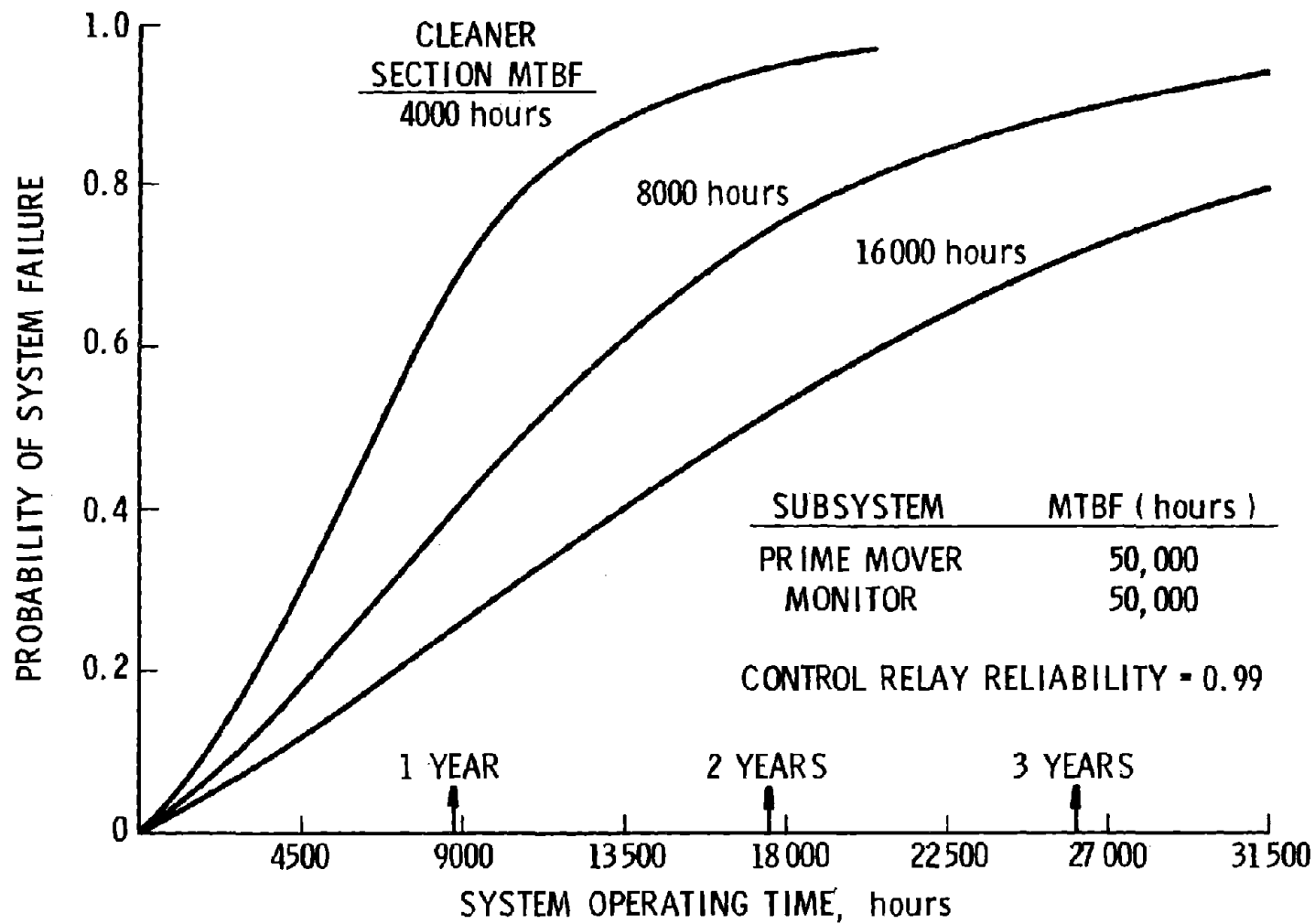


Figure IV.9 System Reliability : Effect of Air Cleaner MTBF and Operating Time for Case I

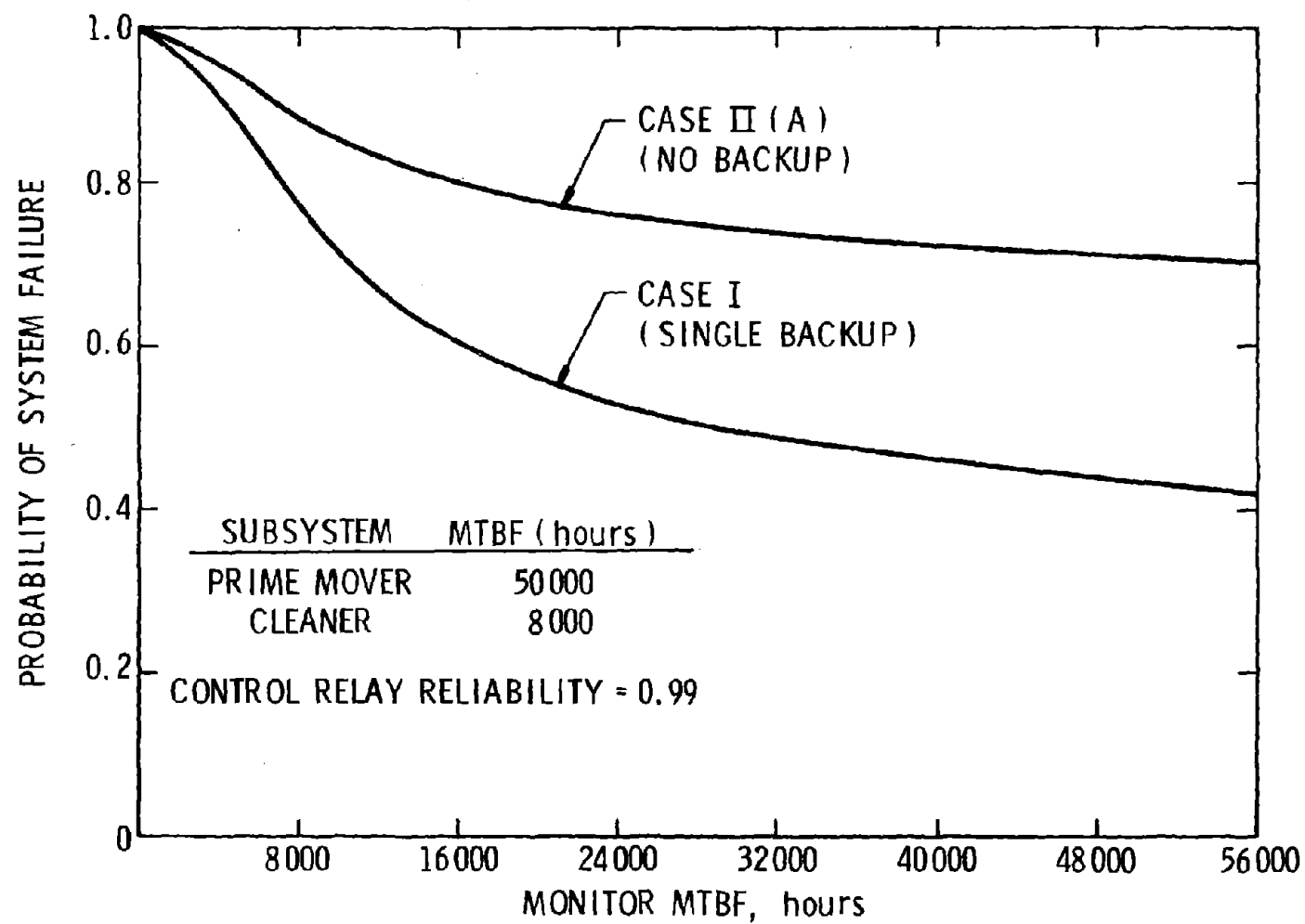


Figure IV.10 System Reliability: Effect of Contaminant Monitor MTBF for a One Year Operating Interval (8,760 Hours)

IV.1.5 Maintenance Considerations

Every major manufacturer of air cleaning equipment will furnish to the user a fairly detailed set of maintenance instructions and procedures for his particular type of equipment. The proper implementation of these maintenance procedures is the duty of the user. Each user must establish his own periodic maintenance schedules based on individual experience and the unique cleaning requirements of the facility. The maintenance schedule will depend on the type and quantity of the contaminant that is to be removed from the air stream. System components deteriorate at different rates. For example, it is common experience that ionizing wires in electrostatic precipitators require more frequent maintenance than any other component. Therefore, frequent inspection after initial startup is the best practical method of establishing a routine maintenance schedule. Reference IV.7 presents an excellent summary of maintenance and startup problems in recirculating air cleaning systems.

Effect of Preventive Maintenance on System Reliability

Predictions of the influence of preventive maintenance levels on system reliability is usually not too fruitful because of the many uncertainties that are involved. For example, the time required to perform various maintenance tasks varies from minutes to hours depending on the skill level of maintenance technicians, their familiarity with the specific subsystem, and the corporate policy on maintenance procedures. These uncertainties limit the accuracy of any analytical expressions that attempt to relate preventive maintenance and system reliability. Intuitively, preventive maintenance is advantageous for those subsystems and components whose failure rates increase with time. The exponential time to failure distribution that was used in this analysis, is based on a constant failure rate, i.e., the failure rate (MTBF) is independent of the operating time. However, this is an assumption, which may or may not be accurate. If data were available to construct the hypothetical curves that are shown in Figure IV.11, then these data could be used to predict the influence of various preventive maintenance levels on system reliability. The curves in Figure IV.11 are arbitrary and are used for illustrative purposes only. A typical example is shown in Figure IV.12. Using Curve A of Figure IV.11, the curve in Figure IV.12 indicates that increasing the maintenance level beyond about 0.01 hour per operating hour would be uneconomical.

IV.1.6 Inferences

The following list summarizes the major conclusions that pertain to the reliability and maintenance aspects of a fail-safe recirculating exhaust air system.

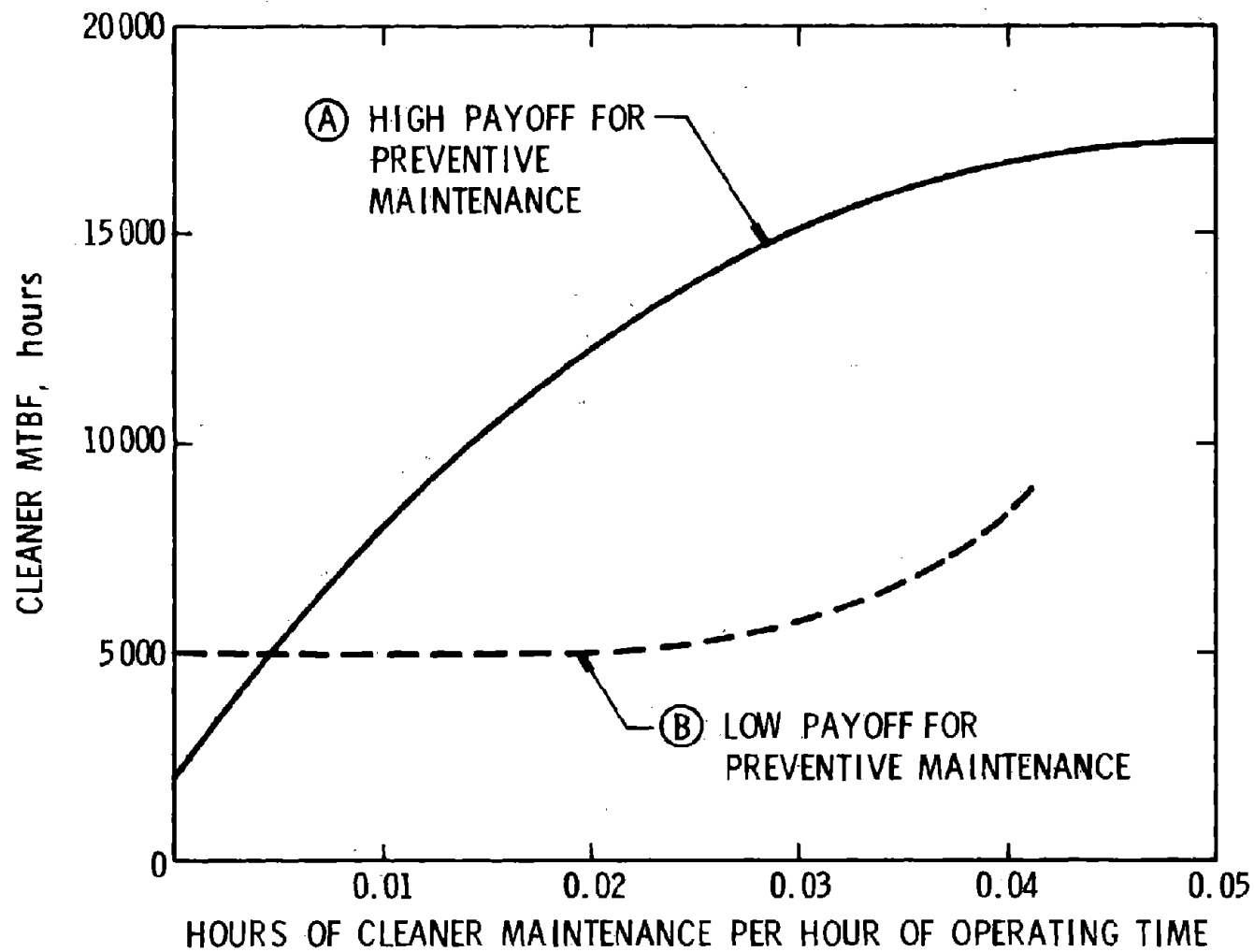


Figure IV.11 Relationship Between Preventive Maintenance and Air Cleaner MTBF

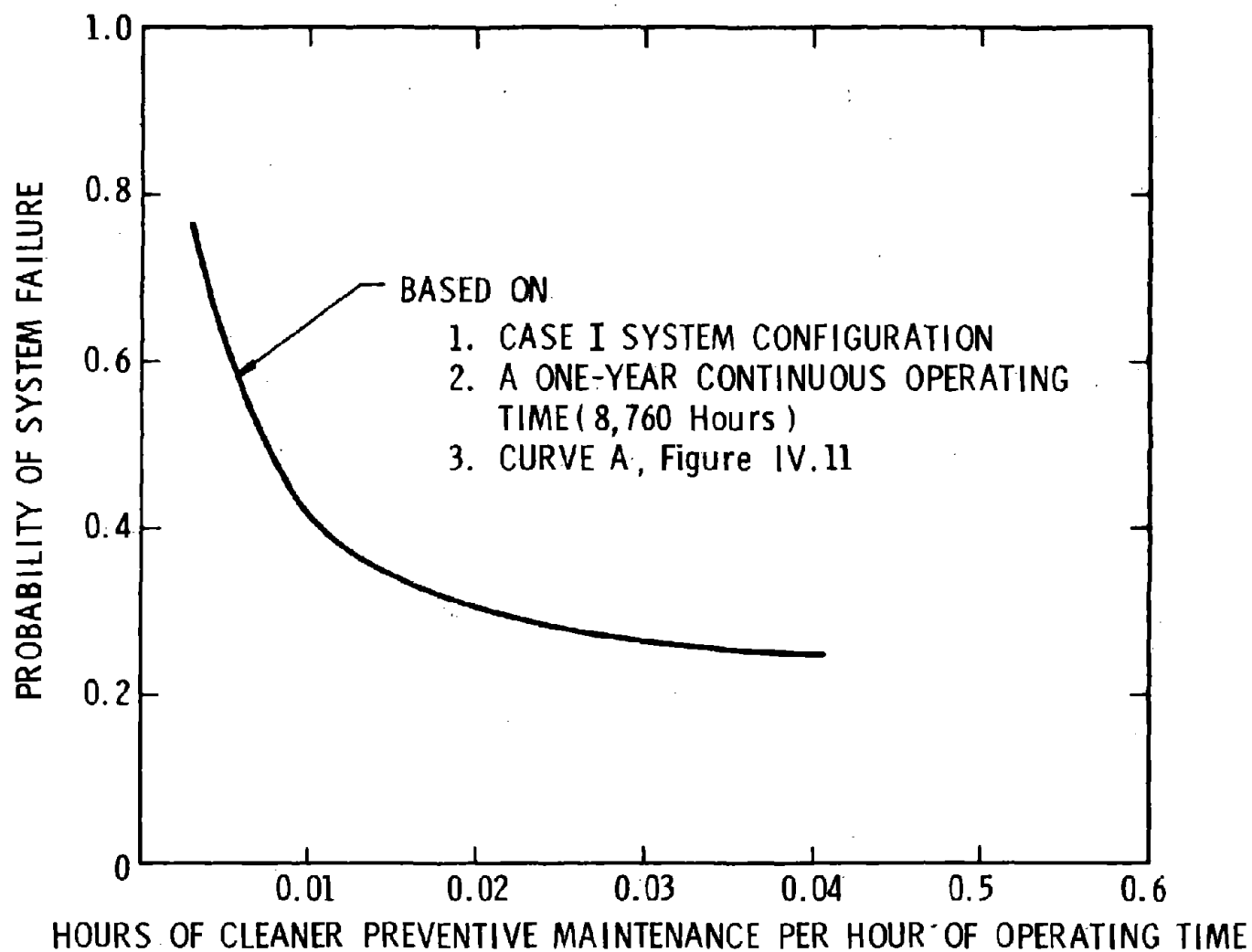


Figure IV.12 Effect of Preventive Maintenance on the Probability of System Failure

- (1) A major program is needed to organize, collect, classify, document and publish reliability data on the equipment that will be used in air recirculation systems. A typical program, recently instituted by the Nuclear Industry, is described in Reference IV. 8.
- (2) The economic feasibility of fail-safe recirculation of exhaust air, as it is influenced by equipment reliability and maintenance parameters, can be estimated or bracketed by analytic techniques, using the data and information that would be obtained from the program that is suggested above.
- (3) The analytic methodology developed in this study, with suitable extension and development, could form the basis for accomplishing Items (1) and (2).

IV.2 Control and Sampling Logic

IV.2.1 Control System Logic

Reliable and safe operation of a system for the recirculation of workroom air requires that status checks be made on the system with appropriate corrective action in the event of a component failure. These requirements necessitate the use of continuous monitors and logic control subsystems. Logic control systems can be used for either automatic or manual control. For a complex or fail-safe system, automatic control must be used. Automatic control or switching is initiated by an alarm signal that is generated when a system parameter exceeds a safe operating level. The complexity of the alarm and control system is a function of the number of critical parameters to be monitored and the degree of automatic switching that is to be initiated. To aid in the design of complex systems, general logic diagrams can be derived for the interaction of the alarm signals and the automatic controls.

General functional logic diagrams consist of a comparator, a logic gate and a control switch. The transducer converts a critical system parameter to an electrical signal. The comparator consists of a monitor that receives the signal from the transducer. Examples of operating parameters include current, voltage, pressure drop, flow rate, temperature, vibration and concentration. Thus, part of the function of a comparator is to receive the electrical signals and electronically produce a readout in engineering units.

Another function of a comparator is to produce an electrical signal when the measured parameter is within preset limits. If the measured parameter exceeds these limits, the previous signal would be nullified, and another output control signal would result. Thus originates the binary logic signals of 1 (high) or 0 (low). Three comparator outputs can exist by using two setpoints. Each setpoint has an output signal. The third output is formed using NOR logic with the two setpoint outputs. The setpoint outputs have a high (1) level if the input signal is outside the setpoint range. Thus, if the input signal is less than the lower setpoint, the comparator output is high, and if the input signal is greater than the high setpoint, the respective output is also high. The third output is high only when both high and low set point outputs are low (0). For the general logic diagram, the comparator is depicted as having only two outputs, one for system in normal operation and the other for system failure. These two outputs are complements of each other since both cannot exist simultaneously.

There are four types of logic gates: AND, OR, INVERTER, and DELAY. The AND gate produces a high level output when operations are normal. A malfunction of any part of the system produces a change in one of the logical signals and causes the AND gate to change to a low level output. The OR gate produces a low level signal when all input signals are in alarm state. The INVERTER gate changes a low level signal to a high level signal or vice versa. The logical DELAY remains at a high state for some increment of time after its input has gone low, and, if the input returns to a high level during the increment of time, no change in the output is produced.

The control switch has three ports: input, output, and control. The control switch is used to control electrical power to a process. The logical control switch has two states, either ON or OFF. For the general logic diagram, a high level control signal turns the switch ON, whereas a low-level control signal turns the system OFF.

Control system logic diagrams have been developed for automatic control of air recirculation Cases I and II (see Figures IV.1 and IV.2). These diagrams, which are shown in Figures IV.13 and IV.14, are consistent with the functional models in Figures IV.3 and IV.4 that formed the basis for the reliability analysis.

For Case I, three automatically-controlled switchings result from a system failure. Two of the controlled switchings are required for changing from a primary to a backup system, and the third switching is required for automatic shutdown of the process for a total system failure. For this general case, the primary blower and cleaner are considered as the primary unit; therefore, any primary mode failure results in switching to secondary blower and cleaner.

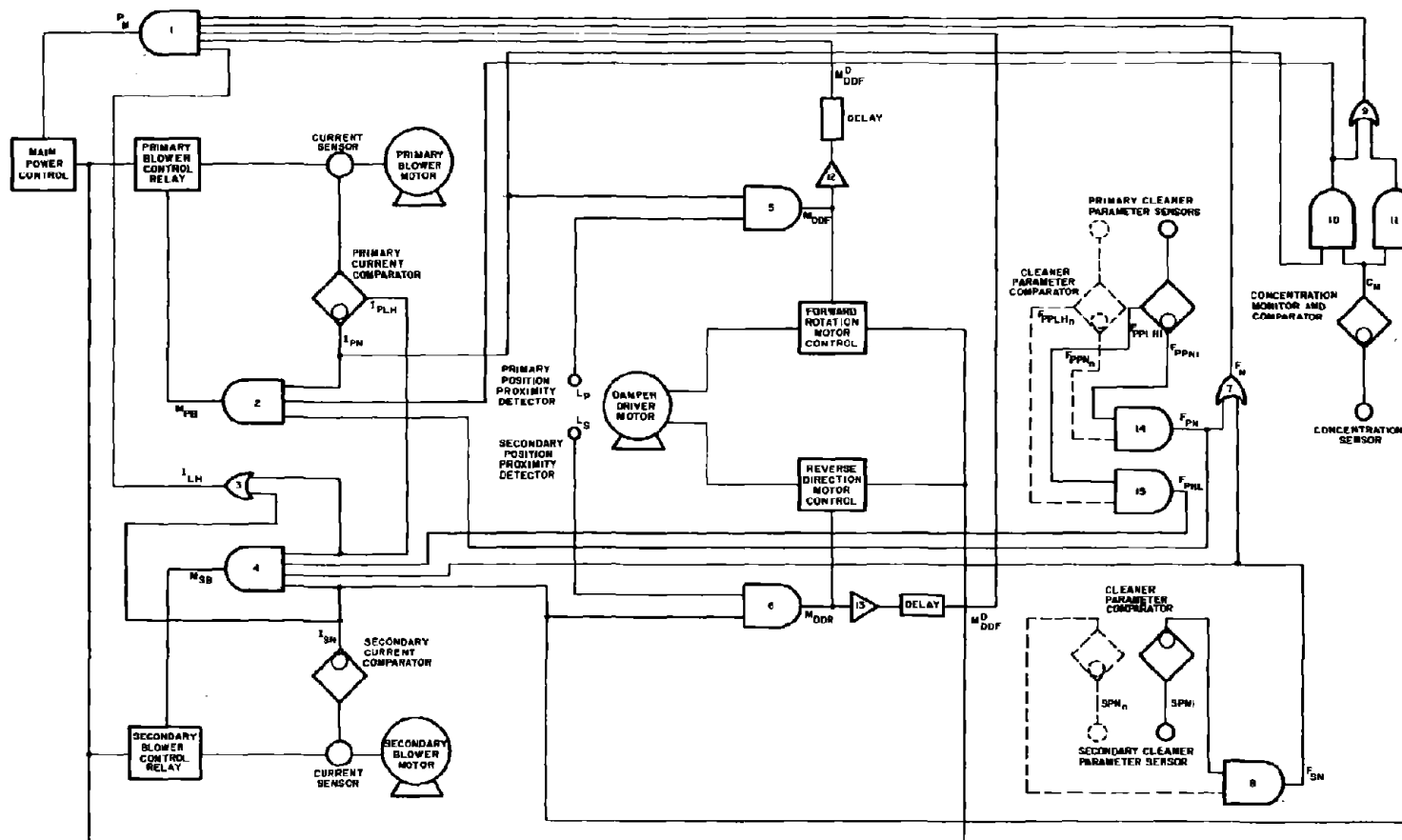


Figure IV.13 Control System Logic for Case I: Redundant Air Cleaners

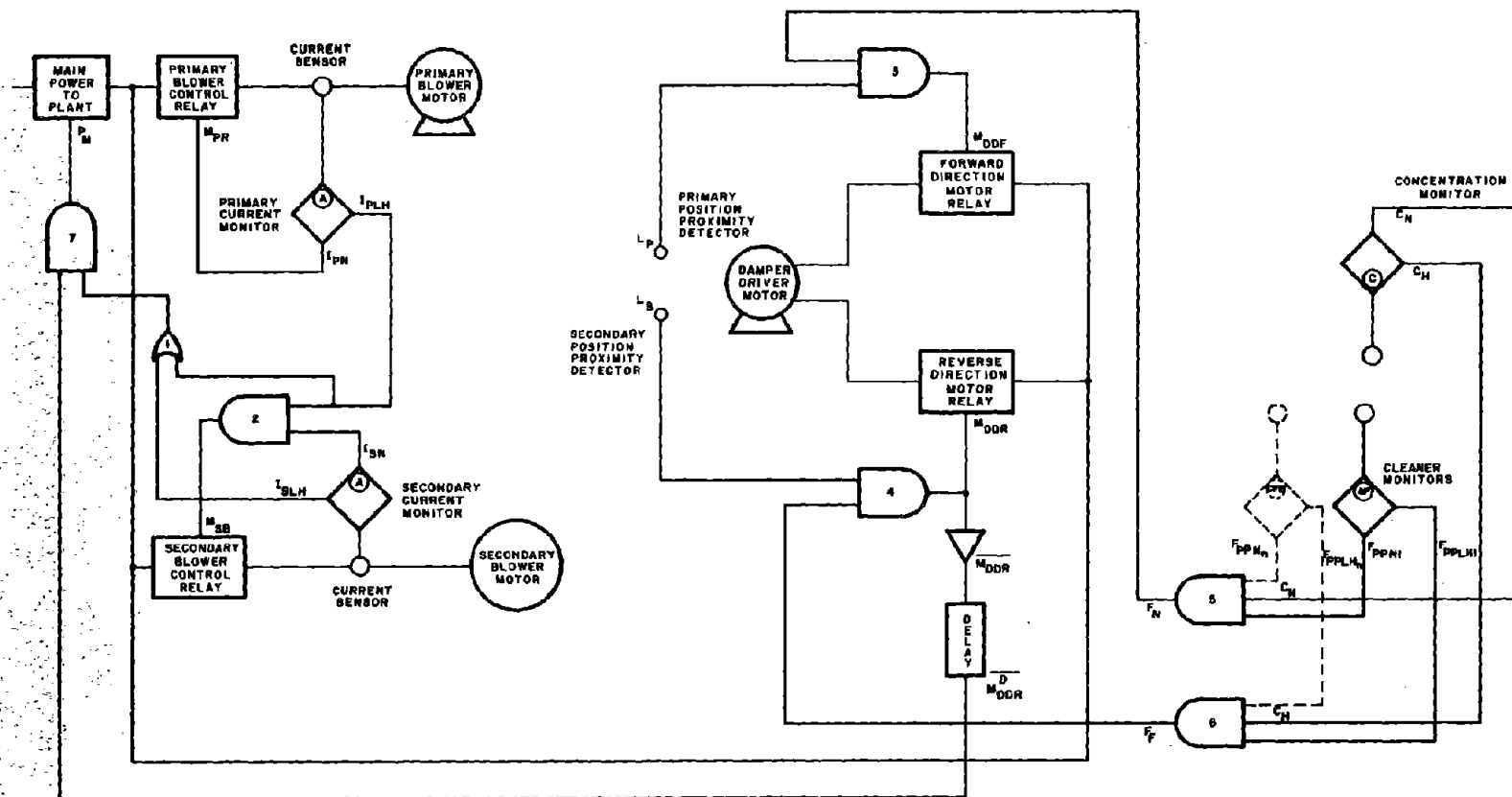


Figure IV.14 Control System Logic for Case II : Bypass to the Atmosphere

The automatic control switches have a set of logic control variables that are defined as follows:

- P_M - logic signal at high level used to control power to the process. P_M at low level causes a complete shutdown of process.
- M_{PB} - logic signal at high level allows primary motor to operate. M_{PB} at low level causes primary motor shutdown.
- M_{SB} - logic signal at high level allows secondary motor to operate. M_{SB} at low level causes secondary motor shutdown.
- M_{DDF} - logic signal at high level operates damper motor in forward direction to rotate damper into primary position.
- M_{DDR} - logic signal at high level operates damper motor in reverse direction to rotate damper into secondary position.

To provide the logic signals that are necessary for switching control, comparator monitors must be used on critical parameters of the primary and secondary blower system, damper system, primary and secondary air cleaners, and the air concentration monitor. An appropriate set of logic control variables is required, and they are defined as follows:

- $*I_{PN}$ - high level output signal of comparator for the primary fan motor current when in normal mode of operation.
- $*I_{PLH}$ - high level output signal of comparator for the primary fan motor current when an alarm condition is present,
 $I_{PLH} = I_{PN}$
- $*I_{SN}$ - high level output signal of the comparator for the secondary fan motor current when in normal mode of operation.

*The current, I , has been used as a general parameter for the blower motor. "I" could be replaced by a variable for rpm or flow rate, but a high-low monitor would still be necessary. High-low setpoints should be 10 percent above and below the normal operating point for the input parameter.

- * I_{SLH} - high level output signal of the comparator for the secondary fan motor current when an alarm condition is present, $I_{SLH} = I_{SN}$.
- L_P - logic signal at high level when the damper is not in primary position.
- L_S - logic signal at high level when the damper is not in secondary position.
- F_{PPNn} - logic signal at high level for any of n comparators for the primary air cleaner parameters when the cleaner is operating between given limits.
- F_{PPLHn} - logic signal at high level for any of n comparators for the primary air cleaner parameters when the cleaner is operating out of normal range, $F_{PPLHn} = F_{PPNn}$.
- F_{SPNn} - logic signal at high level for any of n comparators for the secondary air cleaner parameters when the cleaner is operating out of normal range, $F_{SPLHn} = F_{SPNn}$.
- C_N - logic signal at high level for contaminant concentration less than a maximum allowable level.
- C_H - logic signal at high level for contaminant concentration higher than a maximum acceptable level.

Using these logic variables[†], the set of system control equations is as follows:

$$P_M = F_{PN} C_N L_P^D L_S^D I_{SN}^D + F_{PN} C_N L_P^D I_{PN}^D L_S^D + F_{SN} C_N L_P^D I_{SN}^D + F_{SN} C_N L_P^D I_{PN}^D L_S^D \quad (IV.10)$$

$$M_{PB} = I_{PN} C_N F_{PN}$$

$$M_{DDF} = L_P I_{PN}$$

[†] Superscript D indicates logic delay as defined previously.

$$M_{DDR} = L_S L_{PN}$$

$$M_{SB} = I_{PN} F_{PN} F_{SN} I_{SN}$$

where

$$F_{PN} = F_{PPN1} F_{PPN2} \dots F_{PPNn}$$

$$F_{SN} = F_{SPN1} F_{SPN2} \dots F_{SPNn}$$

The diagram for Case I (Figure IV. 13) illustrates motors, power control switches, comparators and control logic. Alarms are not shown. Alarms are classified as either visual or audio. Control variables which produce visual alarms are:

$$I_{PLH}, I_{SLH}, M_{DDF}, M_{DDR}, F_{PPLHn}, F_{SPLHn}, \text{ and } C_H.$$

Control variables which produce visual and audio alarms are:

$$M_{PB}, M_{SB}, \text{ and } P_M.$$

Case II has the same three switching functions as Case I. The system is simplified because any failure of the air cleaner results in bypass of all air flow to the atmosphere. For this case, the primary blower motor is removed from the system only in the event of a primary blower failure. The automatic switches for Case II have the following set of control variables that have already been defined: $P_M, M_{PB}, M_{DDF}, M_{DDR}$. The set of control variables which have also been defined previously are: $I_{PN}, I_{PLH}, I_{SN}, I_{SLH}, L_P, L_S, F_{PPLHn}, F_{SPLHn}, C_N,$ and C_H .

Using these variables, the set of system logic equations are as follows:

$$P_M = I_{SN} M_{DDF}^D + I_{PN} M_{DDR}^D$$

$$M_{PB} = I_{PN} \tag{IV. 11}$$

$$M_{SB} = I_{PN} I_{SN}$$

$$M_{DDF} = L_P F_N$$

where

$$F_N = C_N F_{PPN1} F_{PPN2} \dots F_{PPNn}$$

$$M_{DDR} = L_S F_F$$

$$F_F = C_H F_{PPLH1} F_{PPLH2} \dots F_{PPLHn}$$

Control variables which produce only visual alarms are I_{SLH} , I_{PLH} , C_N , C_H , F_{PPLHn} . Control variables that produce visual and audio alarms are M_{PB} , M_{SB} , and P_M .

The alarm logic diagrams serve as an aid in the design of recirculation control systems by providing a guide for the implementation of equipment. Motorized systems are equipped with a motor control relay which provides control of large motor currents with low level signals. The logic elements of the diagram are replaced with relays or, for a more elaborate system, with electronic digital chips. The most critical part of a control system design involves the implementation of the comparator. The sequence for the selection of comparators is to first decide on the parameters to be sensed for control, then select appropriate transducers, and finally specify the comparators. Many types of commercial comparators are available; however, the most widely used in industry are meter relays.

Meter relays combine two of the most inexpensive commercial devices with which to form a comparator. The D'Arsonval galvanometer serves as the meter portion of the comparator. This type of meter is used to directly read the millivolt output of common transducers. By combining the meter with electromechanical or electro-optical low current contacts and an output relay, large electrical currents can be easily controlled. This arrangement reduces the need for electronic amplifiers which must be used with potentiometric controllers. The meter relay provides necessary monitoring for system status checks as well as system control. The output of the meter relay changes state as the input crosses a setpoint. Both single and double setpoint meter relays are available. These meter relays have a tri-state output and require a low and a high setpoint terminal. It is also possible to latch an output state such that the change of input signal has no effect on the output. This mode of operation is called "latching". An application of the latching mode of a meter relay is the prevention of negative pressure buildup in the workroom.

For example, when the air cleaner fails in Case II, the entire exhaust stream is diverted or bypassed to the atmosphere. Either the air cleaner failure signal or the damper closure signal can be input to the meter

relay which in turn activates a standby general ventilation blower or blowers whose combined flow rate capacity balances the bypass flow rate. Pressure equilibrium will thus be maintained. This additional general ventilation system would continue to operate even though the air cleaner sensor signals may return to the normal operating range.

Table IV.3 contains a general list of the types of meter relays that are commercially available, including specific information on input, output, latching capabilities, number of setpoints, and type of relay output. A general discussion of meter relay operating principles is given below.

Optical Meter Relay

The optical meter relay contains a light source and a photo cell connected to a set pointer. The setpoint may be located at any position on the meter. The indicator needle carries an aluminum shield that breaks the light beam when the pointer passes the setpoint. The broken beam de-energizes (fail-safe) or switches the relay. Meter relays with two setpoints are available if high and low limits need to be monitored. Meter relays are generally designed to maintain the de-energized position of the relay as long as the pointer is above or below the setpoint. A desirable feature is the "latching" capability. When the input signal is an unacceptable value, the relay is de-energized and will remain so until it is manually reset even though the indicator may fall back into the acceptable range. Optical meter relays are available that have a programmable time delay on the relay actuation. This time delay prevents switching during a start-up or shut-down period when control switching may not be required.

The relays contained in the meter are generally rated at 5 amps and 120 VAC. This size relay can be used for switching an audio-visual alarm system; however, when corrective action must be initiated, additional slave relays are required for devices such as motors and valves.

Because of their simplicity, optical meter relays are extremely reliable. The life-time of the light source is approximately 40,000 to 60,000 hours (7 years). Input current to the meter relay varies somewhat for different models, but generally, it is in the milliamp range, which is compatible with the output of most transducers and thermocouples. Optical meter relays are available specifically for controlling AC motors. The meter indicates the percent load on the motor, and the setpoints can be adjusted to the desired operating range. A blocked filter, worn bearing, or change in supply line voltage could be detected using this controller. Of the various relay types, the optical meter appears to be the most widely used.

TABLE IV.3
SUMMARY OF METER RELAY PERFORMANCE DATA

Manufacturer and Model	Type	Input	Output	Latching Capabilities	Setpoints		Relay	Other
					1	2		
1 Meter Relay	Optical		5a @ 120 VAC Resistive or 28 VDC	Yes, connections are shown on schematic for latching		✓	DPDT for 1 setpoint 2 DPDT for double setpoint	Schematic available for connections
1 AC Motor Load Controller	Optical	.7 to 7.5a signal voltage limited to 240 V	5a @ 28 VDC or 115 VAC resistive	Yes, reset accomplished by front panel switch. Can be operated w/out latching - independent of each setpoint		✓	One SPDT for each setpoint	Has a user selected time delay; prevents actuation due to start-up
2 Compark IV Controller 603-X Temp 503-X us	Solid State	DC and Thermocouple	5a @ 125 VAC	Not indicated		✓	SPDT per setpoint. ON/OFF limit rated at 5a @ 125 VAC	
2 Digital Compar- ator 4310, 4355	Compat- ible to digital system	BDC NO	DETAILS	Not Indicated GIVEN				Compares BCD input to preset value and provides ON/OFF control
2 Digital Control Meter 4350-K 4354-K		NO	DETAILS	GIVEN			REED	Displays and controls input; if point is ex- ceeded, then panel light comes on and relay switches
2 Meter Relay	Locking Coil	NO	DETAILS	GIVEN				
2 Meter Relay	Magnetic Contact	NO	DETAILS	Yes GIVEN				
2 Meter Relay	Optical	NO	DETAILS	GIVEN				
3 Meter Relay 195, 196 rpm, amp, temp	Optical	20 ma AC higher with aux. transformer DC power option	5a @ 120 VAC 5a DC non- ductive @ 28 V	Yes, manual reset Can be self-contained or external		✓	3 PDT - Manual reset	Alarm light is on panel to indicate when relay is thrown
4 Photocell Output Type	Optical		10a @ 115 VAC	Not indicated		✓	1 DPDT for each setpoint	
4 Amplifier Output Type 323 XO	Optical	DC self con- tained range 5 mv - 500 V 5 ua - 10 a AC 500 mv - 500 V 100 ua - 5 a	40 VDC 100 ma switching cap. Generally used to switch slave relays	Not indicated		✓	Transistor SPST NPN for each setpoint	
4 Relay Output Type 3223 XA	Optical	DC 5 mv - 500 V 5 ua - 10 a AC 500 mv - 500 V 100 ua - 5 a	10a @ 115 VAC	Not indicated		✓	DPDT for each setpoint	
4 Contact M.R. 29 XA	Electro- mechan.		10 ma @ 15 VDC on resistive or diode protective inductive loads	Possible, using latching slave relay (diagram available)		✓	Slave Relays	

Electromechanical Meter Relays

A less expensive but equally reliable meter relay is the contact type meter. This relay resembles the optical meter in that it has the same general features of dual or single setpoints, and a milliamp input range. The limit contacts are set along the meter arc by means of an externally adjustable gear drive. These contacts are non-latching and are intended to be used either with external slave relays that have latching provisions or for light duty, non-latching applications. The external slave relays can be chosen to match the meter requirements and the desired switching requirements.

The availability of contact meter relays is somewhat less than that of the optical meter relays. The cost, however, is substantially lower than optical meter relay and does not include the cost of the external relays that would be necessary for control applications.

Electronic Meter Relays (Solid State)

Solid state meter relays perform the same type of functions as optical or contact relays but they do not depend on any mechanical function. The limit setpoints are selected by adjustment of a potentiometer. The input voltage is amplified and brought into a differential amplifier which compares the input signal to the setpoint level. The comparator produces a positive output if the input voltage is above the setpoint and a negative output if the input voltage is below the setpoint. The output is used to switch a single pole-double throw relay. If two setpoints are contained in the meter relay, then an additional single pole-double throw relay of opposite polarity is required. The only solid state controller (other than a temperature controller) for which information was readily available has a 5 amp-125 VAC rating. This particular model does not have a latching capability. The solid state meter relay should be expected to be a highly reliable device over an extended period of time.

IV.2.2 Redundant Manual Sampling Requirements

The air cleaner and the on-line contaminant monitor are the most critical elements in the recirculation system. Despite the fact that the exhaust system design incorporates numerous fail-safe features, which will theoretically ensure an acceptable air quality in the work room, there still exists an indeterminate probability that the cleaner, the monitor or both may fail to operate properly. That probability is undefined at this time primarily because of the lack of well-established failure rate data.

A monitor failure followed closely by an air cleaner failure could recirculate excessive, undetected levels of contaminant to the work space. In order to minimize the probability of such an event, it is advantageous to incorporate, as an integral part of a preventive maintenance program,

a requirement for a manual, redundant sampling of the air cleaner effluent. In order to implement this requirement it is necessary to specify the time interval between successive samples. Two methods can be used to estimate that time interval. The first method is based on the reliability of system components, and the second method is based on the theoretical recirculation models that are derived in Section V of this report.

A manual sample will detect a monitor or monitor/cleaner failure if the sampling interval is such that there is a high probability that all system components are operable at the time that the sample is collected. Assume that all system components obey an exponential probability law. The probability that the m-th component is operable is

$$R_m = e^{-t/\text{MTBF}_m} ; \quad m = 1, \dots, n \quad (\text{IV. 12})$$

where MTBF is the mean time between failure for any particular component. From a reliability standpoint, the component with the smallest MTBF will govern the sampling interval. Assume that it is the j-th component. If the sample interval, t_j , coincides with MTBF_j , there will be only a 34 percent probability that the j-th component is working. This probability is obviously unsatisfactory. Therefore, the systems engineer should specify the desired probability level, $\bar{R}_j$, e.g. 95 percent. The corresponding manual sampling interval, based on reliability considerations, is

$$t_j = -\text{MTBF}_j (\ln \bar{R}_j) \quad (\text{IV. 13})$$

At this sampling interval, the probability is even greater than $\bar{R}_j$ that all other components are operating.

The mathematical model for air cleaner failure (Equation V.36 of this report) predicts that the time required for the mean room concentration to exceed the short term exposure limit (Threshold Limit Value times the appropriate Excursion Factor) is

$$t_{\text{ex}} = \frac{V}{Q_V} \ln \left\{ \frac{n[\epsilon + Q_R/Q_V]}{\left[1 - \frac{(\text{TLV})(\text{EF})Q_V}{\dot{m}}\right] \left[1 + \frac{nQ_R}{Q_V}\right]} \right\} \quad (\text{IV. 14})$$

where

- $\forall$ = room volume
- Q_V = general ventilation flow rate
- Q_R = recirculation flow rate
- η = nominal air cleaner efficiency prior to failure
- EF = permissible excursion factor for a particular contaminant
- $\dot{m}$ = contaminant generation rate
- ϵ = scavenging efficiency of the local exhaust system(s)
- TLV = threshold limit value for a particular compound

Logic dictates that the manual sampling interval should not exceed t_j or t_{exp} , which ever is smaller; that is,

$$t_{MSI} = \text{minimum} \left\{ \begin{matrix} t_j \\ t_{ex} \end{matrix} \right\} \quad (IV.15)$$

The time interval between successive samples can, of course, be reduced as required with the assurance that it is highly probable that all subsystems are operable, and if the cleaner and/or the monitor has failed then the room concentration has not yet exceeded the short term exposure limit.

For example, for the following numerical values of the system parameters

- $\bar{R}_j$ = 0.9
- MTBF_j = 500 hours
- $\forall$ = 100,000 ft³
- ϵ = 0.9
- η = 0.9
- EF = 1.5

$$TLV = 100 \text{ ppm } (1.895 \times 10^{-5} \text{ lb/ft}^3)$$

$$Q_R = 500 \text{ cfm}$$

$$Q_V = 500 \text{ cfm}$$

$$\dot{m} = 1.0 \text{ lb/hr } (0.0166 \text{ lb/min})$$

the sampling interval is calculated to be

$$t_{MSI} = \text{minimum} \left\{ \begin{array}{l} t_j = 527 \text{ hours} \\ t_{ex} = 6.1 \text{ hours} \end{array} \right\} \quad (\text{IV. 16})$$

A manual sample approximately every 8-hour shift is indicated for this example.

This example is meant only to illustrate the application of two independent concepts. Care should be exercised in applying the equation for the time to exceed the short term exposure concentration because of the inherent mathematical limitations on the magnitude of the denominator in the logarithm. This aspect is discussed in Section V.

Mathematical modeling of contaminant concentration in a exhaust recirculation system and the prediction of post-failure performance of the air cleaner has yet to be validated experimentally. Undoubtedly, as reliable failure rate data for the monitor and cleaner are obtained from practical experience, a probabilistic prediction of the manual sampling interval will be the controlling factor.

A laboratory analysis of the acquired sample is not desirable because such procedures usually require a considerable amount of time. Analysis by portable, direct-reading instrumentation is indicated. If the concentration obtained by manual sampling agrees within prescribed limits with the digital or analog output of the on-line monitor, then the monitor and cleaner are assumed to be operating properly. However, if they disagree, it must be assumed, at this point, that there is a malfunction in the on-line monitor, the cleaner or both components. In this event, it is recommended that the process be taken off-stream. Preventive maintenance actions can then be initiated to isolate the problem.

IV.3 Sampling of Duct Flows

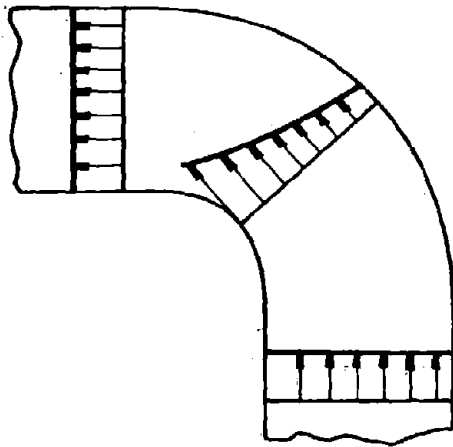
Sampling for contaminant concentration in the effluent duct of a recirculated exhaust air system is analogous to stack sampling of stationary sources in the sense that both methods involve confined gas and particulate

flows. Traditionally, stack sampling has been used to determine emission rates and the degree of compliance with federal and local air pollution regulations. Because of this analog, it should be expected that certain procedural elements are common to both cases. The procedures for recirculation ducts must necessarily depart from the source sampling test methods when it is necessary to be responsive to the performance criteria and constraints of the entire recirculation system.

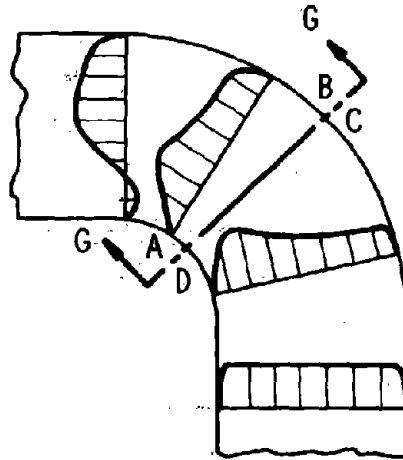
Standard methods of test for stack sampling, which were originally promulgated by the Environmental Protection Agency, are described in detail in Reference IV.9.

When the contaminant is a particulate, it is necessary to perform isokinetic traverses of the duct in order to collect a representative sample. Method 1 of Reference IV.9 provides the basis for selecting the location of the sampling port and the number of traverse points that are needed for velocity profile (flow rate) determination and sample collection. If possible, the sampling port should be located eight duct diameters downstream and two duct diameters upstream of any flow disturbances. The object is to maintain steady flow conditions with a minimum of distortion of the velocity profile at the sampling plane. However, geometric disturbances such as bends, and elbows generate secondary flows which result in highly skewed, three dimensional velocity profiles (References IV.10 and IV.11). Figure IV.15 illustrates the flow of an ideal (no viscosity) fluid through a bend. The predicted velocity profiles immediately upstream and downstream of the bend are uniform. Typical profiles for a real fluid flowing through a bend are shown in Figure IV.15. Here, because of the centrifugal force gradient which exists at the start of the turn, the high energy fluid tends to migrate to the outside of the bend while the low energy fluid migrates to the inside of the bend. Hence, P_1 is greater than P_2 (Figures IV.15). Also due to viscosity effects, the velocity at wall AD is less than at the central plane of the duct. Consequently, P_3 and P_4 are greater than either P_1 or P_2 . These pressure gradients result in two flow spirals superimposed on the main flow, and the secondary flow effect is present for several duct diameters downstream of the disturbance.

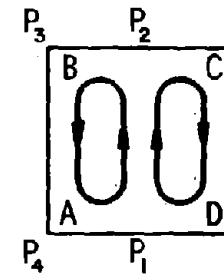
In recognition of this highly asymmetric flow profile near an elbow or disturbance the number of traverse of sampling points must be increased according to Figures IV.16. Failure to increase the number of traverse points will result in less accurate determinations. When the duct is rectangular, the equivalent diameter or hydraulic diameter is used for establishing the number of traverse points. The hydraulic diameter is calculated from the following equation.



(a) Flow of ideal fluid through bend



(b) Flow of real fluid through bend



SECTION "G - G"

(c) Secondary flow of a real fluid

Figure IV.15 Velocity Contours for Ideal and Real Fluid Flow in a Bend

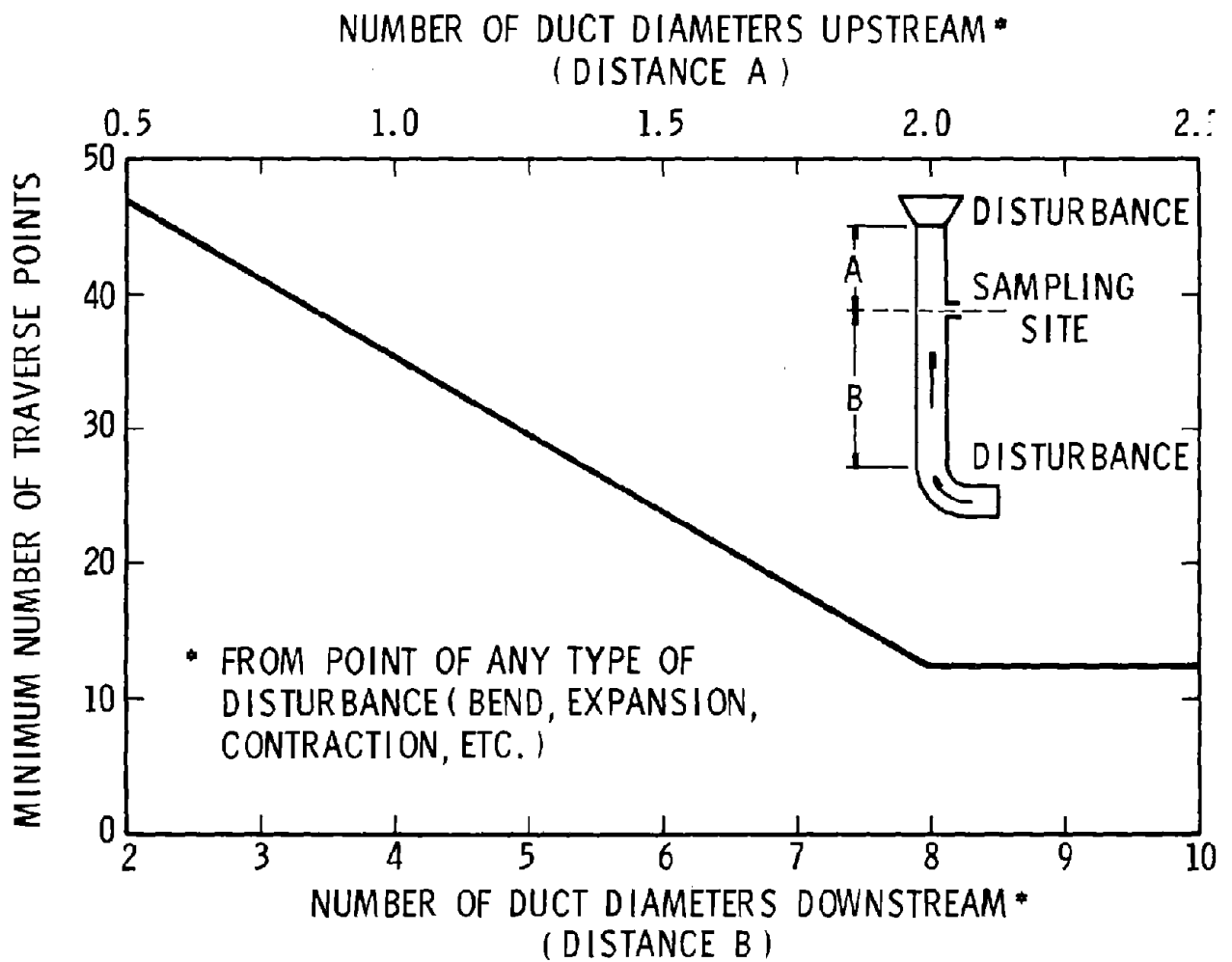


Figure IV.16 Effect of Disturbance Location on the Number of Sampling Traverse Points (Reference IV.9)

$$d_h = \frac{2 (\text{length})(\text{width})}{\text{length} + \text{width}} \quad (\text{IV. 17})$$

In the strictest sense this equation applies only to turbulent pipe flow, i. e., Reynold's Number greater than approximately 2000. In addition, ventilation duct flows are subsonic, and pressure perturbations from blowers and air cleaners will be propagated upstream and downstream at nearly the speed of sound in the carrier gas. The amplitude of these disturbances decreases with distance due to viscous damping. If these pressure perturbations reach the sampling port, the local free stream velocity becomes unsteady, and the task of maintaining isokinetic conditions is exceedingly difficult. The diametral location of the traverse points is contained in References IV. 9, IV. 12, and IV. 13.

For particulates, it is recommended that Method 1 be applied to recirculated exhaust systems because current ventilation test procedures do not contain the data in Figure IV. 16, which may be critical under certain conditions.

IV. 3. 1 Gases and Vapors

When the contaminated flow contains only gases or vapors, sampling can be accomplished by a fixed probe located at a convenient position in the duct, e. g. on the duct centerline downstream of the air cleaner. Isokinetic traverses are not required because, for most practical recirculation situations, the contaminant is homogeneously distributed throughout the carrier gas by the processes of laminar diffusion or turbulent mixing. This fact is implied in Method 6, Reference IV. 9. To prove analytically that this is the case for laminar flow, it must be shown that the concentration gradient vanishes normal to the flow direction at some distance from the generation site.

Consider the two component (gaseous contaminant and carrier gas), single phase (gas) flow field shown in Figure IV. 17. Contaminant species A issues from a point source at a rate W_A moles/sec into a uniform airflow field (species B) of velocity v_o . Per Reference IV. 14, the downstream concentration of contaminant in the flow field is given by

$$C_A = \frac{W_A}{4\pi D_{AB}s} \exp \left[-\frac{v_o}{2D_{AB}}(s-z) \right] \quad (\text{IV. 18})$$

where D_{AB} is the diffusion coefficient for A into B. The radial concentration profile for species A in any sampling plane downstream of the injection point can be obtained by differentiating the above expression with respect to the radial coordinate, r .

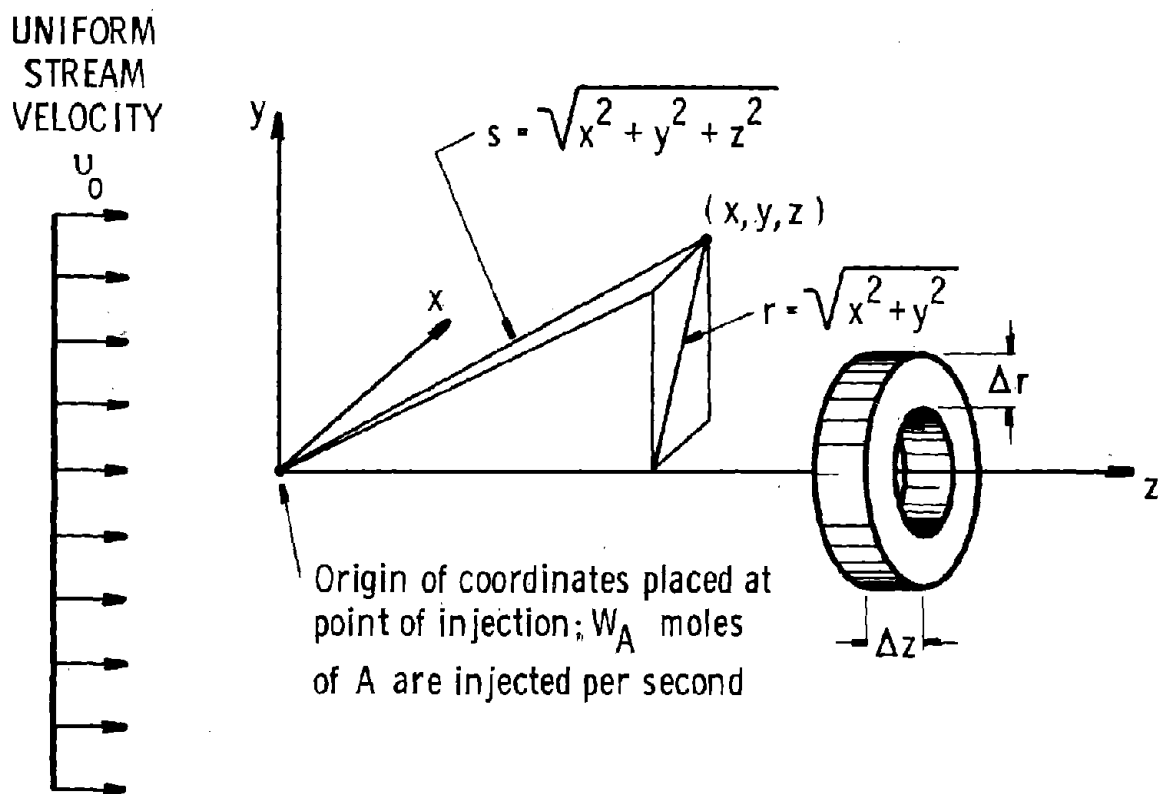


Figure IV.17 Diffusion from a Point Source in a Constant-Velocity Stream
(Reference IV.14)

$$\frac{\partial C_A}{\partial r} \sim e^{-(\sqrt{r^2 + z^2} - z)} \left[\frac{r}{(r^2 + z^2)^{3/2}} + \frac{r}{r^2 + z^2} \right] \quad (\text{IV.19})$$

In the limit, as the longitudinal distance, z , between the generation point and the sampling plane becomes large, the concentration profile takes the form

$$\lim_{z \rightarrow \infty} \frac{\partial C_A}{\partial r} = 0 \quad (\text{IV.20})$$

That is the concentration profile is constant. To illustrate this result, let $r = 0.1z$ in Equation IV.19. Then,

$$\frac{\partial C_A}{\partial r} \sim \frac{1}{z^2} \quad (\text{IV.21})$$

Although this example lacks a certain degree of mathematical rigor and is derived for contaminant generation in an unbounded, uniform laminar flow, it does demonstrate the desired behavior of the concentration profile.

Method 6, Reference IV.9, states that the sampling flow rate shall be proportional to the duct flow rate. A representative flow rate can be achieved by employing

- (1) The null probe method that is described in the next subsection, or
- (2) The fixed rate sampling pump that is an integral part of many gas and vapor monitors. Proportionality cannot be maintained with a fixed sampling rate if the duct flow is unsteady.

IV.3.2 Particulates

The object of this section is to develop fluid mechanics and control system criteria that are applicable to automatic sampling of particulate-laden flows in recirculation ducts. The sampling system is defined to begin at the sampling probe and end at the sampling pump.

The sampling problems associated with recirculation duct systems are somewhat different than those associated with the more familiar gas stacks.

Cross-sectional areas are much smaller in ducted systems; hence, a useful sampling scheme must incorporate equipment that presents little or no impedance to flow. This requirement implies small or non-intrusive probes. The cross-sectional shape of recirculation ducts may be either rectangular or circular, and accessibility will generally pose problems. Recirculation duct systems offer certain advantages over gas stacks. In a recirculation duct, air temperature is likely to be closer to ambient temperature and the turbulence level will generally be lower than in a gas stack. From a sampling point of view, recirculation duct flow may be considered as two-dimensional.

The following list represents an attempt to define the sampling system requirements; however, not all of these requirements will be addressed in this report.

System Requirements

- (1) automatic traversing of circular and rectangular ducts
- (2) automatic sampling (fixed flow rate and variable isokinetic rate)
- (3) inexpensive components
- (4) low power consumption
- (5) operable by unskilled labor
- (6) clogged sampling orifices should be easily checked
- (7) ease of system calibration
- (8) compatible with potential on-line analysis equipment
- (9) possible visual displays for
 - (a) pressure drop across sampling filter
 - (b) elapsed time
 - (c) end of traverse
 - (d) probe position

The basic format of this section will be to investigate each component of the sampling train in an analytical fashion. Then, the information will be used to design a probe system, step-by-step, as the section progresses.

By the time the end of the section is reached, major constituents of a sampling probe system will be assembled into a workable unit capable of automatic sampling of particulate flows.

Particulate-laden gas flows pose difficult sampling problems. The particle distribution across and duct section is, in general, nonuniform. Also, certain types of particles exhibit electrostatic forces and irregular shapes. The presence of solid particles may initiate a condensation process by providing a surface upon which the vapor can condense.

In order to minimize flow field disturbances and thus obtain a representative sample, the isokinetic sampling criterion is employed. Isokinetic conditions exist when the velocity of the gas through the sample probe is exactly equal to the local velocity of the undisturbed flow field.

In order to sample isokinetically, the local flow velocity profile must be known a priori or it must be inferred by measurement during the sampling process. Usually the flow in a recirculation exhaust duct has a fully developed, turbulent profile which for a circular duct can be described by a simple power law. For example, the required sample flow rate for a 3/8-inch diameter probe inserted into a 12-inch circular duct carrying 785 cfm at standard conditions would be determined as follows. The mean duct velocity, $\bar{u}$, and the mean flow Reynolds number, R_e , are

$$\bar{u} = Q/A = \frac{4(785)}{\pi(1)^2} = 1000 \text{ ft/min}$$

$$R_e = \frac{\bar{u}D}{\nu} = \frac{\left(\frac{1000}{60}\right)(1)}{160 \times 10^{-6}} = 1.04 \times 10^5$$

Therefore, the flow is turbulent because $R_e \gg 2000$. For turbulent pipe flow, the power law for the velocity profile is

$$\frac{u}{U} = \left(\frac{Y}{R}\right)^{1/7} \quad \text{and} \quad \frac{\bar{u}}{U} = 0.817 \quad (\text{IV.22})$$

where

- u = local velocity or sampling velocity
- U = centerline velocity in the pipe

$\bar{u}$	=	mean flow velocity
y	=	radial coordinate measured from the pipe wall
R	=	duct radius

The relationship between mean velocity and centerline velocity is well known, and has been proven for turbulent flow. Table IV.4 has been constructed from Equation IV.22, the sampling probe diameter, and the flow conditions that were cited above.

TABLE IV.4
ISOKINETIC SAMPLING CONDITIONS IN
TURBULENT DUCT FLOW

$\frac{y}{R}$	$\frac{u}{U}$	$\frac{\bar{u}}{u}$	$u(\text{ft/min})$	$Q_{\text{SAMPLE}} (\text{cfm})$
0.1	0.720	0.881	881	0.675
0.2	0.795	0.973	973	0.746
0.3	0.842	1.03	1030	0.789
0.4	0.877	1.07	1070	0.820
0.5	0.906	1.11	1110	0.851
0.6	0.930	1.14	1140	0.874
0.7	0.950	1.16	1160	0.889
0.8	0.969	1.19	1190	0.912
0.9	0.985	1.21	1210	0.928
1.0	1.0	1.22	1220	0.935

It can be seen that the probe velocity, u , varies by approximately ± 20 percent of the mean velocity in the region of practical measurements. The outside diameter of the probe must be consistent with the duct radius so that the probe can be positioned at values of y/R less than 0.1 (see Reference IV.13).

Sampling System Design (Pneumatic Components)

Using the data from the above example problem, the design of the probe system will be carried further on the assumption that the sampling flow train is as shown in Figure IV.18. We shall consider each item individually, i.e., the vacuum pump, system pressure drops, valve size, sensor, and pneumatic control loop.

Vacuum Pump Considerations

By examining Table IV.4, we observe that the flow range is between

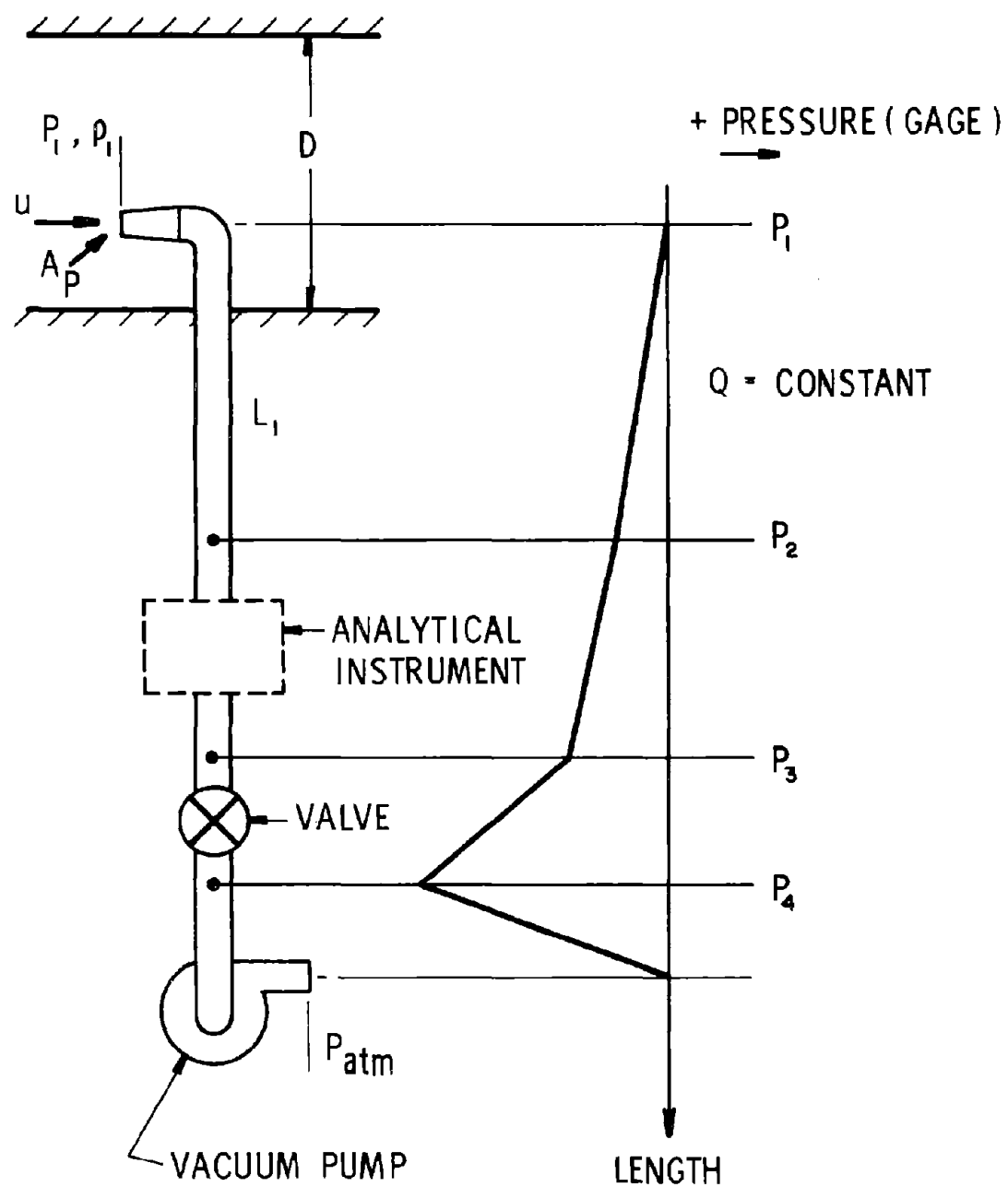


Figure IV.18 Pressure Drop Profile in a Sampling System

0.675 and 0.935 scfm. The vacuum pump must have sufficient capacity at its rated inlet pressure. In Figure IV.19 the pressure-volume curve is shown for a typical vacuum pump. Generally, when the performance of a vacuum pump is determined, flow rate measurements are made at the system inlet. The next item in the experimental setup is usually a control valve. The vacuum pump inlet pressure is measured somewhere between the control valve and the pump inlet. A performance map is constructed using the system inlet flow rate, corrected to scfm, plotted against vacuum inlet pressure. If a single curve is presented, then the pump is intended for constant speed operation.

Since the general approach for control valve sizing will be graphical, and since the sampling system pressure drop is dependent upon the local gas density, the performance map must be converted to acfm plotted against inlet vacuum pressure. The scfm pressure map is converted to an acfm pressure map as follows:

$$\text{scfm} = \text{acfm} \left[\frac{P_{\text{pump inlet}}}{14.7} \right] \frac{519}{T_{\text{pump}}} \quad (\text{IV.23})$$

where T_{pump} is the pump inlet temperature in degrees Rankine, and the units of pressure are psia. In most cases the temperature correction is unnecessary. Also if P_1 (inlet pressure of the sampling probe) is equal to 14.7 psia, Equation IV.23 may be written as

$$\text{scfm} = \text{acfm} \left[\frac{14.7 - \Delta P_{\text{system}}}{14.7} \right] \quad (\text{IV.24})$$

or

$$\text{acfm} = \left[\frac{\text{scfm}}{1 - \frac{\Delta P_{\text{system}}}{14.7}} \right] \quad (\text{IV.25})$$

Noting that the inlet pressure of the vacuum pump must equal $14.7 - \Delta P_{\text{system}}$ we may replot Figure IV.19 as Figure IV.20 using ΔP_{system} interchangeably as "psi vacuum at the pump inlet". Table IV.5 illustrates the calculations for this example.

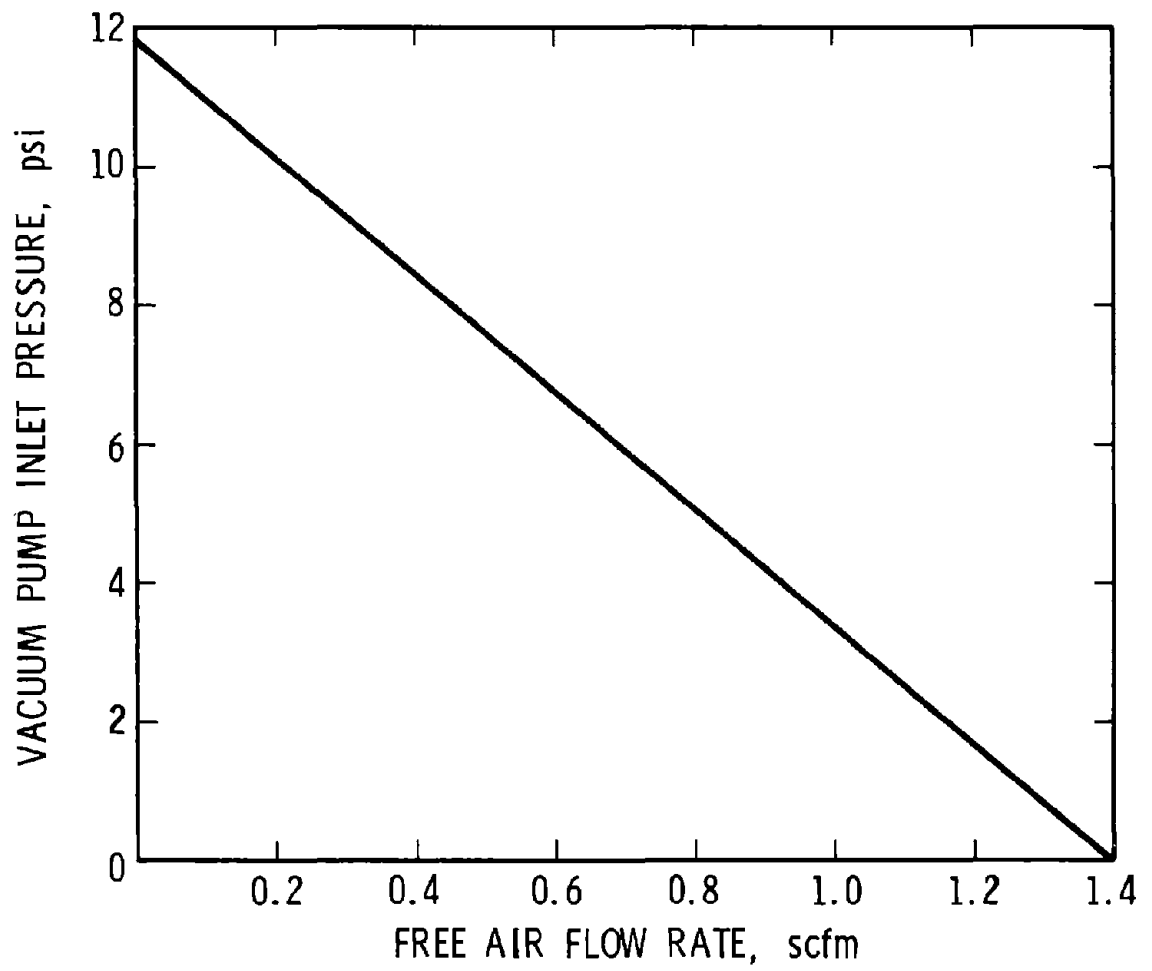


Figure IV.19 Vacuum Pump Performance for Constant Speed Operation

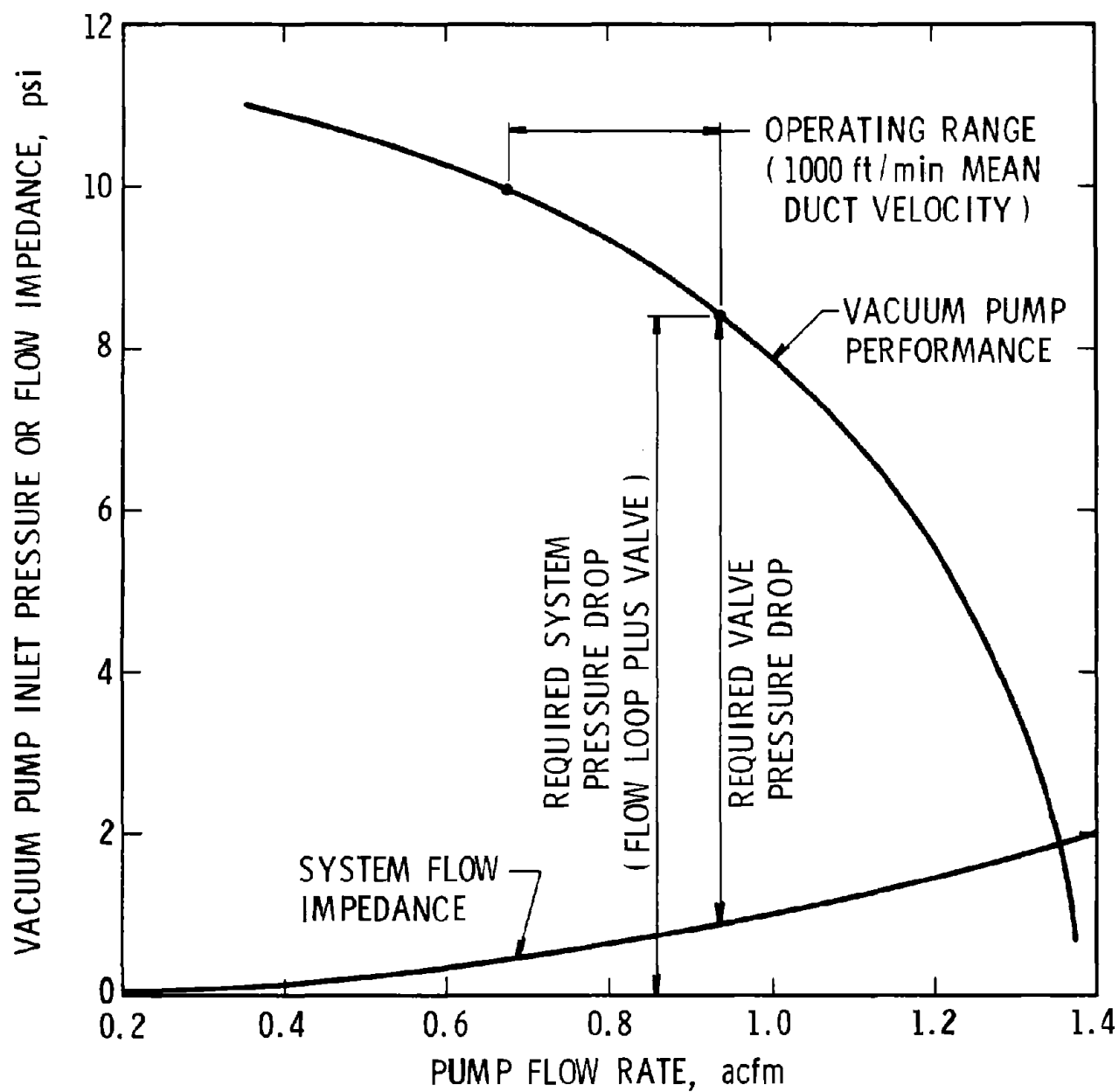


Figure IV.20 Corrected Vacuum Pump Performance and System Flow Impedance

TABLE IV.5
CONVERSION OF PUMP PERFORMANCE CURVE

<u>Q(scfm)</u>	<u>Vacuum Psi</u>	<u>Correction Factor</u> <u>(1 - Δ P/14.7)</u>	<u>Q(acfm)</u>
1.3	0.8	0.946	1.37
1.2	1.7	0.884	1.36
1.1	2.5	0.829	1.33
1.0	3.4	0.768	1.30
0.9	4.2	0.714	1.26
0.8	5.1	0.653	1.23
0.7	5.9	0.598	1.17
0.6	6.8	0.537	1.12
0.5	7.6	0.482	1.03
0.4	8.9	0.428	0.933
0.3	9.3	0.367	0.817
0.2	10.1	0.312	0.639
0.1	10.9	0.259	0.389

Referring back to Table IV.4, we observe that the acfm range for the 3/8-inch diameter probe is 0.675 acfm to 0.935 acfm. These two points are indicated in Figure IV.20. We can now determine the required pressure drop of the probe system and size the control valve to meet the inlet conditions of the vacuum pump.

System Pressure Drops

The pressure drop from Station 1 to Station 2 may be considered as an incompressible process; however, an additional pressure drop correction is needed to account for the sharp radius elbow near the probe tip (Figure IV.18). Normally, this is accomplished by adding an equivalent number of L/d 's (ratio of tube length to inside diameter) to the Darcy friction factor formula. Therefore, we may specify the pressure drop as

$$\Delta P_{1-2} = f \left(\frac{L}{D_p} + n \right) \frac{1}{2} \rho_1 V^2 \quad (\text{IV.26})$$

where n accounts for the apparent increase in tube resistance due to the presence of the elbow, f is the friction factor and D_p is the probe inside diameter. In terms of the volumetric flow rate

$$\Delta P_{1-2} = f \left(\frac{L}{D_p} + n \right) \frac{\rho_1 Q^2}{2 A_p^2} \quad (\text{IV.27})$$

The next item in the sampling train is an on-line, analytical measurement device. When the analytical instrument is used to measure the concentration of contaminant gases and vapors, the entire sampling system is usually sized to meet the flow rate requirements of the analytical instrument. If particulates are being measured, the isokinetic criterion dictates the system flow rate. A serious problem could develop if the analytical instrument that was used to measure particulate concentration was designed for a specific flow rate. In this case, an elaborate by-pass system must be devised. For practical purposes, the pressure drop across the instrument is considered to be proportional to the square of the flow rate, or

$$\Delta P_{2-3} = K Q^2 \quad (\text{IV.28})$$

By adding Equation IV.27 and IV.28 we may determine the pressure at Station 3 as

$$\Delta P_{1-3} = \left[f \left(\frac{L}{D_p} + n \right) \frac{\rho_1}{2 A_p^2} + K \right] Q^2 \quad (\text{IV.29})$$

We now know the pressure at Station 3 as a function of Q , and we also know the pressure at Station 4 which is determined from the vacuum pump performance curve. Thus, we arrive at the required valve pressure drop as a function of the flow rate, Q , that is necessary to control the system, assuming that pressure losses resulting from interference effects can be neglected. Adding new data to our sampling train, let us assume that $K = 144$, $n = 16$, $f = 0.02$, $L/D_p = 96$, and $\rho_1/2A_p^2 = 1.55$. Substituting these values into Equation IV.29 we may determine the system impedance curve that is plotted on the lower portion of the pump performance map (Figure IV.20). The distance between these curves represents the amount of pressure drop required by the valve to bring the system into flow equilibrium.

Valve Size

Valve sizes are normally specified in terms of a valve coefficient, C_v . For the subcritical flow case,

$$C_v = \frac{\text{scfm}}{16.05 \sqrt{\frac{P_3^2 - P_4^2}{T}}} \quad (\text{IV.30})$$

and for the critical case,

$$C_v = \frac{\text{scfm}}{13.61 \sqrt{\frac{P_3^2}{T}}} \quad (\text{IV.31})$$

where T is the absolute air temperature at the valve. The pressure drop, ΔP_{3-4} and the absolute values of P_3 and P_4 are now easily determined from the graph in Figure IV.20. These data are used to generate the required valve coefficient, C_v , for the volumetric flow rate range. This curve has been determined for our example problem and is shown in Figure IV.21.

Typically, valve manufacturers will supply a curve relating C_v to a pneumatic control signal or to the number of valve stem rotations. The flow capacity curve for a commercially available valve is reproduced as Figure IV.22. Using this valve, C_v , as a function of the number of valve stem rotations is easily described by the linear function

$$N_{vt} = 20 C_v \quad (\text{IV.32})$$

From Figure IV.21 we may model C_v in terms of acfm as

$$C_v = 0.11 \text{ acfm} + 0.001 \quad (\text{IV.33})$$

Combining Equations IV.32 and IV.33

$$N_{vt} = 2.2 \text{ acfm} + 0.02$$

and for the range of flow under consideration, we conclude that N_{vt} operates between 1.505 and 2.077 valve stem rotations, and $\Delta N = 0.572$, which translates into a flow control sensitivity of

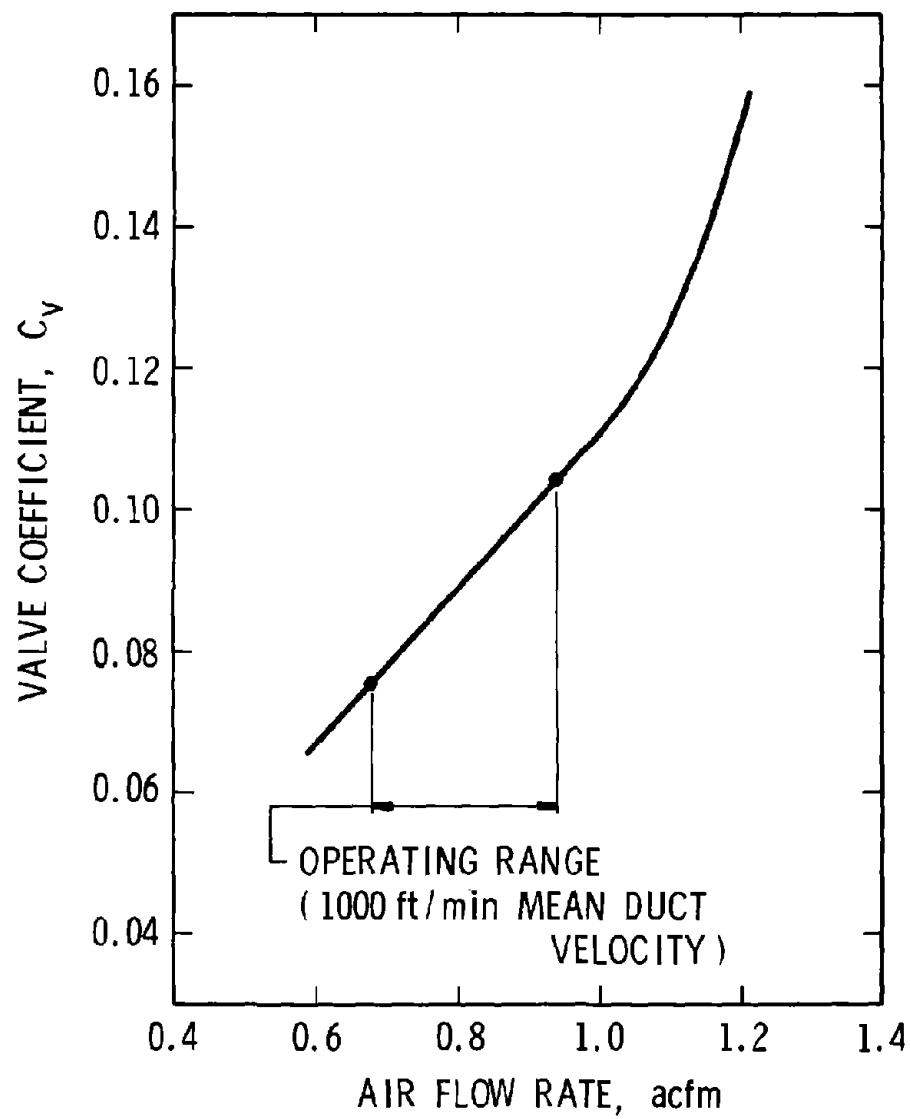


Figure IV.21 Valve Coefficient as a Function of Flow Rate

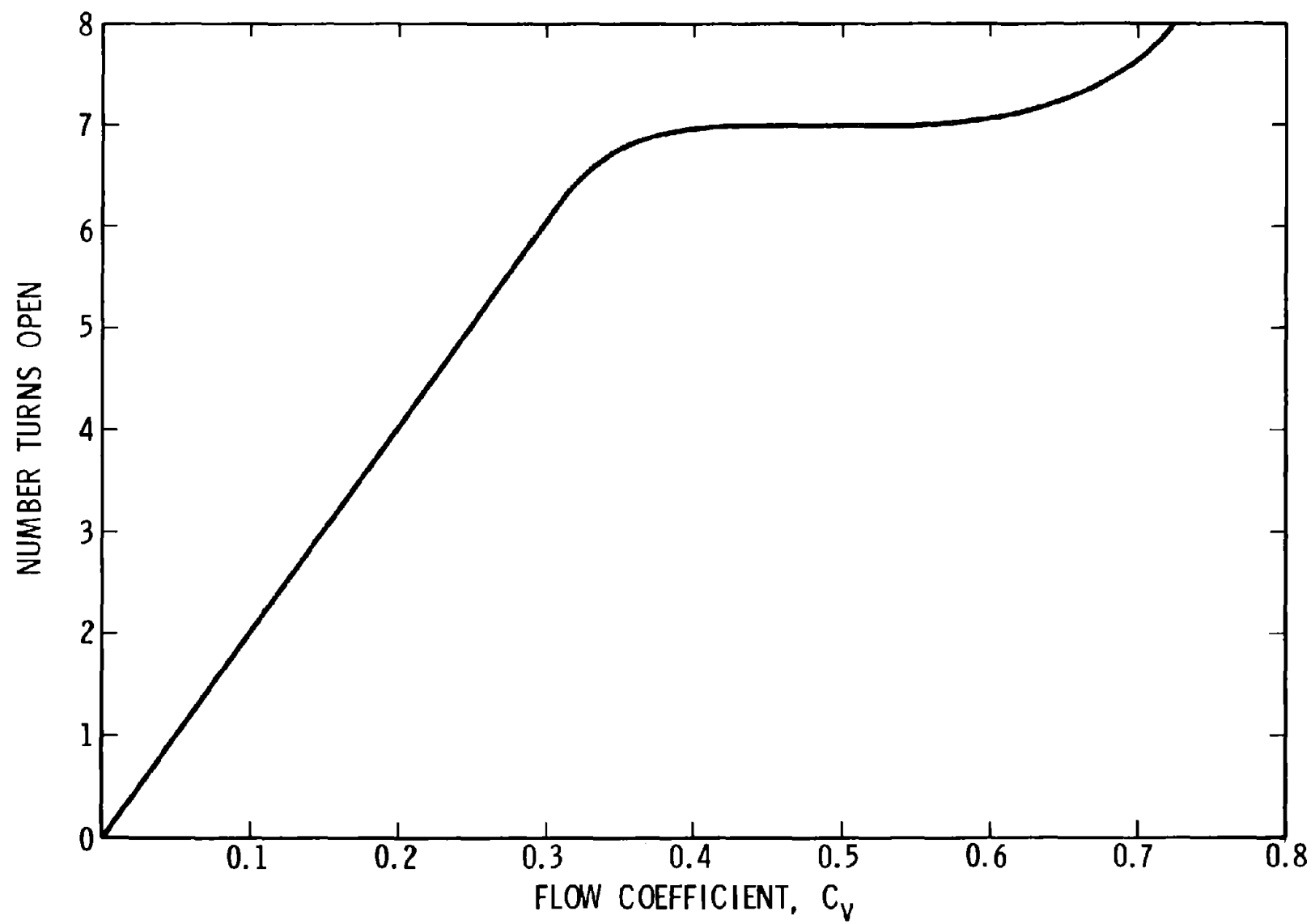


Figure IV. 22 Valve Performance Curve

$$\frac{\Delta N_{vt}}{\Delta acfm} = 2.2 \frac{\text{turns}}{\text{acfm}}$$

Up to this point we have discussed the flow dynamics, and it has been shown that this particular sampling system is inherently nonlinear but, with respect to the valve control, it can be modeled as a linear system over the specified flow rate range,

$$N_{vt} = mQ + b \quad (\text{IV.34})$$

By writing Equation IV.34 in terms of the probe inlet velocity,

$$N_{vt} = K_N V_{IN} + b \quad (\text{IV.35})$$

where

$$K_N = mA_p$$

Sensor

A balanced tube probe is used as the isokinetic sensor, and a typical layout of the probe is shown in Figure IV.23. This probe is designed to sense the local free stream static pressure and the static pressure of the sampling stream. Excluding certain geometric constraints, the static pressure in Sensing Chamber A will equal the pressure in Sensing Chamber B when the local duct velocity is equal to the velocity of the sampling stream, or stated another way, the pressure difference, $P_A - P_B$, will equal zero when isokinetic conditions exist. The user of this probe should be aware of the performance characteristics. A typical steady state performance map of the balanced tube is shown in Figure IV.24. It is readily demonstrated that $(P_A - P_B)$ is a function of the local duct velocity and the sampling flow rate.

Mathematically, in functional notation,

$$(P_A - P_B) = f(Q, V) \quad (\text{IV.36})$$

where Q is the sampling flow rate and V is the local duct velocity. The

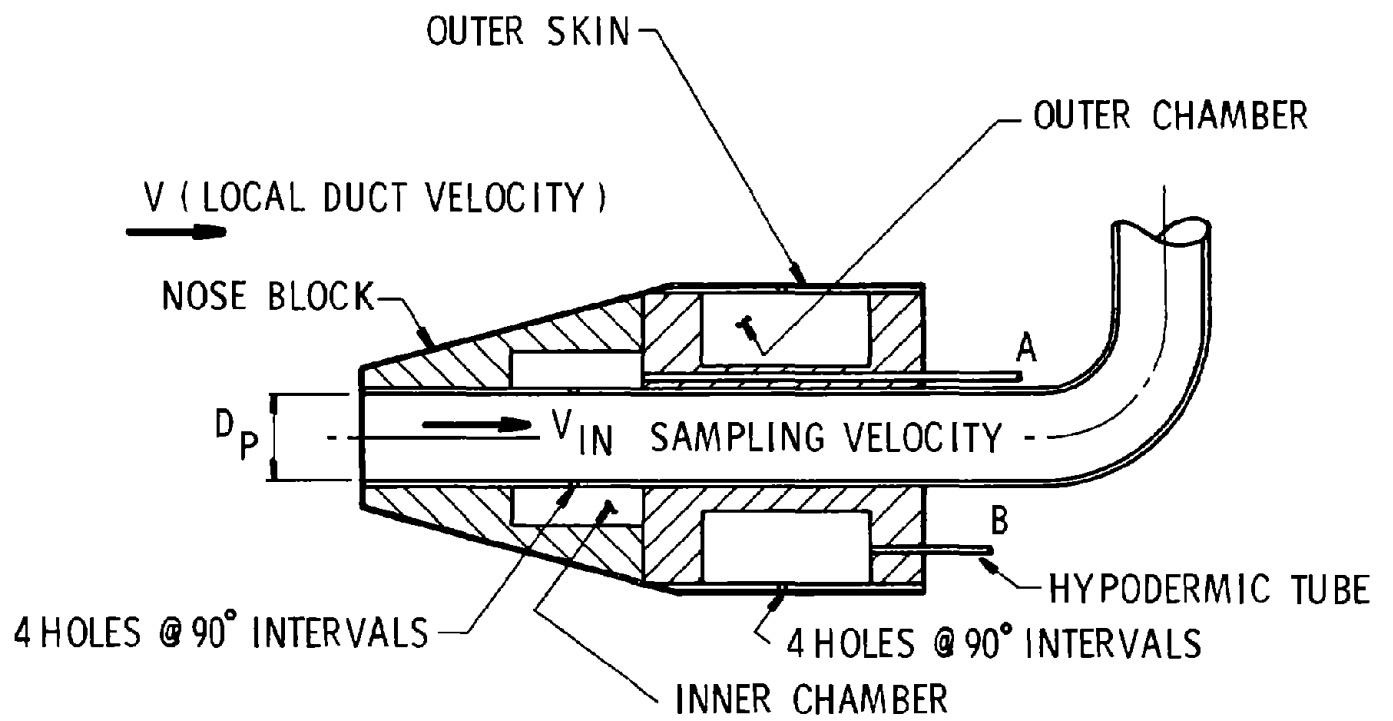


Figure IV.23 Balanced Tube Sensor

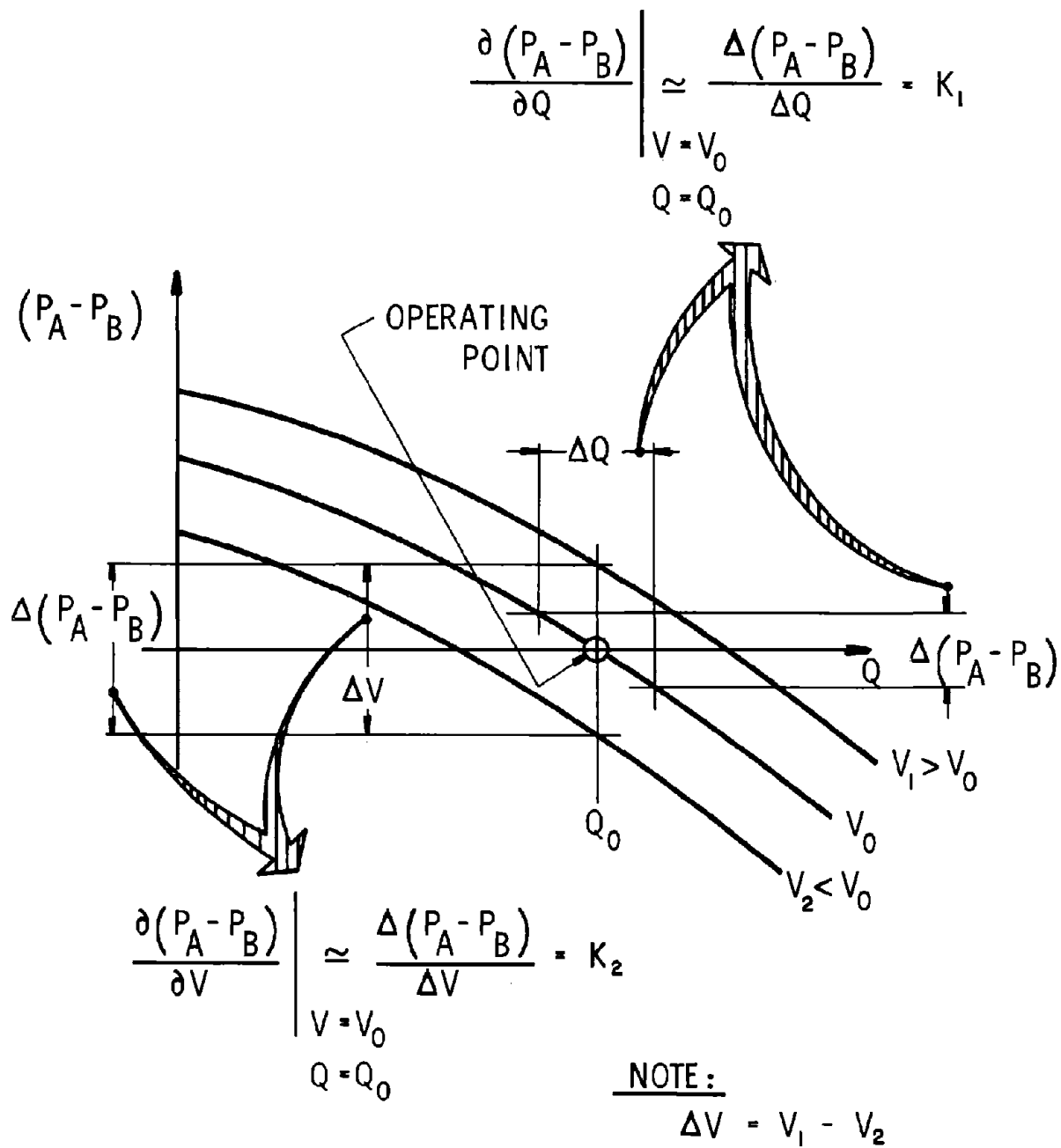


Figure IV.24 Steady-State Performance Map for a Balanced Tube Sensor

perturbation in $(P_A - P_B)$ is determined as the Taylor series expansion about the operating point which is designated by the subscript "o".

$$\Delta(P_A - P_B) = \frac{\partial(P_A - P_B)}{\partial Q} \left| \begin{array}{l} \Delta Q + \frac{\partial(P_A - P_B)}{\partial V} \Delta V + \text{Higher Order Terms} \\ V = V_o \\ Q = Q_o \end{array} \right| \quad (IV.37)$$

Equation IV.37 translates into a linear function for small changes in flow rate and velocity

$$\Delta(P_A - P_B) = K_1 \Delta Q + K_2 \Delta V \quad (IV.38)$$

The function of a controller would be to maintain $\Delta(P_A - P_B)$ equal to zero. Therefore,

$$\Delta Q = - \frac{K_2}{K_1} \Delta V \quad (IV.39)$$

The constant, K_1 , will be a negative value because a positive change in ΔQ results in a negative change in $\Delta(P_A - P_B)$ when V_o is held constant. Hence, Equation IV.39 is of the form

$$\Delta Q = K_3 \Delta V \quad (IV.40)$$

This result is expected because an increase in local duct velocity requires a higher suction flow rate in the sampling train.

Equation IV.38 also specifies the sensitivity of the sampling probe. The velocity sensitivity is defined as

$$S_v = \frac{\Delta(P_A - P_B)}{\Delta V} = K_2, \quad \Delta Q = 0 \quad (IV.41)$$

and the flow rate sensitivity is defined as

$$S_Q = \frac{\Delta(P_A - P_B)}{\Delta Q} = K_1, \quad \Delta V = 0 \quad (\text{IV.42})$$

Probe Response Factors

A point of interest for system control applications, but one which will not be dealt with in this report, is the response of the probe to a sudden change in velocity. The response time for a step input limits the rate at which the probe may be traversed across a velocity gradient. Also, the control system stability is influenced by the velocity disturbance input. For the system under consideration, the effect of velocity disturbances will be integrated or smoothed because of the long pneumatic sensing leads. Another factor that affects probe response is the "concentration response time". The probe may be considered as a geometric volume in which a contaminant is being ingested at a certain rate. A finite time is required for the concentration level that is sensed downstream in the sampling train (specifically in the analytical instrument) to reach the concentration level of the local duct stream. The time required for the concentration level at the analytical instrument to equal 99 percent of the concentration level in the duct stream can be calculated from Reference IV. 15,

$$\Delta t = 4.61 \frac{V}{Q} \quad (\text{IV.43})$$

where Δt is the response time in minutes, V is the sample volume in cubic feet, and Q is the isokinetic sampling rate in cfm. Response times range from milliseconds, for small, high flow rate probes, to minutes for the large probes that are used in gas stack sampling. For the system that we have been considering, the response time would be approximately 0.65 seconds when the probe is placed at a radial position of 0.1 R and the mean flow velocity in the duct is 1000 ft/min. It can be appreciated that this response time could greatly increase for very low velocity duct flows.

Pneumatic Control Loop

When all of the components of the control loop are assembled, a very interesting loop is generated that is somewhat different than might be expected. Figure IV.25 shows the overall system, which is termed a nulling control loop because a control action is initiated only when the system is out of null.

Upon inspecting the various loop components, it is observed that the sampling probe acts as the summing junction. A pneumatic error signal is generated that is proportional to the difference of $K_2 \Delta V$ and $K_1 \Delta Q$. The pneumatic signal is then converted to an electrical signal via a pressure transducer, and this electrical input is amplified by a constant gain K_4 . The amplified signal controls a DC torque servometer which in turn rotates the valve stem

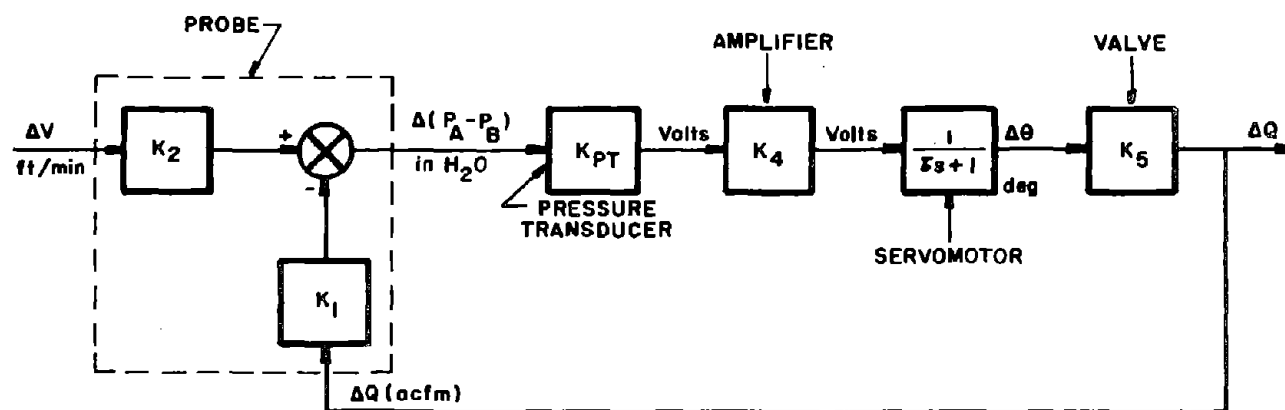


Figure IV.25 Block Diagram of a Balanced Tube Control Loop

to control the sampling flow rate. Any change in the local flow rate is sensed by the sampling probe which acts as a pneumatic feedback path.

The steady state valve-vacuum pump performance, as mentioned earlier, is mathematically defined as

$$\theta = 360(2.2)Q + 7.2 \quad (\text{IV.44})$$

and the valve sensitivity is

$$\frac{\Delta Q}{\Delta \theta} = \frac{1}{360(2.2)} = K_5 \quad (\text{IV.45})$$

If the response of the servomotor is slow compared to the response of other components in the loop, then the diagram pictured in Figure IV.25 is essentially correct. However, if the converse is true, then the dynamics of the sensor, valve, and vacuum pump must be considered.

Sampling System Design (Positioning Components)

The sampling system is composed of two independent control loops. The first, which has been discussed in detail, is the pneumatic system that consists of the vacuum pump, the control valve, the analytical instrument, and the sensor. The second control loop to be considered is the probe positioning system.

Two positioning control schemes are applicable. One is a Discrete Point Position Control (DPPC) and the second is a Continuous Motion Position Control (CMPC). If contaminant distribution across the duct is important, then the DPCC system is more appropriate, because the probe can be programmed to dwell at a point long enough for the analytical instrument to respond. Alternatively, sampling can be accomplished automatically using a "sweep technique". The spatial integration process is performed by allowing the probe to sweep equal areas in equal times, i.e., traverse the duct diameter at a constant velocity. Therefore, the CMPC system would be used, and more specifically, a "constant velocity position control" would be required.

The response of the pneumatic control loop and the response of the analytical instrument, limit the sweep rate. The response of the pneumatic control loop is determined by the sensor response which in turn is governed by the diameter of the sensing orifice holes, sensing chamber volume, the volume of the pneumatic lines that lead to the transducer, and finally the termination volume of the transducer itself. Also, the "contamination

response" is determined by the sampling flow rate and the volume of the sampling train. The term V/Q is known as the sampling time constant, and, generally, an acceptable response is 3.5 to 4.5 time constants. The preceding factors limit the sweep rate as imposed by the pneumatic control loop; however, certain analytical instruments require a minimum time to adequately accumulate enough contaminant for accurate concentration determinations.

Position Control Loop

Since servo-design is, in most cases, straightforward for low order systems (such as required here), and the approach is usually individualistic, only a few comments will be made regarding the application of a rate servo system to the constant velocity control. For the DPPC system, an electronic sequencer is desired. Further, rate and position systems are commercially available. It is usually a matter of complementing the servo system components with an actuator; therefore, comments will be directed toward the system as a whole.

Force requirements for our case are small. Typically, the predominant force is that which is required to overcome the inertia of the probe system and the friction at the sealing gland between the probe and the duct wall. Traversing velocity requirements are low, typically less than 2.5 inches/minute. Usually when a d.c. servomotor is employed, the speed reducer that is required to match the traversing speed to the motor speed will result in an enormous torque amplification whose magnitude will be much larger than actually required.

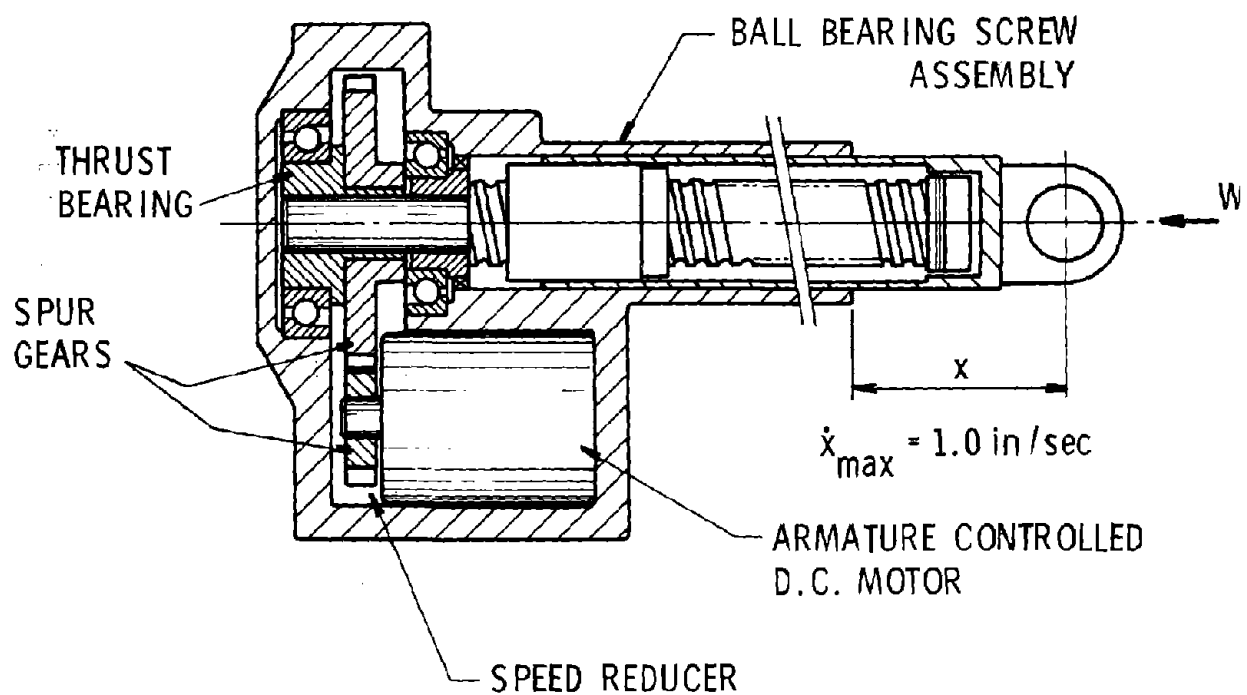
Loop Design

A rate-servo using a permanent magnet d.c. servomotor has been chosen as the driving source. The d.c. servomotor may be either configured as a rate-sensitive system using tachometer feedback or as a position system using an appropriate position feedback transducer. In both cases, the appropriate actuator would be a ball-bearing screw mechanism geared to the servomotor. The ball-bearing screw is a highly efficient device for converting torque to force, and it can be built into a small package. Figure IV.26 shows the actuator-motor assembly.

Signal Generation for DPPC

A noteworthy point to consider for DPPC systems is the problem of generating a signal to the servo which will control both probe position and dwell time at a specific point on the duct diameter.

In the past, time-position control was accomplished by using such devices as drum sequencers, paper tape readers, and other mechanical devices.



TORQUE - FORCE CONVERSION

$$T = \frac{WL}{2\pi e_1}$$

T = torque (in - lb)
 W = load (lbs)
 L = thread lead (inches)
 e_1 = efficiency = 0.9

$$P = \frac{\omega (T/12)}{5250}$$

P = horsepower
 ω = speed (rpm)

Figure IV.26 Motor - Actuator Schematic

With the advent of integrated circuits, a rather flexible and inexpensive "electronic sequencer" can be designed whose component cost is approximately 20 percent of an equivalent drum sequencer.

A servo loop requires a reference signal, which the servo system tries to match. A simple programmable "electronic sequencer" is shown in Figure IV.27. The system clock is derived from the 60 Hz power line frequency. The Schmitt trigger converts the power line sinusoidal wave to 60 pulses per second (pps). By using divider circuits (counters), pulses are generated at any desired rate that is less than 60 pps, e.g. 1 ppm. In DPFC systems, it may be desired to generate pulses in 15-minute intervals. These pulses are input to a preset counter which will generate a binary code according to the number of pulses counted. This binary code is used as a channel identification code for an integrated circuit known as a "multiplexer with decode". When a specific channel is addressed, the input that is present on that channel is transferred to the output of the device.

The voltage inputs are derived from potentiometers that have been set to generate a voltage proportional to the desired probe position. Thus, all that is required to program the device is to dial in a "divide number" and set the potentiometers to specific values. Most commercially available multiplexers have either eight or sixteen channels; hence, it is possible to generate up to 16 duct probe positions with one multiplexer.

Overall Systems

When all of the components are assembled, including the sampling probe, actuator electronic package, flow control, vacuum pump, and analytical instruments, the general physical configuration would be as indicated in Figure IV.28. This system can be configured for either automatic DPFC or CMPC operation.

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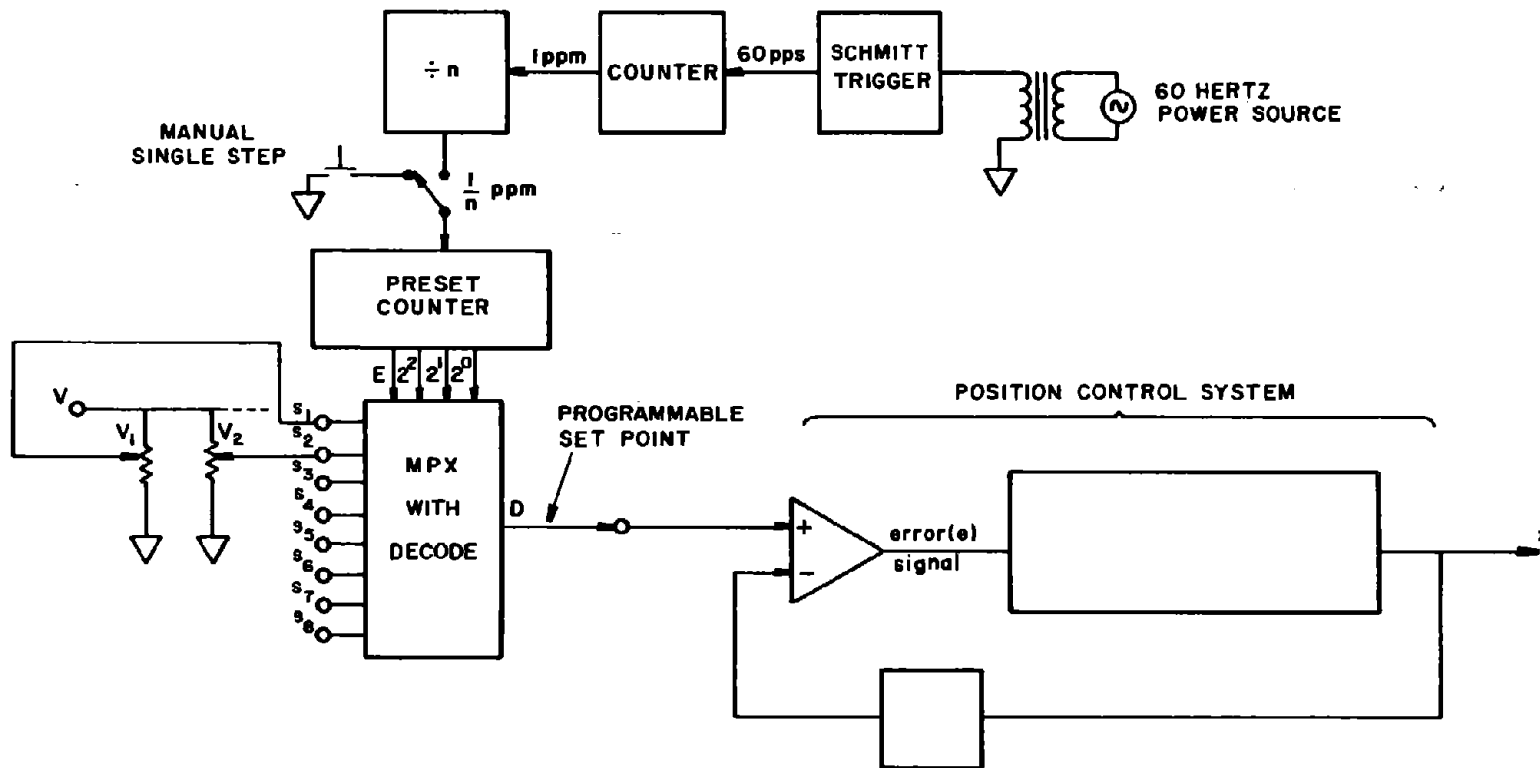


Figure IV.27 Programmable Electronic Sequencer

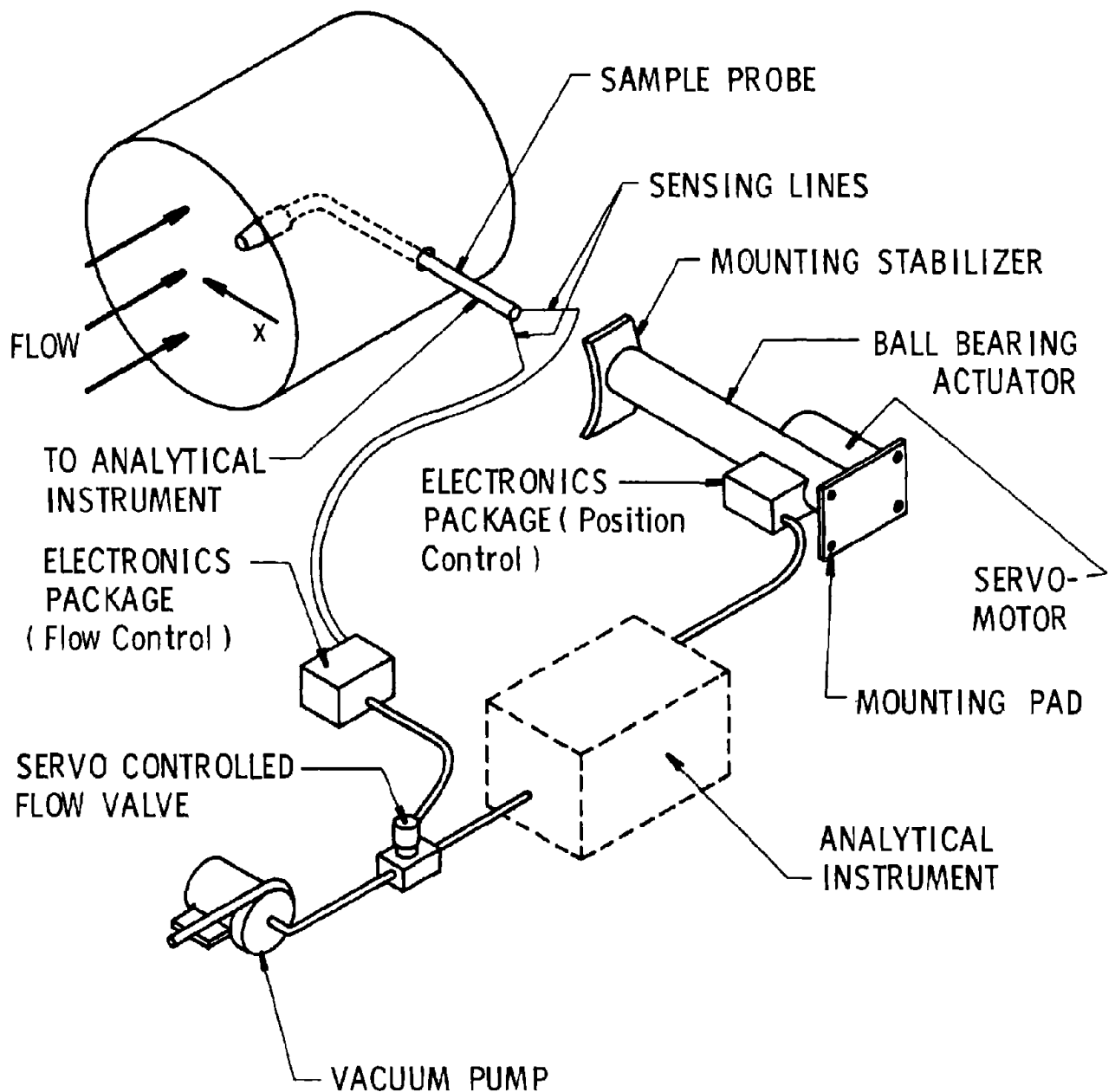


Figure IV.28 Physical Configuration of the Automatic Sampling System

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V. ANALYTICAL RECIRCULATION MODELS

V.1 Recirculation by Local Exhaust Ventilation (Model 1)

An analytical model is required in order to determine the ranges of system parameters that will maintain the workplace concentration below the TLV and to weigh various alternatives in selecting system components. In the following paragraphs, a model is developed which specifies the required recirculation flow rate or the allowable concentration in the recirculated air discharge in terms of the release rate of the contaminant, the efficiency of the air cleaning system, the overall ventilation rate, and the TLV of the contaminant.

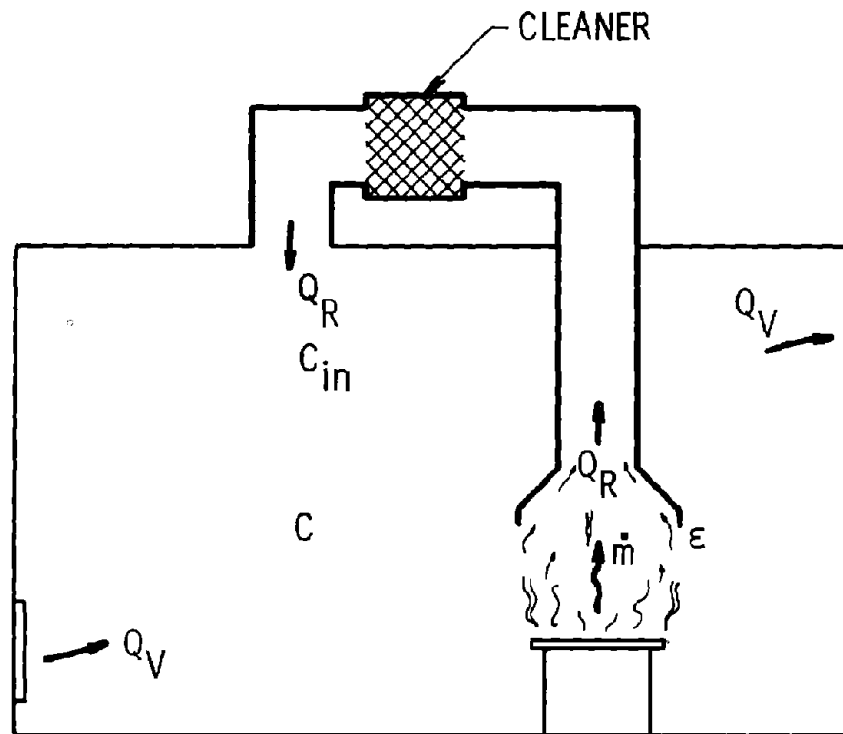
An exact solution of the contaminant concentration in a space requires solution of the turbulent diffusion-convection equations of fluid mechanics. Although these non-linear partial differential equations can be formulated and perhaps solved numerically, their complexity and computer solutions are likely to be of secondary value to the designer compared to a less cumbersome method that can be applied readily to design. Therefore, an overall or mass-balance method is used here.

Consider the representative case shown in Figure V.1 where a contaminant is released at a rate m (say, lb/min) from a localized workplace. An exhaust system is used to scavenge the contaminant from the room air; an overall dilution system is considered later. The exhaust scavenging system (e.g., hood) should be designed according to the guidelines presented in Reference V.1. The recirculated air has a flow rate Q_R (ft³/min) and is passed through a cleaning system before being discharged back to the work space. The efficiency of the air cleaning system is η , where η is defined as

$$\eta = 100 (1 - \text{Penetration}) \quad (V.1)$$

and

$$\text{Penetration} = \frac{\text{output concentration}}{\text{input concentration}} = \frac{C_{in}}{C_d} \quad (V.2)$$



- $\dot{m}$ = CONTAMINANT GENERATION RATE
- ϵ = HOOD CAPTURE EFFICIENCY
- C = ROOM CONCENTRATION
- η = AIR CLEANER EFFICIENCY
- Q_R = RECIRCULATED AIRFLOW
- Q_V = GENERAL VENTILATION AIRFLOW
- C_{in} = RECIRCULATED AIR CONCENTRATION

Figure V.1 Local Exhaust Recirculation Model

This efficiency can be a function of the total contaminant that has passed through the cleaner, the recirculation flow rate, or other system variables. The overall concentration of contaminant in the room is C (lb/ft³ or other consistent units such as ppm). The room is assumed to be "well-mixed" so that C is uniform throughout the bulk of the room. A mixing factor, K , will be incorporated in the analysis later to allow for non-uniform concentrations.

The rate at which contaminant is generated in the room is

$$\dot{m}_{\text{generated}} = \dot{m} \quad (\text{V.3})$$

The rate at which contaminant enters the room is

$$\dot{m}_{\text{enter}} = Q_R C_{\text{in}} \quad (\text{V.4})$$

The concentration of this contaminant in the overall ventilation flow rate Q_V entering the room is assumed to be very small. Q_V can, in principle, also include infiltration and exfiltration (Reference V.2).

The rate at which contaminant leaves the room is

$$\dot{m}_{\text{leave}} = \epsilon \dot{m} + Q_R C + Q_V C \quad (\text{V.5})$$

where ϵ is the efficiency of the scavenging system. Estimation of ϵ can be made by principles outlined in References V.1 and V.3 or by experiment or experience with similar designs.

The contaminant mass balance on the room is, therefore,

$$\dot{m}_{\text{generated}} + \dot{m}_{\text{enter}} - \dot{m}_{\text{leave}} = \dot{m}_{\text{build-up}} \quad (\text{V.6})$$

so

$$\dot{m} + Q_R C_{\text{in}} - \epsilon \dot{m} - Q_R C - Q_V C = \varphi \frac{dC}{dt} \quad (\text{V.7})$$

Here, φ is the volume of the workspace, and dC/dt is the time rate-of-change of the workspace contaminant. Equation V.7 can be simplified by using Equations V.1 and V.2, as follows. The contaminant concentration entering the air cleaner is

$$C_d = \frac{\epsilon \dot{m} + Q_R C}{Q_R} = \frac{\epsilon \dot{m}}{Q_R} + C \quad (\text{V.8})$$

Therefore, the concentration in the recirculation discharge is

$$C_{in} = (1 - \eta) C_d = (1 - \eta) \left(C + \frac{\epsilon \dot{m}}{Q_R} \right) \quad (V.9)$$

The overall mass balance can thus be written as

$$\bar{V} \frac{dC}{dt} + (\eta Q_R + Q_V) C = \dot{m} (1 - \epsilon \eta) \quad (V.10)$$

Letting C_o be the room concentration at time $t = 0$, the solution of this differential equation is

$$C = \frac{\dot{m} (1 - \epsilon \eta)}{\eta Q_R + Q_V} + \left[C_o - \frac{\dot{m} (1 - \epsilon \eta)}{\eta Q_R + Q_V} \right] e^{-\left(\frac{\eta Q_R + Q_V}{\bar{V}} \right) t} \quad (V.11)$$

An expression for the contaminant concentration in the recirculated airflow entering the room can be derived by substituting Equation V.11 into Equation V.9.

$$C_{in} = (1 - \eta) \left\{ \frac{\dot{m} \left(1 + \epsilon \frac{Q_V}{Q_R} \right)}{\eta Q_R + Q_V} + \left[C_o - \frac{\dot{m} (1 - \epsilon \eta)}{\eta Q_R + Q_V} \right] e^{-\left(\frac{\eta Q_R + Q_V}{\bar{V}} \right) t} \right\} \quad (V.12)$$

Equations V.11 and V.12 can be used in several ways, depending upon whether an existing exhaust ventilation system is to be modified for recirculation or a new system is to be designed. In either case, the contaminant generation rate $\dot{m}$ and the room volume $\bar{V}$ would be known. When an existing system is to be modified, the variables under the control of the designer would be the hood and air cleaner efficiencies (ϵ , η); in this case, Q_R is fixed by the existing local exhaust ventilation requirements. For a new installation, Q_R is dependent upon the required process ventilation, which can be estimated using the procedures that are recommended in the Industrial Ventilation Manual. As will be shown later, a lower bound on Q_R can be calculated on the basis of contaminant toxicity and system parameters. Consider first an existing ventilation exhaust system that is to be modified for recirculation. For this case, the air cleaner and hood efficiencies must be large enough that the concentration in the room or in the return airflow does not exceed the TLV. For small $\bar{V}$ or large Q_R , this means that the eventual steady-state concentrations must be kept below the TLV, but for large $\bar{V}$ or small Q_R , the concentrations may not build up to the steady-state value during the normal working hours. For

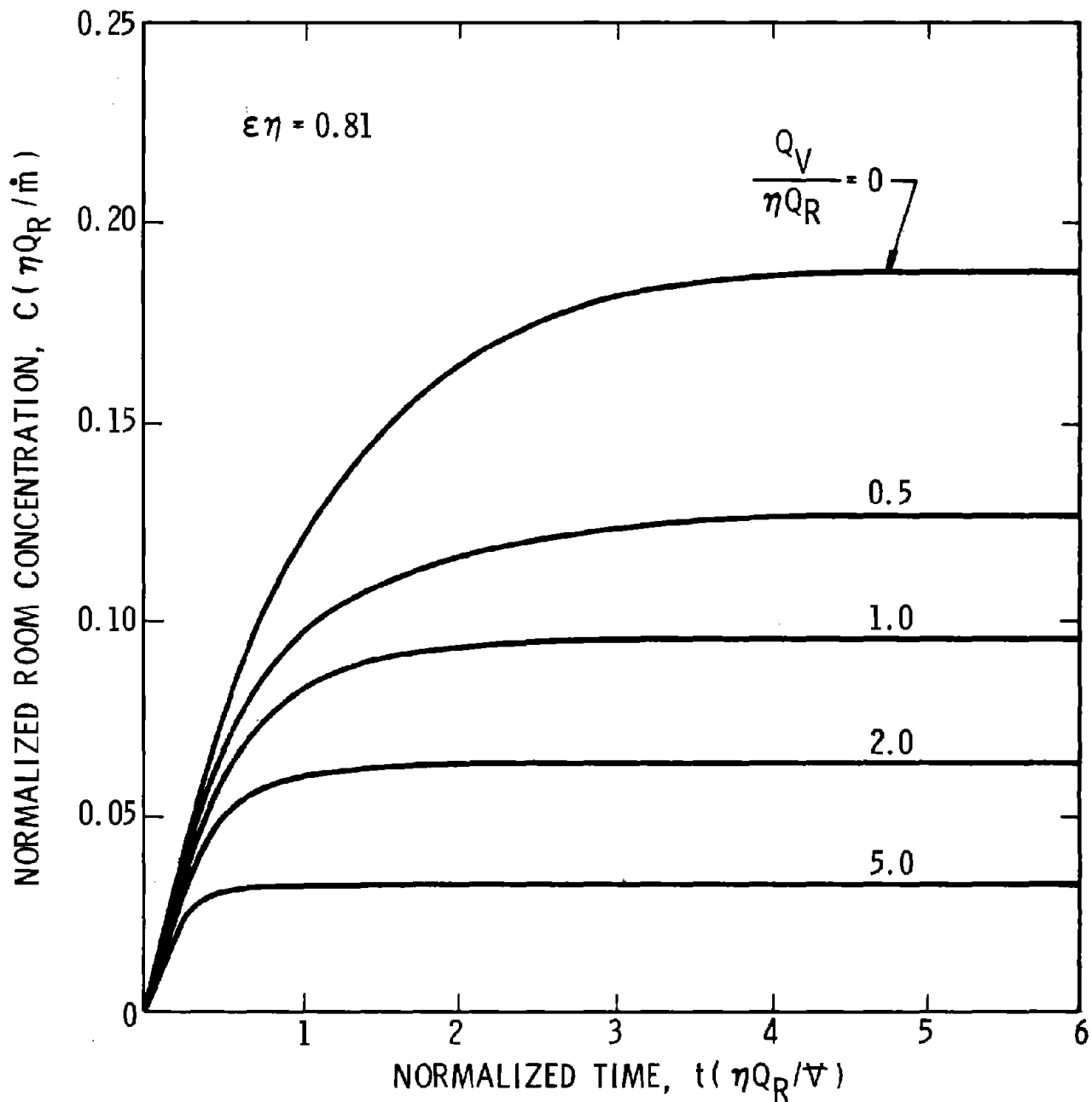
this case, all that is required is that the concentrations at the end of the work day be below the TLV. (This assumes that the room air is uncontaminated at the start of the next work day.) The generalized plot of Equation V.11, which is shown in Figure V.2, can be used to determine the eventual steady-state concentration in the room, the time to attain the steady-state, and the value of the room concentration at any time after the start of the process, for the case when the room is uncontaminated at the beginning of the work day ($C_0 = 0$ when $t = 0$). Although the curves have been calculated for a value of $\epsilon\eta = 0.81$, the concentrations read from the curves can be converted to the actual value of $\epsilon\eta$ by multiplying them by the factor $(1 - \epsilon\eta)/0.19$.

Example 1. Determine the steady-state room concentration and the time needed to reach it, for the case when butanol vapor is generated at a rate of 1.0 lb/hr in a 100,000 ft³ room, and Q_R and Q_V are 500 cfm and 2000 cfm, respectively. The hood capture efficiency is estimated to be 0.8, and the air cleaner efficiency is 0.9. Since $Q_V/\eta Q_R = (2000)/(0.9 \times 500) = 4.44$, the normalized steady-state concentration can be read from the graph as $C(\eta Q_R/\dot{m}) \approx 0.035$ at a normalized time of $t(\eta Q_R/V) \approx 0.75$. The concentration has to be corrected since $\epsilon\eta$ for this case is 0.72. Thus, $C(\eta Q_R/\dot{m}) \approx 0.035(1 - 0.72)/(0.19) = 0.052$. With $\dot{m} = 1.0$ lb/hr (0.0166 lb/min), $\eta = 0.9$, and $Q_R = 500$ cfm, the actual value of the steady-state room concentration is $C = 0.052(0.0166)/(0.9 \times 500) = 1.92 \times 10^{-6}$ lb/ft³. Since 1.0 ppm of butanol is equivalent to 1.895×10^{-7} lb/ft³, the room concentration is approximately 10 ppm, well below the TLV of 100 ppm. The time needed to reach the steady-state is $t = 0.75 V/\eta Q_R = 166$ minutes, or about 2 hrs 45 minutes.

Example 2. For the same conditions as Example 1, what is the concentration in the return air when a steady-state is reached? The steady-state can be calculated from Equation V.12 by setting the time-exponential term equal to zero. Thus,

$$C_{in} = (1 - \eta) \left[\frac{\dot{m} \left(1 + \epsilon \frac{Q_V}{Q_R} \right)}{\eta Q_R + Q_V} \right] = 0.1 \left\{ \frac{0.0166 \left[1 + 0.8 \left(\frac{2000}{500} \right) \right]}{0.9(500) + 2000} \right\}$$

$C_{in} = 2.85 \times 10^{-6}$ lb/ft³ = 15 ppm of butanol. The time needed to reach the steady-state is the same as for Example 1.



NOTE: THE CONCENTRATION FOR OTHER VALUES OF $\epsilon \eta$ CAN BE OBTAINED BY MULTIPLYING THE VALUES FROM THE GRAPH BY THE FACTOR $(1 - \epsilon \eta) / 0.19$

Figure V.2 Normalized Room Concentration as a Function of Normalized Operating Time and Local Exhaust Recirculation Air Flow Rate

In general, the curves of Figure V.2 show that the larger Q_V is, the smaller the room concentration will be for all times, assuming equal values of Q_R and $\dot{V}$. The time required to reach the steady-state also decreases as Q_V increases. Increasing ϵ or η also decreases the concentration. Changes in ϵ do not affect the time needed to reach a steady-state, but an increase in η decreases this time.

Several restrictions ought to be kept in mind when using Equation V.11 or the curves shown in Figure V.2. First, these expressions assume a homogeneous mixture of air and contaminant throughout the room. This should not be expected to occur in practice, and to account for the non-homogeneity, a mixing factor, K , is usually employed. This factor, K , essentially insures that the peak concentration for the actual distribution of contaminant in the room is below the TLV. This is accomplished by lowering the average or assumed homogeneous distribution by the factor, K , as will be discussed in Section V.5. Second, all recirculation systems that do not have redundant air cleaners should incorporate provisions for bypass of the recirculated airflow to the outside in the event of an air cleaner failure. (A possible exception could be a system whose recirculation flow rate and contaminant toxicity are both low.). Partial bypass may be required in any event to meet the room or the return air concentration limit. These considerations are discussed in Sections V.3 and V.6. Third, the contaminant that is discharged with the general ventilation flow, Q_V , should be examined to determine that it will not collect in dangerous levels elsewhere in the ventilation system. This is unlikely because the concentration in Q_V should be well below the TLV and because Q_V will subsequently be mixed with airflows from other non-contaminated spaces.

Now consider the design of a new recirculation system. For this case it is possible to evaluate the recirculated airflow rate with regard to maintaining acceptable room and return air concentrations. The design should be based on steady-state calculations unless the calculations indicate that a steady-state will not be attained during a normal work day. From Equation V.10, the minimum recirculation airflow can be derived by setting the room concentration equal to TLV/ K . The result is

$$Q_R \geq \frac{\dot{m} (1 - \epsilon\eta) K}{\eta(TLV)} - \frac{Q_V}{\eta} \quad (V.13)$$

It is explicitly assumed that the magnitude of the mixing factor, K , can be derived from the properties of the process and the contaminant. The corresponding return air concentration, from Equation V.12, is

$$C_{in} = (1 - \eta) \left[\frac{\dot{m}(1 + \epsilon \frac{Q_V}{Q_R})}{\eta Q_R + Q_V} \right] \quad (V. 14)$$

A negative value of Q_R resulting from Equation V. 13 implies that the overall ventilation airflow provides sufficient dilution with no recirculation.

If possible, the recirculation airflow rate should be chosen as the minimum value from Equation V. 13, and the exhaust flow rate calculated from the Industrial Ventilation Manual should be greater than or equal to this value. The value of C_{in} should then be checked. If the calculated C_{in} is below the TLV, then the design is satisfactory. Otherwise, Q_R must be increased or the air cleaner efficiency, η , improved. The minimum value of η that will maintain the return air concentration below the TLV for a specified Q_R can be obtained from Equation V. 14. The result is

$$(\eta)_{min} = \frac{1 - \frac{(TLV)Q_V}{\dot{m}(1 + \epsilon \frac{Q_V}{Q_R})}}{1 + \frac{(TLV)Q_R}{\dot{m}(1 + \epsilon \frac{Q_V}{Q_R})}} \quad (V. 15)$$

Example 3. Butanol is evaporated at a work station at the rate of 2 lb/hr. A vent hood with $\epsilon = 0.9$ will be used to capture the vapor. The cleaner specifications give an efficiency of 0.9. The new facility is to include an overall ventilation flow of 750 cfm. The TLV of butanol is 100 ppm. What is the required minimum recirculation airflow, assuming fairly good mixing ($K=3?$). Since the 100 ppm of butanol = 1.895×10^{-5} lb/ft³ and 2 lb/hr = 0.0333 lb/min, Equation V. 14 gives

$$Q_R \geq \frac{0.0333(1 - 0.81)(3)}{0.9 \times 1.895 \times 10^{-5}} - \frac{750}{0.9} = 310 \text{ cfm}$$

For $Q_R = 310$ cfm, the return air concentration is

$$C_{in} = 0.1 \left\{ \frac{0.0333 [1 + 0.9(750/310)]}{0.9(310) + 750} \right\}$$

$$= 1.03 \times 10^{-5} \text{ lb/ft}^3 = 54 \text{ ppm.}$$

Thus, the design is acceptable with $Q_R = 310 \text{ ft}^3/\text{min.}$

Example 4. In Example 3, suppose $Q_V = 1000 \text{ cfm.}$ For this case, Equation V.13 predicts that $Q_R = -2 \text{ cfm,}$ so Q_R must be chosen on the basis of Equation V.14. Setting $C_{in} = \text{TLV} = 1.895 \times 10^{-5} \text{ lb/ft}^3$, Equation V.14 can be solved for Q_R . The result, after trial-and-error or the solution of a quadratic equation, is $Q_R = 165 \text{ cfm.}$ The room concentration is substantially below TLV/K for this recirculation flow, but the return air concentration is exactly equal to the TLV.

V.2 Recirculation Based on Dilution Ventilation (Model 2)

In some circumstances, for example when sources of contaminant are located at several areas of the work space or when an existing dilution ventilation system is converted to a recirculation system, localized scavenging equipment (for example, hoods) may not be feasible. Instead, the generated contaminant is allowed to mix with the work space air, and the air subsequently cleaned by a dilution-recirculation system. This dilution-recirculation should probably not be used except for nuisance contaminants because of the potential for localized high concentrations of contaminant near the generation sites.

Mathematically, a dilution-recirculation system corresponds to a very small value of ϵ , the scavenging or direct-capture efficiency of the recirculation system, and ideally $\epsilon = 0$. The appropriate equations can be derived by setting $\epsilon = 0$ in the results given in the previous section. Thus, the room concentration is

$$C = \frac{\dot{m}}{\eta Q_R + Q_V} + \left[C_o - \frac{\dot{m}}{\eta Q_R + Q_V} \right] e^{-\left(\frac{\eta Q_R + Q_V}{V} \right) t} \quad (\text{V. 16})$$

and the return air concentration is

$$C_{in} = (1 - \eta) \left\{ \frac{\dot{m}}{\eta Q_R + Q_V} + \left[C_o - \frac{\dot{m}}{\eta Q_R + Q_V} \right] e^{-\left(\frac{\eta Q_R + Q_V}{V} \right) t} \right\} \quad (\text{V. 17})$$

The steady-state form of these equations can be developed by setting the time-exponential term equal to zero.

Figure V.3 shows a plot of Equation V.16 in terms of normalized variables, for the case when the initial concentration, C_0 , is equal to zero. The room concentrations can be seen to be much higher for the same Q_R and $\dot{m}$ than when local exhaust hoods are used. Thus, more recirculation airflow is needed for a dilution-recirculation system than for a direct-capture system.

V.3 Model With Use of Partial Bypass

There may be occasions when the recirculation system must be operated with either partial or complete bypass of the recirculated air. These occasions can arise when cleaners are being replaced or are operating at less than the design performance or when temporarily excessive rates of contaminant are generated. In other cases, partial bypass may be required continuously because the toxicity of the contaminant would require impractical or uneconomical amounts of recirculation airflow. Figure V.4 shows a model for this case.

If BR is the bypass ratio, $BR = Q_B/Q_R$ where Q_B is the volume flow rate of recirculated air that is exhausted to the outside either before or after cleaning, then Equation V.7 is modified as follows:

$$\dot{m} + Q_R(1 - BR) C_{in} - \epsilon \dot{m} - Q_R C - Q_V C = V \frac{dC}{dt} \quad (V.18)$$

It is assumed in this equation that make-up air is added at a rate equal to Q_B . Equation V.9 can be used to eliminate C_{in} from Equation V.18.

$$V \frac{dC}{dt} + \left\{ Q_V + Q_R [\eta + BR(1 - \eta)] \right\} C = \dot{m} \left\{ 1 - \epsilon [\eta + BR(1 - \eta)] \right\} \quad (V.19)$$

The solution of this equation is

$$C = \frac{\dot{m} \left\{ 1 - \epsilon [\eta + BR(1 - \eta)] \right\}}{Q_V + Q_R [\eta + BR(1 - \eta)]} + \left\{ C_0 - \frac{\dot{m} \left\{ 1 - \epsilon [\eta + BR(1 - \eta)] \right\}}{Q_V + Q_R [\eta + BR(1 - \eta)]} \right\} e^{-\left\{ Q_V + Q_R [\eta + BR(1 - \eta)] \right\} \frac{t}{V}} \quad (V.20)$$

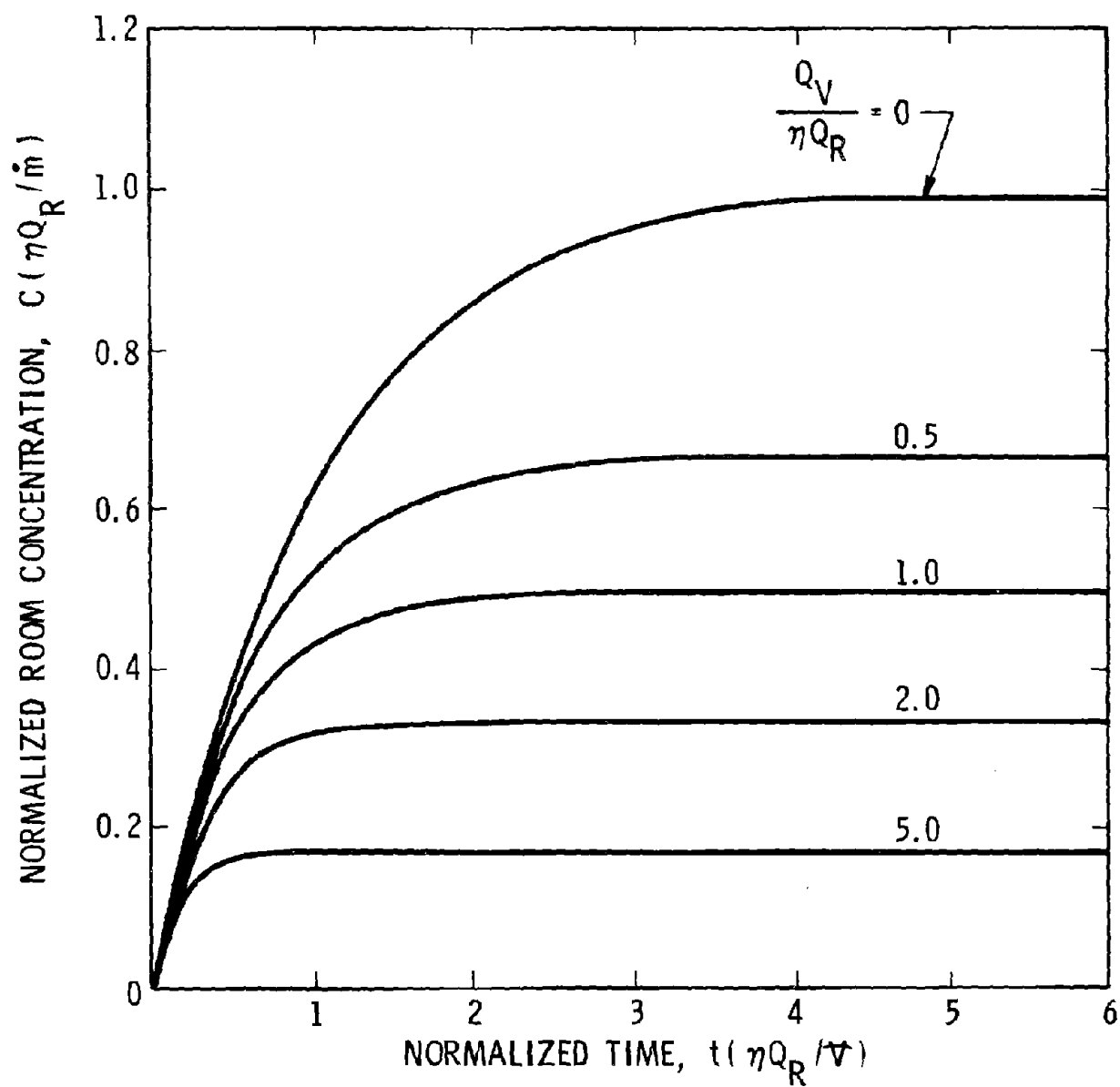
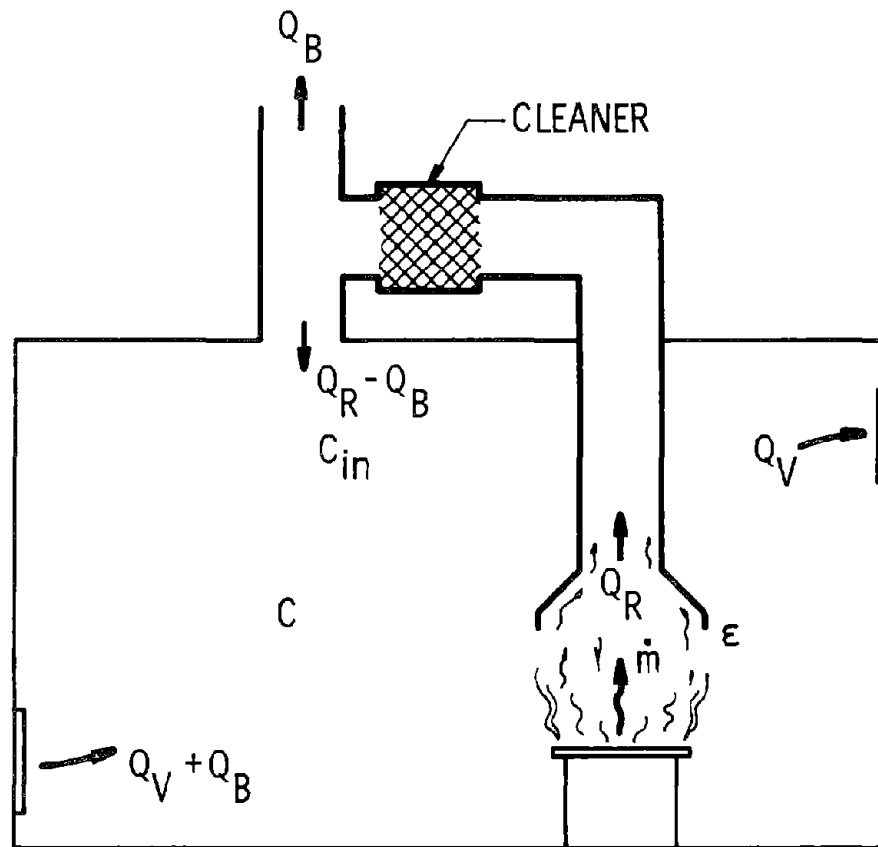


Figure V.3 Normalized Room Concentration as a Function of Normalized Time and Air Flow Rate for the Dilution Recirculation Model ($\epsilon = 0$)



- $\dot{m}$ = CONTAMINANT GENERATION RATE
- ϵ = HOOD CAPTURE EFFICIENCY
- C = ROOM CONCENTRATION
- C_{in} = RECIRCULATED AIR CONCENTRATION
- $Q_R - Q_B$ = RECIRCULATED AIRFLOW
- Q_B = BYPASS AIRFLOW
- Q_V = GENERAL VENTILATION AIRFLOW
- η = AIR CLEANER EFFICIENCY

Figure V.4 Recirculation Model with Partial Bypass

The concentration in the return air duct is

$$C_{in} = \frac{\dot{m}(1 + \epsilon \frac{Q_V}{Q_R})}{Q_V + Q_R [\eta + BR(1 - \eta)]} + \left\{ C_o - \frac{\dot{m} \{1 - \epsilon [\eta + BR(1 - \eta)]\}}{Q_V + Q_R [\eta + BR(1 - \eta)]} \right\} e^{-\left\{ Q_V + Q_R [\eta + BR(1 - \eta)] \right\} \frac{t}{V}} \quad (V.21)$$

The steady-state room and return air concentrations can be obtained by setting the time-exponential terms equal to zero. Corresponding equations for dilution-recirculation can be derived by setting $\epsilon = 0$ in Equation V.20 and V.21.

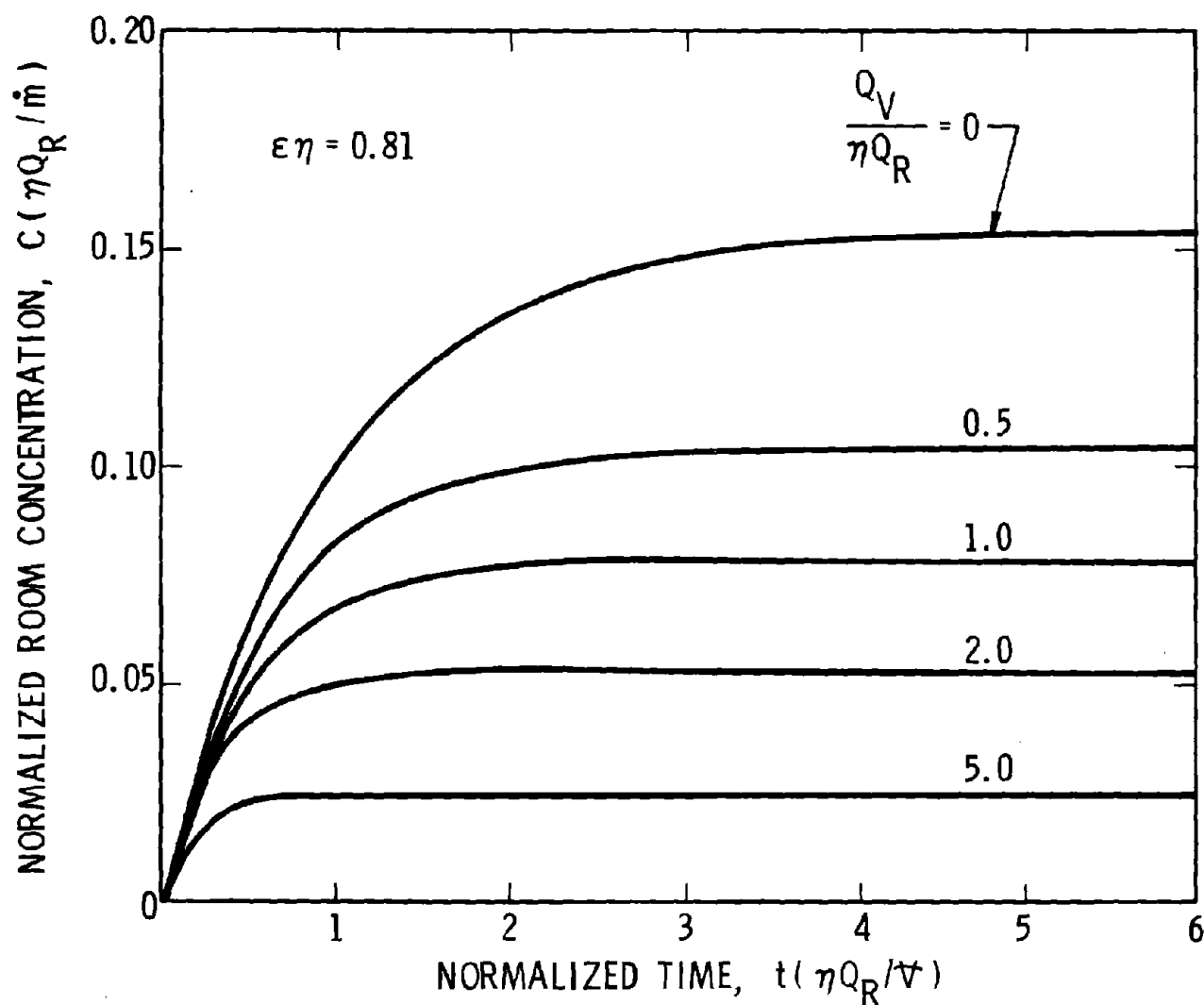
The most direct use of Equations V.20 and V.21 would be to determine the amount of bypass for existing ventilation systems that have been modified for recirculation, when the room concentration cannot be maintained at an acceptable level without using bypass. They are also of use in determining the value of bypass when an air cleaner fails, as will be discussed in Section V.5. From the steady-state form of Equation V.20, the minimum bypass ratio that is required to maintain the room concentration below TLV/K for a given Q_R and Q_V is

$$(BR)_{min} = \left(\frac{1 - \eta}{\eta} \right) \frac{\left[1 + \frac{\dot{m} \epsilon K}{Q_R(TLV)} \right]}{\left[\frac{\dot{m}(1 - \epsilon \eta)K}{Q_R(TLV)} - \frac{Q_V}{\eta Q_R} - 1 \right]} \quad (V.22)$$

Whenever this equation predicts that BR is greater than one, either the recirculated airflow, Q_R , must be increased if the design is for a new facility or the efficiency of the hood or the cleaner must be improved.

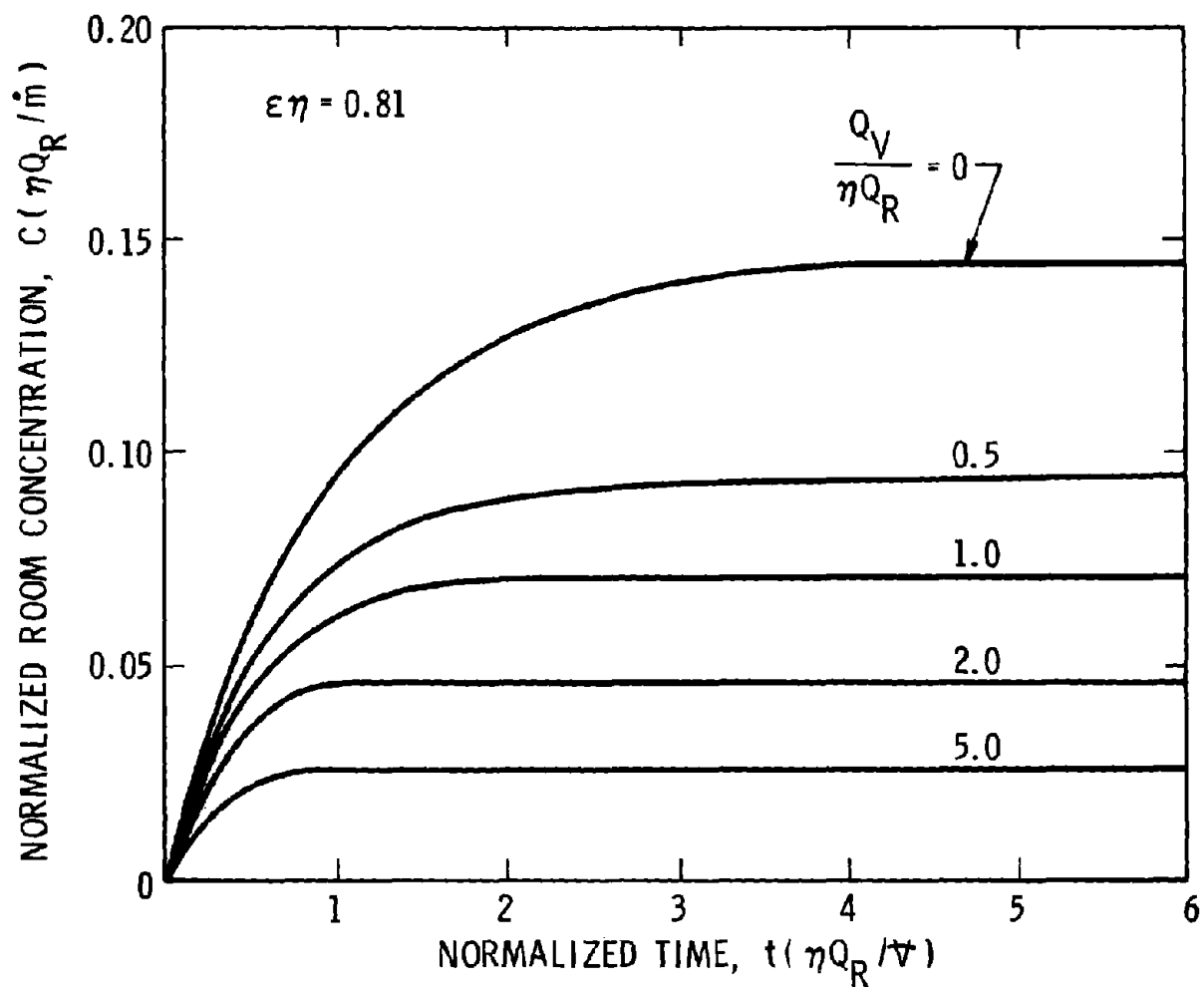
Generalized plots of Equation V.20, the room concentration as a function of time, are shown in Figures V.5 and V.6 for 33 percent and 50 percent bypass and the initial concentration equal to zero. These plots have been prepared for a value of $\eta = 0.9$; however, there is only a negligible change for values of η between about 0.8 and 1.0.

Example 5. Determine the effect of a 50 percent bypass of the recirculated air, for the release of 3 lb/hr of butanol in a 100,000 ft³ room, when $Q_R = Q_V = 1500$ cfm, $\epsilon = 0.8$, and $\eta = 0.9$. The TLV of butanol is 100 ppm, and the mixing factor, K, is estimated



NOTE: THE CONCENTRATION FOR OTHER VALUES OF $\epsilon \eta$ CAN BE OBTAINED BY MULTIPLYING THE VALUES FROM THE GRAPH BY THE FACTOR $\left[1 - \epsilon \eta \left(\frac{2}{3} + \frac{1}{3} \eta \right) \right] / 0.16$

Figure V.5 Normalized Room Concentration as a Function of Normalized Operating Time for a Bypass Ratio of Thirty-Three Percent



NOTE: THE CONCENTRATION FOR OTHER VALUES OF η CAN BE OBTAINED BY MULTIPLYING THE VALUES FROM THE GRAPH BY THE FACTOR $\left[1 - \epsilon \eta \left(\frac{1}{2} + \frac{1}{2\eta} \right) \right] / 0.145$

Figure V.6 Normalized Room Concentration as a Function of Normalized Operating Time for a Bypass Ratio of Fifty Percent

to be 4. To reiterate a previous point, it should be emphasized that the required value of K cannot be determined precisely from the current state-of-the-art. The value of K , in this example, is for illustrative purposes only. Since $Q_V/\eta Q_R = 1.11$, Figure V.6 shows the normalized steady-state room concentration is about 0.068, which has to be corrected for the fact that $\epsilon\eta$ is not equal to 0.81. Thus,

$$C(\eta Q_R/\dot{m}) = 0.068 \left[\frac{1 - 0.72(0.5 + 0.556)}{0.145} \right] = 0.11,$$

and the actual average room concentration is

$$C = 0.11 \left[\frac{0.0498 \text{ lb/min}}{0.9 \times 1500 \text{ ft}^3/\text{min}} \right] = 4.06 \times 10^{-6} \text{ lb/ft}^3 = 21 \text{ ppm}.$$

The effect of non-homogenous mixing is to create regions of concentration that are greater than C . The peak concentration is about K times the average, or 84 ppm. Without partial bypass, Figure V.2 can be used to show that the average room concentration is 25 ppm, so the peak concentration is likely to exceed the TLV.

V.4 Comparison of Models with the "Industrial Ventilation Manual Model"

In the 13th Edition of Industrial Ventilation Manual (Reference V.1), recirculation is discussed. That reference indicates that the pertinent recommendation for the allowable contaminant concentration in the recirculated air under equilibrium conditions is

$$(C_{in})_{allow} = \frac{1}{2}(TLV - C^*) \left(\frac{Q_R + Q_V}{KQ_R} \right) \quad (V.23)$$

(For nuisance contaminants, the factor of $\frac{1}{2}$ is replaced by 0.9). In this equation C^* is the contaminant concentration in the room when an airflow equal to the actual recirculated airflow is exhausted outside and fresh make-up air is supplied in an equal quantity. The model proposed in this report can be put into a similar format, by first calculating the fictitious concentration C^* . In fact, C^* corresponds to perfect cleaning of the recirculated air, so from Equation V.11 with $\eta = 1$ and the time-exponential equal to zero (equilibrium condition), the following result is obtained.

$$\frac{C^*}{K} = \frac{\dot{m}(1 - \epsilon)}{(Q_R + Q_V)} \quad (V.24)$$

or

$$\dot{m}(1 - \epsilon) = \frac{C^*}{K} (Q_R + Q_V) \quad (V.25)$$

where the K-factor has been introduced to be consistent with its use in the other relations. Introducing Equation (V.25) into Equation (V.12) yields

$$(C_{in})_{allow} = (TLV - C^*) \frac{Q_R + Q_V}{KQ_R} \quad (V.26)$$

This is identical to the equation presented in Industrial Ventilation Manual with the exception of the factor $\frac{1}{2}$, which is apparently an additional factor of safety.

Equation V.23 has the advantage that it applies regardless of the value of ϵ or η or whether bypass air is utilized. However, it has the disadvantage that the fictitious quantity C^* must be calculated or measured experimentally, and it does not specify, except implicitly, the required values of the other system parameters.

V.5 Derivation of Mixing Factor, K

In the recommended equations for calculating the allowable concentrations or the required recirculated airflow, an effectiveness-of-mixing factor K is included. It serves as a multi-purpose safety factor to maintain air concentrations below the TLV everywhere in the work space. In selecting K it is recommended in Reference V.1 that the designer should consider the toxicity of the contaminant, its generation rate, and the effectiveness of the ventilation system to mix the contaminant uniformly throughout the entire ventilated space. The recommended values of K vary from 3 to 10, with 3 corresponding to "good" mixing, but no guidance is given in selecting K as a function of the system parameters. In order to provide this guidance, the following simplified model is presented. The physical situation is sketched in Figure V.7.

Because of non-perfect scavenging of the contaminant by both the recirculation system and the overall ventilation system, some small portion of the generated contaminant will collect in corners or in other "dead" spots; at these locations the ventilation system does not effectively mix the air with the remaining room air that will eventually be cleaned or otherwise exhausted. The concentration of contaminant in the dead spot will therefore increase until such time as the mass diffusion of contaminant back into the well-mixed parts of the room, which arises because of the gradients in concentration, is equal to the rate at which the contaminant drifts into the dead spot. A region of higher concentration is thereby set-up. After a steady-state is attained, all of the generated contaminant enters the

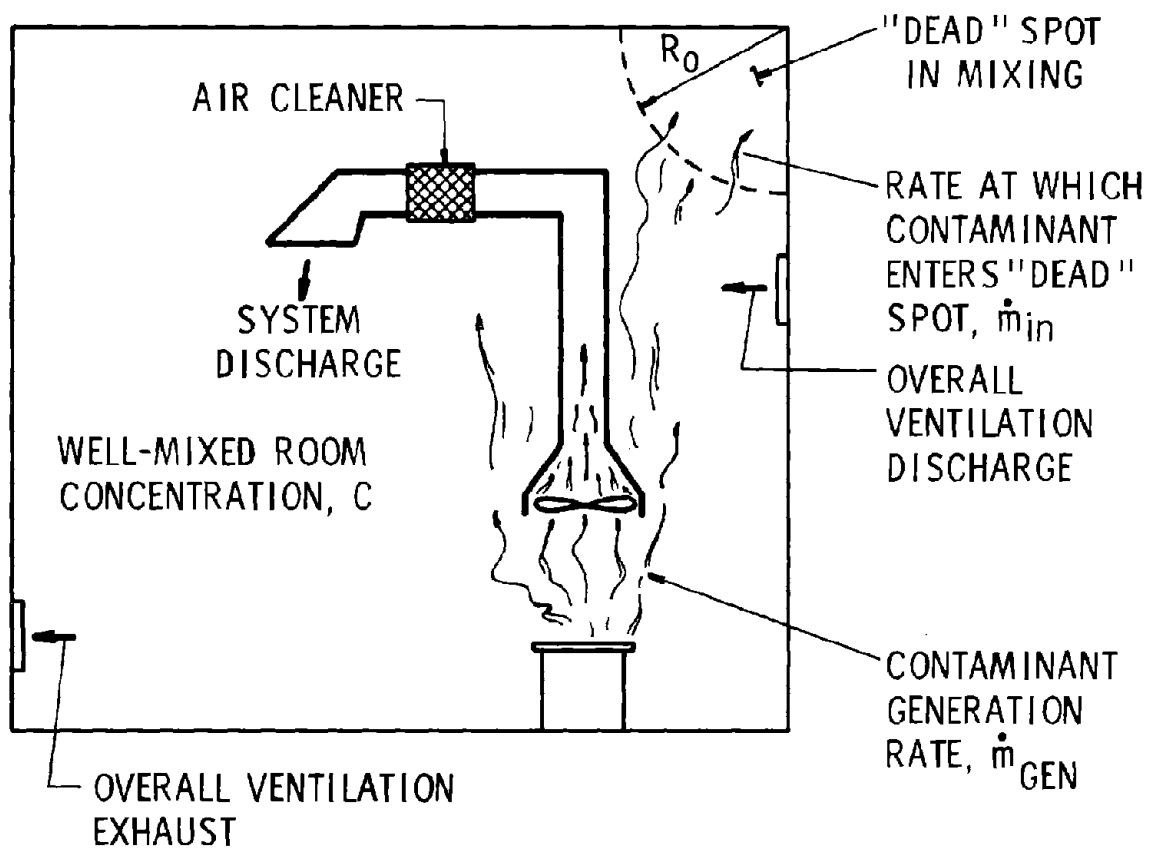


Figure V.7 Typical Recirculated Exhaust Air System Including a Localized Dead Spot

exhaust or recirculation system, either directly or by diffusion into the well-mixed air from the dead spots. Now, consider a dead spot (perhaps in a corner of the room) having a significant dimension of R_0 , where R_0 is the radius of a spherical surface centered at the corner and enclosing all the poorly-mixed space. In order to simplify the calculations, it is assumed that the contaminant drifting into the dead spot is more or less evenly distributed over the entire dead space. This is equivalent to assuming a volumetric generation rate $\dot{m}_{in}$ (say, lb/ft³ - min) in the dead space; $\dot{m}_{in}$ is equal to the rate at which contaminant enters the dead space divided by the volume of the space. Outside the dead space $\dot{m}_{in}$ is zero, and the concentration of the contaminant is C , the well-mixed room concentration.

Assuming spherical symmetry with the origin of the r -coordinate at the corner, a mass balance of contaminant on an elemental volume $\frac{1}{2}\pi r^2 \Delta r$ of the dead spot gives

$$\left[\frac{1}{2}\pi r^2 D \frac{dC_d}{dr} + \frac{d}{dr} \left(\frac{1}{2}\pi r^2 D \frac{dC_d}{dr} \right) \Delta r \right] + \frac{1}{2}\pi r^2 \Delta r \dot{m}_{in} - \frac{1}{2}\pi r^2 D \frac{dC_d}{dr} = 0 \quad (V.27)$$

After combining and dividing through by common factors, the result is

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{dC_d}{dr} \right) = - \frac{\dot{m}_{in}}{D} \quad (V.28)$$

In Equation V.28, C_d is the variable contaminant concentration in the dead spot and D is the diffusion coefficient for a dilute mixture of the contaminant in air. (If the contaminant is in gaseous or vapor form, D can be readily calculated; otherwise experimental results must be used.)

The solution of Equation V.28 is

$$C_d = - \frac{1}{6} \left(\frac{\dot{m}_{in}}{D} \right) r^2 + \frac{A_1}{r} + A_2 \quad (V.29)$$

where A_1 and A_2 are constants of integration. The integration constants can be evaluated by the requirement that $C_d = C$ at $r = R_0$ and that the concentration of contaminant does not become infinitely large at $r = 0$. These boundary conditions yield

$$C_d = C + \frac{1}{6} \left(\frac{\dot{m}_{in}}{D} \right) (R_o^2 - r^2) \quad (V.30)$$

Equation V.30 predicts that the maximum concentration in the dead spot occurs at $r = 0$ (the apex of the corner) and is equal to

$$C_{max} = C + \frac{1}{6} \left(\frac{\dot{m}_{in}}{D} \right) R_o^2 \quad (V.31)$$

In order to make sure that C_{max} is not greater than some pre-set allowable value, C_{allow} , the well-mixed room concentration, C , must be maintained below C_{allow} . Letting $C_{max} = KC$, where K is the "effectiveness-of-mixing" parameter and is identical to the K used in the previous sections, Equation V.31 can be rearranged to give

$$K = \frac{1}{1 - \frac{1}{6} \left(\frac{\dot{m}_{in}}{D} \right) \frac{R_o^2}{C_{allow}}} \quad (V.32)$$

In many cases C_{allow} is selected to be the TLV, perhaps divided by a factor-of-safety greater than unity.

Determination of $\dot{m}_{in}$ is a difficult problem. It depends on the effectiveness of the scavenging process but in any case is proportional to $\dot{m}_{gen}$, the total generation rate of contaminant. One estimate of $\dot{m}_{in}$ is $\dot{m}_{gen}/\Psi$, where Ψ is the volume of the ventilated space. Therefore,

$$K \approx \frac{1}{1 - \frac{1}{6} \left(\frac{\dot{m}_{gen}}{D\Psi} \right) \frac{R_o^2}{TLV}} \quad (V.33)$$

Equation V.33 is not sufficiently accurate to permit K to be evaluated directly. However, it does indicate trends. For example, more toxic contaminants (small values of TLV) will require larger values of K than will less toxic contaminants. Likewise larger values of K should be used when contaminant generation rates are large. Finally, since R_o^2/Ψ decreases as the volume of the work space increases, large rooms require smaller values of K than do small rooms.

V.6 Mathematical Interpretation of Air Cleaner Failure

There may be occasions when the air cleaner will fail. The designer must have assurance that an adequate amount of time is available before the concentration anywhere in the work space exceeds a predetermined level. The contaminant generation must stop or else partial or complete bypass of the recirculated air must be initiated.

Equation V.11 or V.21 can be used to investigate air cleaner failures. For this purpose, C_0 in these equations should be set equal to the room concentration at the instant of cleaner failure, and $t = 0$ should now be the time at which the failure occurs. If bypass of the recirculated air is begun at some time after the air cleaner fails, a combination of these equations must be used, as will be discussed below.

If it is assumed that the room concentration is equal to the steady-state value for normal operation when the air cleaner fails, then generalized relations can be derived. Letting η be the cleaner efficiency before the failure. The room concentration (without bypass) after the failure is

$$C = \frac{\dot{m}}{Q_V} - \frac{\dot{m}\eta}{Q_V} \left[\frac{\epsilon + Q_R/Q_V}{1 + \eta Q_R/Q_V} \right] e^{-\frac{Q_V}{V}t} \quad (V.34)$$

When $Q_V = 0$, Equation V.34 should be replaced by

$$C = \frac{\dot{m}(1 - \epsilon\eta)}{\eta Q_R} + \frac{\dot{m}}{V}t \quad (V.35)$$

When the overall ventilation Q_V is not zero, the room concentration will eventually exceed an allowable limit unless the process is shut down or bypass is started. If Q_V is not zero and the value of $\dot{m}/Q_V$ is larger than the allowable concentration (say TLV times an excursion factor), then the concentration will again eventually exceed the allowable level. The time after the failure that is needed to exceed the allowable concentration C_{allow} is,

$$t_{ex} = \frac{V}{Q_V} \ln \left\{ \frac{\eta[\epsilon + Q_R/Q_V]}{[1 - (C_{allow} Q_V)/\dot{m}][1 + \eta Q_R/Q_V]} \right\} \quad (V.36)$$

or if Q_V is zero,

$$t_{ex} = \frac{\forall C_{allow}}{\dot{m}} \left[1 - \frac{\dot{m}(1 - \epsilon \eta)}{\eta Q_R C_{allow}} \right] \quad (V.37)$$

When partial bypass is the normal method of operation, the corresponding equations are:

$$C = \frac{\dot{m}(1 - \epsilon \cdot BR)}{Q_V + BR \cdot Q_R} - \frac{\dot{m} \eta (1 - BR)}{Q_V + BR \cdot Q_R} \left\{ \frac{\epsilon + \frac{Q_R}{Q_V}}{1 + \frac{Q_R}{Q_V} [\eta + BR(1 - \eta)]} \right\} \times \quad (V.38)$$

$$e^{-\frac{Q_V}{\forall} \left[1 + \frac{Q_R}{Q_V} \cdot BR \right] t}$$

or when Q_V is zero,

$$C = \frac{\dot{m} \{1 - \epsilon [\eta + BR(1 - \eta)]\}}{Q_V + Q_R [\eta + BR(1 - \eta)]} + \frac{\dot{m} [1 - \epsilon \cdot BR]}{\forall} t \quad (V.39)$$

The time required to exceed the allowable concentration is

$$t_{ex} = \frac{\forall}{Q_V + Q_R \cdot BR} \ln \left\{ \frac{\eta \left(\frac{1 - BR}{1 - \epsilon \cdot BR} \right) (\epsilon Q_V + Q_R)}{\left[1 - \frac{C_{allow} (Q_V + BR \cdot Q_R)}{\dot{m}} \right] \left[Q_V + Q_R (\eta + BR - BR \cdot \eta) \right]} \right\} \quad (V.40)$$

and when Q_V is zero

$$t_{ex} = \frac{\forall C_{allow}}{\dot{m}(1 - \epsilon \cdot BR)} \left\{ 1 - \frac{1 - \epsilon [\eta + BR(1 - \eta)]}{C_{allow} [Q_V + Q_R (\eta + BR - BR \cdot \eta)]} \right\} \quad (V.41)$$

In Equations V.36 or V.40, the room concentration will never exceed C_{allow} if the argument of the natural logarithm is negative; that is, when the dilution effect of Q_V and the bypassed air is sufficiently large.

Example 6. In a 100,000 ft³ room, 1.0 lb/hr of butanol is being generated. For normal operations a recirculation airflow of 500 cfm and a general ventilation flow rate of 500 cfm are used, with both the hood and the air cleaner efficiencies being 0.9. (For this system, the steady state room concentration is 19 ppm.) If the cleaner fails, how long will it take for the room concentration to exceed the TLV or 100 ppm. Equation V.36 can be used for this case

$$t_{ex} = \frac{1000,000}{500} \ln \left\{ \frac{0.9(0.9 + 1)}{\left[1 - \left(\frac{1.895 \times 10^{-5} \times 500}{0.0166} \right) \right] [1 + 0.9]} \right\}$$

$$t_{ex} = 148 \text{ minutes}$$

The concentration in the "dead" spots will exceed the TLV in a shorter time. This time can be calculated by replacing C_{allow} by C_{allow}/K in the above equations. Again, a deterministic value of K is assumed.

When bypass of the recirculated air is started some time after the air cleaner fails, the computations are more complicated but can still be handled by Equations V.11, V.21, and V.34. If $\bar{C}$ is the concentration in the room (after the cleaner fails) at the instant the bypass is started at $t = t_{BP}$, then the room concentration for $t > t_{BP}$ is

$$C = \frac{\dot{m}(1 - \epsilon \cdot BR)}{Q_V + BR \cdot Q_R} + \left[\bar{C} - \frac{\dot{m}(1 - \epsilon \cdot BR)}{Q_V + BR \cdot Q_R} \right] e^{-\frac{Q_V}{V} \left[1 + \frac{Q_R}{Q_V} \cdot BR \right] (t - t_{BP})} \quad (V.42)$$

Example 7. For the conditions of Example 6, 50 percent bypass is

started whenever the room concentration exceeds 80 percent of the TLV. What is the time history of the room concentration in the event the air cleaner fails? The results are shown in Figure V.8. The room concentration after failure is computed from Equation V.34 until a concentration of 80 ppm is obtained. After this, Equation V.42 is used. It can be seen that a concentration of 80 ppm occurs after about 100 minutes. When 50 percent bypass is started, the concentration begins to decrease. After about two more hours the concentration is about 70 ppm. The new steady-state concentration of 64 ppm is reached after a total time of 16 hours. Presumably, the cleaner would be repaired or the process shut down before this time is reached.

V.7 References

- V.1 Industrial Ventilation Manual, Thirteenth Edition, American Conference of Governmental Industrial Hygienists, 1974.
- V.2 P. W. Kalika, J. D. Holcombe, and W. A. Cote, "The Re-Use of Industrial Air" ASHRAE Journal, November 1970.
- V.3 W. C. L. Hemeon, Plant and Process Ventilation, Industrial Press, New York, 1963.

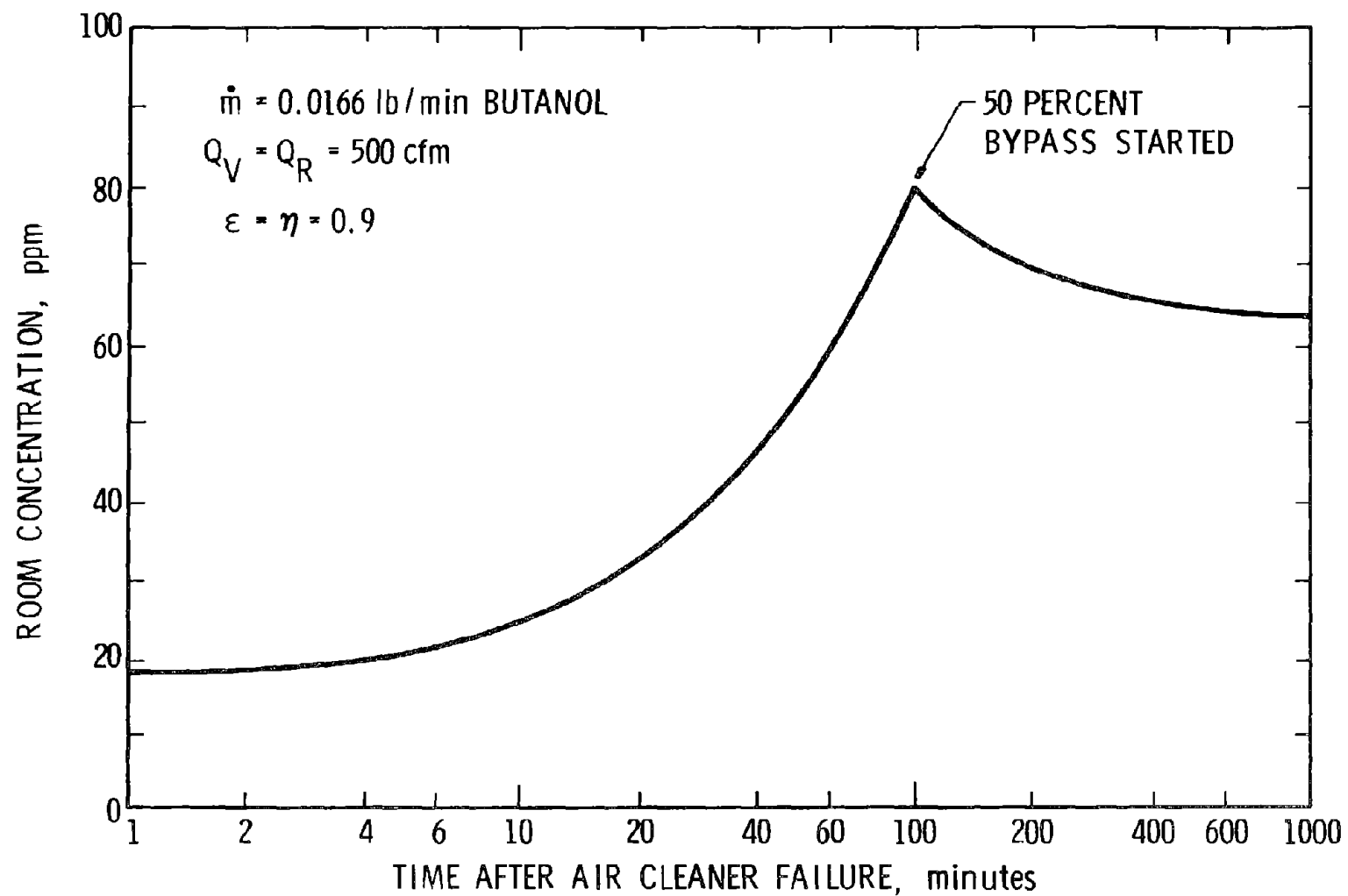


Figure V.8 Room Concentration as a Function of Time After Air Cleaner Failure with Partial Bypass

VI. CONCLUSIONS AND RECOMMENDATIONS

In this report, we have attempted to assess the feasibility of and define criteria for recirculated exhaust air systems from the standpoint of contaminant toxicology, air monitoring and cleaning equipment, fail-safe system design and theoretical modeling of system performance.

The results of this investigation indicate that recirculation of exhaust air is a feasible concept and has the potential for becoming a viable tool for energy conservation while assuring worker protection.

While there are topics that will require further investigation, the vast majority of the conclusions that were derived from this first iteration are positive. The significant conclusions are briefly summarized below.

Based on six quantitative contaminant toxicity criteria, 69 percent or 356 of the 514 compounds that are listed in the body of the 1973 ACGIH TLV table are potentially recirculatable. Carcinogenic compounds and compounds that either have ceiling concentrations or produce neoplastic or systemic effects within permissible excursions above the TLV are to be excluded from recirculation systems.

Fail-safe design principles should be incorporated into every recirculation system regardless of whether the system is a modification to an existing local exhaust ventilation facility or a new installation. Fail-safe design dictates that the recirculation system be instrumented with equipment performance transducers and automatic control systems that can sense component failure and take corrective action so as to eliminate the possibility of recirculating excessive contaminant concentration levels to the work area. One of the most important transducer systems is an on-line, automatic, direct-reading concentration monitor that is specific for a given contaminant and whose sensing probe is located in the effluent duct downstream of the air cleaner. The results of the monitor analysis can be compared electronically with an allowable concentration setpoint to determine if the recirculation system is in a normal or failed operating state. If the setpoint is violated a failure mode is indicated, and corrective action is automatically initiated. Based on a sampling of the air monitor equipment industry, a state-of-the-art monitor, that satisfies the above requirements, is available for 88 percent of the gases and vapors in the ACGIH TLV table. Transducers and

automatic control systems are also state-of-the-art. The specificity requirement for particulate monitors is beyond the current state-of-the-art and would necessitate a development effort.

Reliability analyses indicate that recirculation systems that incorporate backup or redundant air cleaning equipment, either partial or total, have a lower probability of failure for all operating times than systems without backup. If backup cleaning equipment is not feasible because of economic considerations or space limitations, the system should contain provision for exhaust bypass to the atmosphere in the event of an air cleaner or monitor failure. The reliability analyses also indicate that, as the mean time between failure (MTBF) increases for any system component, a point of diminishing returns is reached beyond which the total system reliability is insensitive to further increases in MTBF. Beyond this same point, equipment costs should be expected to increase disproportionately.

Analytical recirculation models have been developed to predict the transient response of workroom concentration as a function of the contaminant generation rate, room volume, general and recirculated air flow rates, and the air cleaner and local exhaust hood efficiencies. The model equations can be used in a preliminary design analysis to size efficiencies and flow rates so that the contaminant concentration in the workroom will not exceed the TLV. This modeling procedure also predicts the concentration in the air cleaner effluent duct which corresponds to that sub-TLV level in the room. As a result of these predictive methods, the setpoint or alarm level requirements for the concentration monitor can be defined.

Air cleaner failure and bypass of exhaust air to the atmosphere have also been modeled. The design equations can be used to estimate the time to exceed a predetermined post-failure room concentration as well as the minimum bypass ratio that is required to maintain a specified sub-TLV room concentration.

Recirculation of exhaust air is a multi-faceted concept. Many of these facets were recognized at the outset of this program, and they, or course, formed the initial base for investigation. As the study progressed, other aspects of the problem became apparent, and, insofar as was practical, the scope of the research effort was broadened to include these areas. In some cases, however, sub-problem areas were identified but could not be incorporated into the research plan because they were either process-oriented or they represented major limitations in the current state of technical development. These areas, which are described below, merit consideration for future investigation in order to assure a successful implementation of recirculation systems.

- (1) The "K-factor" or mixing factor is a somewhat arbitrary

number (3 to 10) whose value is usually assigned on the basis of experience. This K-factor is essentially a safety factor that ideally eliminates dead spots in a room by limiting the concentration of the air cleaner effluent. In this report, several of the parameters that influence the mixing factor have been derived. Guidelines are required for selecting the magnitude of the mixing factor as it is applied to recirculation systems. An attempt to quantify the mixing factor should include scale model (pilot plant) studies of contaminant distribution in a recirculation system, discrete point sampling in industrial plants and perhaps a three-dimensional theoretical analysis of the concentration gradients in a workroom using the turbulent diffusion and convection equations of fluid mechanics. The effect of exhaust duct location should also be considered.

- (2) The criteria that have been developed in this report are process-independent. The next logical step is to develop supplementary criteria that apply to specific processes. These criteria should take into account process parameters such as temperature and the requirements for cooling and humidification or dehumidification of the cleaner effluent prior to its return to the workroom. Toxicological criteria that reflect the additive or synergistic effect of process-generated combinations of vapors and particulates are also required.
- (3) If a process-oriented approach is to be adopted, the logical question is: What process or processes should be investigated and in what order? The implication is a toxic substances priority list that is based on the number of workers by process that are exposed to recirculatable contaminants.
- (4) If the impact of fail-safe system design is to be fully realized, then comprehensive and accurate reliability and failure rate data must be generated for air cleaners, air monitors, sensors and control systems. These data must be in sufficient detail to permit a major reliability model, e.g. an air cleaner, to be derived in terms of the reliability of its operating elements.
- (5) Finally, the economic trade-offs associated with air recirculation must be defined. The increasing cost of energy to maintain the status quo (exhaust to atmosphere with supply of tempered make-up air) must be weighed

against the initial expenditure for capital equipment plus maintenance and repair costs plus the utility cost to operate the recirculation system. Presumably, the differential rate of increase in variable or marginal costs (maintenance, repair and energy) between two alternatives will result in a break-even point beyond which there is a cost-benefit to operate a recirculation system. The break-even point must occur within a realistic time limit. It must be compatible with the company's long term objectives, and economically it must occur well within the operating life-time of the major system components.

Appendix A
Categorization of Workroom Contaminants

This appendix contains an alphabetical listing of the 514 compounds that are included in the ACGIH Threshold Limit Value Table for 1973. Each compound bears a group classification that was derived by applying the toxicological criteria in Section II of this report.

The number of contaminants in each group is as follows:

Group 1.....	128
Group 2.....	116
Group 3.....	103
Group 4.....	9
Group 5.....	64
Group 6.....	94

TOTAL	514

Abate.....	Group 3
Acetaldehyde.....	Group 1
Acetic Acid.....	Group 1
Acetic Anhydride.....	Group 6
Acetone.....	Group 1
Acetonitrile.....	Group 1
2-Acetylaminofluorene.....	Group 6
Acetylene.....	Group 1
Acetylene Dichloride.....	Group 6
Acetylene Tetrabromide.....	Group 5
Acrolein.....	Group 2
Acrylamide.....	Group 2
Acrylonitrile.....	Group 1
Aldrin.....	Group 3
Allyl Alcohol.....	Group 1
Allyl Chloride.....	Group 5
Allyl Glycidyl Ether (AGE).....	Group 1
Allyl Propyl Disulfide.....	Group 1
Alundum.....	Group 6
4-Aminodiphenyl.....	Group 6
2-Aminoethanol.....	Group 6
2-Aminopyridine.....	Group 2
Ammonia.....	Group 1
Ammonium Chloride, fume.....	Group 3
Ammonium Sulfamate (Ammate).....	Group 3

n-Amyl Acetate.....	Group 1
sec-Amyl Acetate.....	Group 1
Aniline.....	Group 1
Anisidine (o, p-isomers).....	Group 5
Antimony & Compounds (as Sb).....	Group 3
ANTU (Alpha Naphthyl Thiourea).....	Group 3
Argon.....	Group 2
Arsenic & Compounds (as As).....	Group 3
Arsine.....	Group 2
Asphalt (petroleum), fume.....	Group 5
Azinphos Methyl.....	Group 3
Barium (soluble compounds).....	Group 3
Benzene (Benzol).....	Group 6
Benzidine.....	Group 6
p-Benzoquinone.....	Group 6
Benzoyl Peroxide.....	Group 3
Benzyl Chloride.....	Group 1
Beryllium.....	Group 6
Biphenyl.....	Group 6
Bismuth Telluride.....	Group 3
Bismuth Telluride (Se-doped).....	Group 3
Boron Oxide.....	Group 3
Boron Tribromide.....	Group 2
Boron Trifluoride.....	Group 6
Bromine.....	Group 2
Bromine Pentafluoride.....	Group 2

Bromoform.....	Group 1
Butadiene (1,3-Butadiene).....	Group 1
Butane.....	Group 1
Butanethiol.....	Group 6
2-Butanone.....	Group 1
2-Butoxy Ethanol (Butyl Cellosolve).....	Group 2
Butyl Acetate (n-Butyl Acetate).....	Group 1
sec-Butyl Acetate.....	Group 1
tert-Butyl Acetate.....	Group 1
Butyl Alcohol.....	Group 1
sec-Butyl Alcohol.....	Group 1
tert-Butyl Alcohol.....	Group 1
Butylamine.....	Group 6
tert-Butyl Chromate (as CrO ₃).....	Group 6
n-Butyl Glycidyl Ether (BGE).....	Group 1
Butyl Mercaptan.....	Group 1
p-tert-Butyltoluene.....	Group 1
Cadmium, metal dusts.....	Group 3
Cadmium, soluble salts.....	Group 5
Cadmium Oxide fume as Cd.....	Group 6
Calcium Carbonate.....	Group 3
Calcium Arsenate.....	Group 3
Calcium Oxide.....	Group 3
Camphor (synthetic).....	Group 5
Carbaryl (Sevin®).....	Group 3
Carbon Black.....	Group 3

Carbon dioxide.....Group 2

Carbon Disulfide.....Group 1

Carbon Monoxide.....Group 2

Carbon Tetrachloride.....Group 1

Cellulose (paper fiber).....Group 3

Chlordane.....Group 3

Chlorinated Camphene.....Group 3

Chlorinated Diphenyl Oxide.....Group 5

Chlorine.....Group 2

Chlorine Dioxide.....Group 1

Chlorine Trifluoride.....Group 6

Chloroacetaldehyde.....Group 6

alpha-Chloroacetophenone (Phenacylchloride)..Group 5

Chlorobenzene (Monochlorobenzene).....Group 1

o-Chlorobenzylidene Malononitrile (OCBM).....Group 3

Chlorobromomethane.....Group 2

2-Chloro-1, 3-Butadiene.....Group 6

Chlorodiphenyl (42% Chlorine).....Group 2

Chlorodiphenyl (54% Chlorine).....Group 2

1-Chloro, 2, 3-Epoxypropane.....Group 6

2-Chloroethanol.....Group 6

Chloroethylene.....Group 6

Chloroform (Trichloromethane).....Group 5

1-Chloro-1-Nitropropane.....Group 5

Chloropicrin.....Group 2

Chloroprene (2-Chloro-1, 3-Butadiene).....	Group 2
Chromic Acid & Chromates (as CrO ₃).....	Group 5
Chromium, soluble Chromic, Chromous Salts....	Group 5
Chromium, Metal and insoluble Salts, as Cr...	Group 6
Coal Tar Pitch Volatiles.....	Group 6
Cobalt, metal fume & dust.....	Group 5
Copper fume, dusts & mists.....	Group 5
Corundum.....	Group 5
Cotton Dust (raw).....	Group 3
Crag [®] Herbicide.....	Group 3
Cresol (all isomers).....	Group 1
Crotonaldehyde.....	Group 1
Cumene.....	Group 1
Cyanide (as CN).....	Group 5
Cyanogen.....	Group 2
Cyclohexane.....	Group 1
Cyclohexanol.....	Group 2
Cyclohexanone.....	Group 1
Cyclohexene.....	Group 1
Cyclopentadiene.....	Group 2
2,4-D.....	Group 3
DDT.....	Group 3
DDVP.....	Group 6
Decaborane.....	Group 2
Demeton [®]	Group 5
Diacetone Alcohol (4-Hydroxy-4-Methyl-2-Pentanone).....	Group 1

1,2-Diaminoethane.....	Group 6
Diazinon.....	Group 3
Diazomethane.....	Group 2
Diborane.....	Group 2
1,2-Dibromoethane (Ethylene Dibromide).....	Group 1
Dibrom [®]	Group 3
2-N Dibutylaminoethanol.....	Group 2
Dibutyl Phosphate.....	Group 2
Dibutylphthalate.....	Group 3
Dichloroacetylene.....	Group 6
o-Dichlorobenzene.....	Group 6
p-Dichlorobenzene.....	Group 5
Dichlorobenzidine.....	Group 6
Dichlorodifluoromethane.....	Group 2
1,3-Dichloro-5, 5-Dimethyl Hydantoin.....	Group 3
1,1-Dichloroethane.....	Group 1
1,2-Dichloroethane.....	Group 1
1,2-Dichloroethylene.....	Group 1
Dichloroethyl Ether.....	Group 2
Dichloromethane.....	Group 6
Dichloromonofluoromethane.....	Group 2
1,1-Dichloro-1-Nitroethane.....	Group 6
1,2-Dichloropropane.....	Group 6
Dichlorotetrafluoroethane.....	Group 2
Dichlorvos (DDVP).....	Group 5
Dieldrin.....	Group 3
Diethylamine.....	Group 1

Diethylamino Ethanol.....Group 2
 Diethylene Triamine.....Group 5
 Diethylether.....Group 6
 Difluorodibromomethane.....Group 2
 Diglycidyl Ether (DGE).....Group 6
 Dihydroxybenzene.....Group 6
 Diisobutyl Ketone.....Group 1
 Diisopropylamine.....Group 1
 Dimethoxymethane.....Group 6
 Dimethyl Acetamide.....Group 5
 Dimethylamine.....Group 1
 4-Dimethylaminoazobenzene.....Group 6
 Dimethylaminobenzene.....Group 6
 Dimethylaniline.....Group 1
 Dimethylbenzene.....Group 6
 Dimethyl 1,2-Dibromo-2-Dichloroethyl
 Phosphate.....Group 6
 Dimethylformamide.....Group 5
 2,6-Dimethylheptanone.....Group 6
 1,1-Dimethylhydrazine.....Group 2
 Dimethylphthalate.....Group 4
 Dimethylsulfate.....Group 5
 Dinitrobenzene (all isomers).....Group 1
 Dinitro-o-cresol.....Group 5
 Dinitrotoluene.....Group 3
 Dioxane (Diethylene Dioxide).....Group 1
 Diphenyl.....Group 3

Diphenyl Amine.....	Group 3
Diphenylmethane Diisocyanate.....	Group 6
Dipropylene Glycol Methyl Ether.....	Group 2
Diquat.....	Group 3
Di-sec, Octyl Phthalate (Di-2-Ethyl hexyl-Phthalate).....	Group 4
Emery.....	Group 3
Endosulfan (Thiodan®).....	Group 3
Endrin.....	Group 3
Epichlorhydrin.....	Group 5
EPN.....	Group 3
1,2-Epoxypropane.....	Group 6
2,3-Epoxy-1-Propanol.....	Group 6
Ethane.....	Group 2
Ethanethiol.....	Group 6
Ethanolamine.....	Group 1
2-Ethoxyethanol.....	Group 1
2-Ethoxyethylacetate (Cellosolve Acetate)....	Group 2
Ethyl Acetate.....	Group 1
Ethyl Acrylate.....	Group 1
Ethyl Alcohol (Ethanol).....	Group 1
Ethylamine.....	Group 2
Ethyl sec-Amyl Ketone (5-Methyl-3- Heptanone).....	Group 1
Ethyl Benzene.....	Group 1
Ethyl Bromide.....	Group 2
Ethyl Butyl Ketone (3-Heptanone).....	Group 1

Ethyl Chloride.....Group 2
 Ethyl Ether.....Group 1
 Ethyl Formate.....Group 2
 Ethyl Mercaptan.....Group 1
 Ethyl Silicate.....Group 1
 Ethylene.....Group 1
 Ethylene Chlorohydrin.....Group 2
 Ethylenediamine.....Group 1
 Ethylene Dibromide.....Group 6
 Ethylene Dichloride.....Group 6
 Ethylene Glycol, particulate.....Group 3
 Ethylene Glycol, vapor.....Group 1
 Ethylene Glycol Dinitrate and/or
 Nitroglycerin.....Group 6
 Ethylene Glycol Monomethyl Ether Acetate
 (Methyl Cellosolve Acetate).....Group 1
 Ethylene Imine.....Group 5
 Ethylene Oxide.....Group 2
 Ethylidine Chloride.....Group 6
 N-Ethylmorpholine.....Group 1
 Ferbam.....Group 3
 Ferrovandium Dust.....Group 3
 Fluoride (as F).....Group 5
 Fluorine.....Group 2
 Fluorotrichloromethane.....Group 2
 Formaldehyde.....Group 6
 Formic Acid.....Group 2
 Furfural.....Group 1

Furfuryl Alcohol.....	Group 2
Gasoline.....	Group 2
Germanium Tetrahydride.....	Group 2
Glass, fibrous or dust.....	Group 3
Glycerin mist.....	Group 3
Glycidol (2,3-Epoxy-1-Propanol).....	Group 2
Glycol Monoethyl Ether.....	Group 6
Graphite (synthetic).....	Group 3
Guthion®.....	Group 6
Gypsum.....	Group 3
Hafnium.....	Group 5
Helium.....	Group 2
Heptachlor.....	Group 3
Heptane (n-Heptane).....	Group 1
Hexachloroethane.....	Group 5
Hexachloronaphthalene.....	Group 3
Hexafluoroacetone.....	Group 2
Hexane (n-Hexane).....	Group 5
2-Hexanone.....	Group 1
Hexone (Methyl Isobutyl Ketone).....	Group 1
sec-Hexyl Acetate.....	Group 2
Hydrazine.....	Group 5
Hydrogen.....	Group 2
Hydrogen Bromide.....	Group 1
Hydrogen Chloride.....	Group 6
Hydrogen Cyanide.....	Group 1
Hydrogen Fluoride.....	Group 1

Hydrogen Peroxide.....	Group 2
Hydrogen Selenide.....	Group 2
Hydrogen Sulfide.....	Group 1
Hydroquinone.....	Group 3
Indene.....	Group 1
Indium and Compounds, as In.....	Group 3
Iodine.....	Group 6
Iron Oxide fume.....	Group 5
Iron Pentacarbonyl.....	Group 2
Iron salts, soluble, as Fe.....	Group 3
Isoamyl Acetate.....	Group 1
Isoamyl Alcohol.....	Group 1
Isobutyl Acetate.....	Group 1
Isobutyl Alcohol.....	Group 1
Isophorone.....	Group 1
Isopropyl Acetate.....	Group 1
Isopropyl Alcohol.....	Group 1
Isopropylamine.....	Group 1
Isopropylether.....	Group 1
Isopropyl Glycidal Ether (IGE).....	Group 1
Kaolin.....	Group 3
Ketene.....	Group 2
Lead, inorganic fumes and dusts.....	Group 3
Lead Arsenate.....	Group 3
Limestone.....	Group 3
Lindane.....	Group 3
Lithium Hydride.....	Group 1

L.P.G. (Liquified Petroleum Gas).....Group 2
 Magnesite.....Group 3
 Magnesium Oxide, fume.....Group 3
 Malathion.....Group 3
 Maleic Anhydride.....Group 1
 Manganese and Compounds, as Mn.....Group 6
 Marble.....Group 3
 Mercury (Alkyl compounds).....Group 2
 Mercury (All forms except Alkyl).....Group 2
 Mesityl Oxide.....Group 1
 Methane.....Group 2
 Methanethiol.....Group 6
 Methoxychlor.....Group 3
 2-Methoxyethanol (Methyl Cellosolve).....Group 2
 Methyl Acetate.....Group 1
 Methyl Acetylene (Propyne).....Group 2
 Methyl Acetylene-Propadiene Mixture (MAPP)...Group 2
 Methyl Acrylate.....Group 1
 Methyl Acrylonitrile.....Group 2
 Methylal (Dimethoxymethane).....Group 2
 Methyl Alcohol (Methanol).....Group 2
 Methylamine.....Group 1
 Methyl Amyl Alcohol.....Group 6
 Methyl 2-Cyanoacrylate.....Group 1
 Methyl Isoamyl Ketone.....Group 1

Methyl (n-Amyl) Ketone (2-Heptanone).....	Group 1
Methyl Bromide.....	Group 5
Methyl Butyl Ketone.....	Group 6
Methyl Cellosolve.....	Group 6
Methyl Cellosolve Acetate.....	Group 6
Methyl Chloride.....	Group 1
Methyl Chloroform.....	Group 1
Methylcyclohexane.....	Group 1
Methylcyclohexanol.....	Group 2
o-Methylcyclohexanone.....	Group 2
Methylcyclopentadienyl Manganese Tricarbonyl (as Mn).....	Group 2
Methyl Demeton.....	Group 4
Methyl Ethyl Ketone (MEK).....	Group 6
Methyl Formate.....	Group 2
Methyl Iodide.....	Group 5
Methyl Isobutyl Carbinol.....	Group 1
Methyl Isobutyl Ketone.....	Group 6
Methyl Isocyanate.....	Group 2
Methyl Mercaptan.....	Group 1
Methyl Methacrylate.....	Group 1
Methyl Parathion.....	Group 4
Methyl Propyl Ketone.....	Group 6
Methyl Silicate.....	Group 6
alpha-Methyl Styrene.....	Group 6
Methylene Bisphenyl Isocyanate (MDI).....	Group 6

Methylene Chloride (Dichloromethane).....	Group 1
Molybdenum (soluble and insoluble compounds).....	Group 3
Monomethyl Aniline.....	Group 5
Monomethyl Hydrazine.....	Group 6
Morpholine.....	Group 1
Naphtha (Coal Tar).....	Group 2
Naphthalene.....	Group 1
beta-Naphthylamine.....	Group 6
Neon.....	Group 2
Nickel Carbonyl.....	Group 6
Nickel, metal and soluble compounds (as Ni)..<	Group 5
Nicotine.....	Group 3
Nitric Acid.....	Group 2
Nitric Oxide.....	Group 1
p-Nitroaniline.....	Group 3
Nitrobenzene.....	Group 2
p-Nitrochlorobenzene.....	Group 3
4-Nitrodiphenyl.....	Group 6
Nitroethane.....	Group 2
Nitrogen.....	Group 2
Nitrogen Dioxide.....	Group 6
Nitrogen Trifluoride.....	Group 2
Nitroglycerin.....	Group 5
Nitromethane.....	Group 1
1- and 2-Nitropropane.....	Group 2
N-Nitrosodimethylamine (Dimethylnitro- soamine).....	Group 6

Nitrotoluene.....	Group 2
Nitrotrichloromethane.....	Group 6
Nitrous Oxide.....	Group 2
Octachloronaphthalene.....	Group 3
Octane.....	Group 1
Oil mist, vapor and particulate.....	Group 4
Osmium Tetroxide.....	Group 2
Oxalic Acid.....	Group 3
Oxygen Difluoride.....	Group 2
Ozone.....	Group 5
Paraquat.....	Group 3
Parathion.....	Group 5
Pentaborane.....	Group 2
Pentachloronaphthalene.....	Group 5
Pentachlorophenol.....	Group 5
Pentaerythritol.....	Group 3
Pentane.....	Group 1
2-Pentanone.....	Group 1
Perchloroethylene.....	Group 1
Perchloromethyl Mercaptan.....	Group 2
Perchloryl Fluoride.....	Group 2
Petroleum Distillates (Naphtha).....	Group 2
Phenol.....	Group 1
Phenothiazine.....	Group 5
p-Phenylene Diamine.....	Group 5
Phenyl Ether vapor.....	Group 1
Phenyl Ether-Diphenyl Mixture vapor.....	Group 1

Phenylethylene.....	Group 6
Phenyl Glycidyl Ether (PGE).....	Group 2
Phenylhydrazine.....	Group 3
Phenylphosphine.....	Group 6
Phosdrin (Mevinphos [®]).....	Group 2
Phosgene (Carbonyl Chloride).....	Group 2
Phosphine.....	Group 2
Phosphoric Acid.....	Group 3
Phosphorus (yellow).....	Group 5
Phosphorus Pentachloride.....	Group 3
Phosphorus Pentasulfide.....	Group 3
Phosphorus Trichloride.....	Group 5
Phthalic Anhydride.....	Group 4
Picric Acid.....	Group 5
Pival [®] (2-Pivalyl-1, 3-Indandione).....	Group 3
Plaster of Paris.....	Group 3
Platinum (soluble salts) as Pt.....	Group 3
Polychlorobiphenyls.....	Group 6
Polytetrafluoroethylene decomposition products.....	Group 5
Propane.....	Group 2
beta-Propiolactone.....	Group 6
Propargyl Alcohol.....	Group 2
n-Propyl Acetate.....	Group 1
Propyl Alcohol.....	Group 1
n-Propyl Nitrate.....	Group 2

Propylene Dichloride (1, 2-Dichloropropane)..Group 1
 Propylene Glycol Monomethyl Ether.....Group 2
 Propylene Imine.....Group 5
 Propylene Oxide.....Group 1
 Propyne.....Group 6
 Pyrethrum.....Group 3
 Pyridine.....Group 1
 Quinone.....Group 4
 RDX.....Group 3
 Rhodium, metal fume and dusts (as Rh)
 and soluble salts.....Group 3
 Ronnel.....Group 3
 Rosin Core Solder, pyrolysis products
 (as Formaldehyde).....Group 5
 Rotenone (commercial).....Group 5
 Rouge.....Group 3
 Selenium Compounds (as Se).....Group 1
 Selenium Hexafluoride.....Group 5
 Silicon.....Group 3
 Silicon Carbide.....Group 3
 Silver, metal and soluble compounds.....Group 5
 Sodium fluoroacetate (1080).....Group 5
 Sodium Hydroxide.....Group 6
 Starch.....Group 3
 Stibine.....Group 2
 Stoddard Solvent.....Group 2
 Strychnine.....Group 3
 Styrene (Monomer) (Phenyl Ethylene).....Group 5

Sucrose.....	Group 3
Sulfur Dioxide.....	Group 1
Sulfur Hexafluoride.....	Group 2
Sulfuric Acid.....	Group 1
Sulfur Monochloride.....	Group 2
Sulfur Pentafluoride.....	Group 5
Sulfur Tetrafluoride.....	Group 2
Sulfuryl Fluoride.....	Group 2
Systox.....	Group 6
2,4,5, T.....	Group 3
Tantalum.....	Group 3
TEDP.....	Group 3
Teflon [®] decomposition products.....	Group 5
Tellurium.....	Group 3
Tellurium Hexafluoride.....	Group 2
TEPP.....	Group 2
Terphenyls.....	Group 6
1,1,1,2-Tetrachloro-2, 2-Difluoroethane.....	Group 2
1,1,2,2-Tetrachloro-1, 2-Difluoroethane.....	Group 2
1,1,2,2-Tetrachloroethane.....	Group 5
Tetrachloroethylene.....	Group 6
Tetrachloromethane.....	Group 6
Tetrachloronaphthalene.....	Group 5
Tetraethyl Lead (as Pb).....	Group 2
Tetrahydrofuran.....	Group 1
Tetramethyl Lead (as Pb).....	Group 2

Tetramethyl Succinonitrile.....	Group 2
Tetranitromethane.....	Group 1
Tetryl (2,4,6-Trinitrophenyl-methyl-nitramine).....	Group 3
Thallium (soluble compounds) (as Tl).....	Group 3
Thiram ^(R)	Group 3
Tin (inorganic compounds, except SnH_4 and SnO_2) as Sn.....	Group 3
Tin (organic compounds).....	Group 3
Tin Oxide.....	Group 3
Titanium Dioxide.....	Group 3
Toluene (Toluol).....	Group 1
Toluene-2, 4-Diisocyanate.....	Group 6
o-Toluidine.....	Group 2
Toxaphene.....	Group 6
Tributyl Phosphate.....	Group 2
1,1,1-Trichloroethane.....	Group 6
1,1,2-Trichloroethane.....	Group 2
Trichloroethylene.....	Group 2
Trichloromethane.....	Group 6
Trichloronaphthalene.....	Group 3
1,2,3-Trichloropropane.....	Group 1
1,1,2-Trichloro 1,2,2-Trifluoroethane.....	Group 2
Triethylamine.....	Group 1
Trifluoromonobromomethane.....	Group 2
Trimethyl Benzene.....	Group 2

2,4,6-Trinitrophenol.....	Group 6
2,4,6-Trinitrophenylmethylnitramine.....	Group 6
Trinitrotoluene.....	Group 4
Triorthocresyl Phosphate.....	Group 3
Triphenyl Phosphate.....	Group 5
Tungsten and Compounds as W.....	Group 4
Turpentine.....	Group 1
Uranium (natural) soluble and insoluble compounds as U.....	Group 5
Vanadium (V ₂ O ₅), as V dust.....	Group 5
Vanadium fume.....	Group 6
Vinyl Acetate.....	Group 1
Vinyl Benzene.....	Group 6
Vinyl Bromide.....	Group 2
Vinyl Chloride.....	Group 6
Vinylcyanide.....	Group 6
Vinyl Toluene.....	Group 1
Warfarin.....	Group 3
Wood dust (nonallergenic).....	Group 5
Xylene (Xylol).....	Group 1
Xylidine.....	Group 6
Yttrium.....	Group 5
Zinc Chloride fume.....	Group 5
Zinc Oxide fume.....	Group 3
Zirconium Compounds as Zr.....	Group 3

Appendix B
Rationale for Group 6 Contaminants

Group 6

COMPOUND	REASON FOR ASSIGNMENT
Acetic Anhydride	ACGIH lists "Ceiling" value
2-Acetylaminofluorene	ACGIH lists as "Experimental Carcinogen"
Acetylene Dichloride	Duplicate; see 1,2-Dichloro-ethylene in Group 1
Alundum	Duplicate; see Corundum in Group 5
4-Aminodiphenyl	ACGIH lists as "Human Carcinogen"
2-Aminoethanol	Duplicate; see Ethanolamine in Group 1
Benzene Benzol	ACGIH lists "Ceiling" value
Benzidine	ACGIH lists "Human Carcinogen."
p-Benzoquinone	Duplicate; see Quinone in Group 4
Beryllium	ACGIH lists as "Experimental Carcinogen"
Biphenyl	Duplicate; see Diphenyl in Group 3
Boron Trifluoride	ACGIH lists "Ceiling" value
Butanethiol	Duplicate; see Butyl Mercaptan in Group 1
Butylamine	ACGIH lists "Ceiling" value
tert-Butyl Chromate (as CrO ₃)	ACGIH lists "Ceiling" value

Group 6

COMPOUND	REASON FOR ASSIGNMENT
Cadmium Oxide fume (as Cd)	ACGIH lists "Ceiling" value
Chlorine Trifluoride	ACGIH lists "Ceiling" value
Chloroacetaldehyde	ACGIH lists "Ceiling" value
2-Chloro-1, 3-Butadiene	Duplicate; see Chloroprene in Group 2
1-Chloro, 2,3-Epoxypropane	Duplicate; see Epichlorhydrin in Group 5
2-Chloroethanol	Duplicate; see Ethylene Chloro- hydrin in Group 2
Chloroethylene	Duplicate; see Vinyl Chloride in Group 6
Chromium, metal and insol- uble salts only	ACGIH lists as "Human Carcin- ogen."
Coal Tar Pitch Volatiles	ACGIH lists as "Human Carcinogen"
DDVP	Duplicate; see Dichlorvos in Group 5
1,2-Diaminoethane	Duplicate; see Ethylenediamine in Group 1
Dichloroacetylene	ACGIH lists "Ceiling" value
o-Dichlorobenzene	ACGIH lists "Ceiling" value
Dichlorobenzidine	ACGIH lists as "Human Carcinogen"
Dichloromethane	Duplicate; see Methylene Chloride in Group 1
1,1-Dichloro-1-Nitroethane	ACGIH lists "Ceiling" value

Group 6

COMPOUND	REASON FOR ASSIGNMENT
1,2-Dichloropropane	Duplicate; see Propylenedi-chloride in Group 1
Diethylether	Duplicate; see Ethyl Ether in Group 1
Diglycidyl Ether (DGE)	ACGIH lists "Ceiling" value
Dihydroxybenzene	Duplicate; see Hydroquinone in Group 3
Dimethoxymethane	Duplicate; see Methylal in Group 2
4-Dimethylaminoazobenzene	ACGIH lists as "Experimental Carcinogen"
Dimethylaminobenzene	Duplicate; see Xylidene in Group 6
Dimethylbenzene	Duplicate; see Xylene in Group 1
Dimethyl 1,2-Dibromo-2-Dichloroethyl Phosphate	Duplicate; see DiBrom [®] in Group 3
2,6-Dimethylheptanone	Duplicate; see Diisobutyl Ketone in Group 1
Diphenylmethane Diisocyanate	Duplicate; see Methylene Bis-phenyl isocyanate (MDI) in Group 6
1,2-Epoxypropane	Duplicate; see Propylene Oxide in Group 1
2,3-Epoxy-1-Propanol	Duplicate; see Glycidol in Group 2
Ethanethiol	Duplicate; see Ethylmercaptan in Group 1
Ethylene Dibromide	Duplicate; see 1,2-Dibromoethane in Group 1

Group 6

COMPOUND	REASON FOR ASSIGNMENT
Ethylene Dichloride	Duplicate; see 1,2-Dichloroethane in Group 1
Ethylene Glycol Dinitrate and/or Nitroglycerin	ACGIH lists "Ceiling" value
Ethylidene Chloride	Duplicate; see 1,1-Dichloroethane in Group 1
Formaldehyde	ACGIH lists "Ceiling" value
Glycol Monoethyl Ether	Duplicate; see 2-Ethoxyethanol in Group 1
Guthion®	Duplicate; see Azinphosmethyl in Group 3
Hydrogen Chloride	ACGIH lists "Ceiling" value
Iodine	ACGIH lists "Ceiling" value
Manganese and Compounds, as Mn	ACGIH lists "Ceiling" value
Methanethiol	Duplicate; see Methyl Mercaptan in Group 1
Methyl Amyl Alcohol	Duplicate; see Methyl Isobutyl Carbinol in Group 1
Methyl Butyl Ketone	Duplicate; see 2-Hexanone in Group 1
Methyl Cellosolve	Duplicate; see 2-Methoxyethanol in Group 2
Methyl Cellosolve Acetate	Duplicate; see Ethylene Glycol Monomethyl Ether Acetate in Group 1
Methyl Ethyl Ketone (MEK)	Duplicate; see 2-Butanone in Group 1
Methyl Isobutyl Ketone	Duplicate; see Hexone in Group 1

Group 6

COMPOUND	REASON FOR ASSIGNMENT
Methyl Propyl Ketone	Duplicate; see 2-Pentanone in Group 1
Methyl Silicate	ACGIH lists "Ceiling" value
alpha-Methyl Styrene	ACGIH lists "Ceiling" value
Methylene Bisphenyl Isocyanate (MDI)	ACGIH lists "Ceiling" value
Monomethyl Hydrazine	ACGIH lists "Ceiling" value
beta-Naphthylamine	ACGIH lists as "Human Carcinogen"
Nickel Carbonyl	ACGIH lists as "Human Carcinogen"
4-Nitrodiphenyl	ACGIH lists as "Human Carcinogen"
Nitrogen Dioxide	ACGIH lists "Ceiling" value
N-Nitrosodimethylamine (Dimethylnitrosoamine)	ACGIH lists as an "Experimental Carcinogen"
Nitrotrichloromethane	Duplicate; see Chloropicrin in Group 2
Phenylethylene	Duplicate; see Styrene in Group 5
Phenylphosphine	ACGIH lists "Ceiling" value
Polychlorobiphenyls	Duplicate; see Chlorodiphenyls in Group 2
beta-Propiolacetone	ACGIH lists as an "Experimental Carcinogen"
Propyne	Duplicate; see Methylacetylene in Group 2
Sodium Hydroxide	ACGIH lists "Ceiling" value

Group 6

COMPOUND	REASON FOR ASSIGNMENT
Systox	Duplicate; see Demeton® in Group 5
Terphenyls	ACGIH lists "Ceiling" value
Tetrachloroethylene	Duplicate; see Perchloroethylene in Group 1
Tetrachloromethane	Duplicate; see Carbon Tetrachloride in Group 1
Toluene-2, 4-Diisocyanate	ACGIH lists "Ceiling" value
Toxaphene	Duplicate; see Chlorinated Camphene in Group 3
1,1,1-Trichloroethane	Duplicate; see Methylchloroform in Group 1
Trichloromethane	Duplicate; see Chloroform in Group 5
2,4,6-Trinitrophenol	Duplicate; see Picric Acid in Group 5
2,4,6-Trinitrophenylmethylnitramine	Duplicate; see Tetryl in Group 3
Vanadium fume	ACGIH lists "Ceiling" value
Vinyl Benzene	Duplicate; see Styrene in Group 5
Vinyl Chloride	Not included by SWRI because of current toxicity findings and controversy
Vinyl Cyanide	Duplicate; see Acrylonitrile in Group 1
Xylidine	Duplicate; see Dimethylaniline in Group 1

Appendix C

Rationale for Group 5 Contaminants

Group 5

COMPOUND	REASON FOR ASSIGNMENT
Acetylene Tetrabromide Tetrabromoethane	Literature recommends medical surveillance even at the current TLV.
Allyl Chloride 3-Chloro-1-Propene	Literature recommends a "ceiling" value that falls within the excursion factor.
Anisidine, o-, p- isomers Methoxyaniline Aminoanisole	Chance of subjective symptoms occurring at the current TLV in some workers.
Asphalt (Petroleum) fumes	Literature cites it as a possible carcinogen.
Cadmium, soluble salts ONLY!	Literature recommends a "ceiling" value.
Camphor (synthetic)	Systemic effects and even irritant effects may possibly fall below the current TLV.
Chlorinated Diphenyl Oxide Chlorinated Phenyl Ether	Literature "infers" that cases of chloracne "might" develop near the TLV and most likely within the excursion factor.
alpha-Chloroacetophenone Phenacyl Chloride	Strong irritation, serious systemic effects and current TLV too marginally separated.
Chloroform Trichloromethane	Literature recommends a "ceiling" value.
1-Chloro-1-Nitropropane	Medical supervision is recommended even at or below the current TLV because of lack of human exposure data.
Chromic Acid and Chromates (as CrO ₃)	Literature mentions carcinogenic effects.
Chromium, soluble Chromium salts, as Cr	Lack of specific evidence in the literature. Salts are known to be responsible for a dermatitis. SWRI suggests that overall accep-

Group 5

COMPOUND	REASON FOR ASSIGNMENT
	tance of Cr salts is not advisable for recirculation, but individual attention should be directed to the specific salt and the process involved.
Cobalt, metal fume and dust	Literature cites neoplastic effects and fatal human dose seems dangerously close to the excursion factor.
Copper, fume, dusts, mists	Systemic effects have been reported below the current TLV.
Corundum Aluminum Oxide Alumina	Experimental neoplastic effects have been demonstrated in the literature.
Cyanide, as Cn (alkali cyanides)	Systemic effect threshold falls within the excursion factor.
Demeton Systox	Systemic effects occur within the excursion factor.
p-Dichlorobenzene	Literature recommends the TLV as a "Ceiling" value.
Dichlorvos DDVP	Systemic effects may occur within the excursion factor (SwRI is considering cholinesterase inhibition as a systemic effect in this case).
Diethylene Triamine	Literature cites incidence of undue irritation occurring at levels where NO concentration has been detected.
Dimethyl Acetamide DMAC	Systemic effects fall within the excursion factor.
Dimethylformamide DMF	Systemic effects cited within the excursion factor.
Dimethylsulfate	ACGIH includes in 1973 "Notice of Intended Changes" as an "Experimental Carcinogen."

Group 5

COMPOUND	REASON FOR ASSIGNMENT
Dinitro-o-Cresol	Possible intoxication to the severe level can occur within the excursion factor.
Epichlorhydrin 1-Chloro-2,3-Epoxypropane Chloropropylene Oxide	Literature cited neoplastic effects.
Ethylene Imine Aziridine	Literature cites systemic effects within the excursion factor and chronic animal studies note mutagenic and carcinogenic effects.
Fluoride, as F ("Fluoride-bearing dusts and fumes" inorganic)	Systemic effects fall within the excursion factor.
Hafnium	Experiments suggest possibility of borderline systemic effects falling within the excursion factor, although SwRI acknowledges the fact this is based on a figure derived from diet and ingestion.
Hexachloroethane Perchloroethane Carbon Hexachloride Phenohep	Current TLV may not be low enough to prevent chronic injury as cited in the literature.
Hexane	Irritant levels can be innocuous within the excursion factor.
Hydrazine	Continuous exposure to animals at current TLV caused some fatalities.
Iron Oxide fume Ferric Sesquioxide Hematite Ferric Oxide Jewelers Rouge	Possibility of some reversible systemic effects occurring within the excursion factor.

Group 5

COMPOUND	REASON FOR ASSIGNMENT
Methyl Bromide Bromomethane Embaforme	Literature cites an agreed upon "Ceiling" value that falls within the excursion factor.
Methyl Iodide Iodomethane	Literature cites experimental carcinogenic effects.
Monomethyl Aniline Methylaniline	Too small a margin between TLV and systemic effects.
Nickel, metal and soluble compounds, as Ni	Literature cites experimental carcinogenic effects.
Nitroglycerin Glyceryl Trinitrate	The literature suggests the current TLV as a "ceiling" value.
Ozone Triatomic Oxygen	Literature cites neoplastic effects in an industrial situation.
Parathion Thiophos 3422 DNTP	Systemic effects noted at TLV and within excursion factor (SWRI is calling a slight cholinesterase activity decrease a systemic effect in this case for recirculation)
Pentachloronaphthalene	Experimental systemic effects noted in the literature within the excursion factor.
Pentachlorophenol	Irritation can be painful within the excursion factor.
Phenothiazine Thiodiphenylamine Dibenzothiazine	Skin irritation and discoloring noted within the excursion factor.
p-Phenylene Diamine p-Diaminobenzene Ursold	Literature cites that current TLV may not be low enough to prevent systemic effects.
Phosphorus (yellow)	Literature cites that current TLV may not be low enough to provide much margin from undesirable effects.

Group 5

COMPOUND	REASON FOR ASSIGNMENT
Phosphorus Trichloride	Systemic effects noted within the excursion factor.
Picric Acid 2,4,6-Trinitrophenol Carbazotic Acid Nitroxanthic Acid Picronitric Acid	Systemic effects noted within the excursion factor and the TLV, although SwRI acknowledges the apparent lack of effects with apparent desensitization.
Polytetrafluoroethylene decomposition products	Not enough literature on toxic effects available (SwRI opinion only) and no safe specific TLV levels set as yet.
Propylene Imine 2-Methylaziridine	Literature suggests possibility of mutagenic or carcinogenic effects that need more study.
Rosin Core Solder, pyrolysis products, as Formaldehyde	Undue irritation is noted within the excursion factor.
Rotenone (commercial)	Current TLV is in question as to possible systemic effects at this level.
Selenium Hexafluoride Selenium Fluoride	Selenium is a suspected carcinogen according to the literature.
Silver, metal and soluble compounds	In some of the silver compounds, tooth mottling or skeletal changes have been noted at the TLV or within the excursion factor.

Group 5

COMPOUND	REASON FOR ASSIGNMENT
Sodium Fluoroacetate (1080)	SwRI rejected because from what literature was located, it said that the compound has no known antidote and that cases of heart damage in humans have been observed because of it <u>possibly</u> .
Styrene (monomer) Phenyl Ethylene	Literature strongly supports current TLV as a "Ceiling" value.
Sulfur Pentafluoride Disulfur Decafluoride	The suggested "Ceiling" value (in the literature) falls within the excursion factor.
Teflon decomposition products	Not enough literature on toxic effects available (SwRI opinion only) and no safe specific TLV levels set as yet.
1,1,2,2-Tetrachloroethane Acetylene Tetrachloride	Literature cites systemic effects within the excursion factor.
Tetrachloronaphthalene	Literature cites systemic effects within the excursion factor.
Triphenyl Phosphate Phosphoric Acid, Tri-phenyl Ester	Systemic effects have been cited within the excursion factor.
Uranium, natural soluble and insoluble compounds, as U	Literature cites that continuous industrial exposure could possibly a cancer hazard.
Vanadium dust (V_2O_5), as V	Literature suggests that values given for both fume and dust should be "Ceiling" values.

Group 5

COMPOUND	REASON FOR ASSIGNMENT
Wood Dust (nonallergenic)	Literature cites that it is doubtful that current TLV is low enough to prevent <u>all</u> systemic effects because of lack of information on degree of exposure in the industry.
Yttrium	Experimental fibrinogenic activity has been noted in the literature.
Zinc Chloride fume	Literature cites this compound as producing neoplastic effects in an experimental situation.

Appendix D
Rational for Group 1 Contaminants

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Acetaldehyde Acetic Aldehyde Ethenal Aldehyde	100 ppm	125 ppm	0.21 ppm 2.3 ppm	fruity	Eye, nose, throat irritation by all persons at 200 ppm
Acetic Acid	10 ppm	15 ppm	0.03 ppm 0.21 ppm 1.63 ppm	vinegar-like	Eye, nose, throat irritation at 25 ppm; intolerable at 50 ppm
Acetone	1000 ppm	1250 ppm	200-400 ppm (fatigue at 700 ppm)	sweetish	Slight irritation of eyes, nose at 2500-3000 ppm
Acetonitrile Methyl Cyanide	40 ppm	60 ppm	40 ppm (fatigue after 2-3 hours)	ether-like	Delayed irritation after about 4 hrs at 160 ppm--nose, throat, respiratory tract
Acetylene (with 0.05% Phosphine in U.S.) Ethyne	500 ppm	625 ppm	2 ppm for pure Phosphine)	garlic (Acetylene)	Slight respiratory tract irritation at 100,000 ppm or headache
Acrylonitrile Propenenitrile Vinyl Cyanide	20 ppm	30 ppm	19 ppm 21.07 ppm	---	Readily absorbed thru skin--source of contact dermatitis. Systemic effects in animals at 153 ppm
Allyl Alcohol Propene 1-ol-3	2 ppm	4 ppm	0.78 ppm	pungent	Slight irritation of eyes, nose at 5 ppm; severe at 25 ppm
Allyl Glycidyl Ether (AGE) Oxirane 2,3-Epoxypropyl Propane, 1-Allyloxy-2,3-Epoxy-	5 ppm	10 ppm	below 10 ppm	sweet	Irritates slightly above 5 ppm in humans; 260 ppm in animals. Affects eye, nose, respiratory tract.
Allyl Propyl Disulfide	2 ppm	4 ppm	0.0002 ppm	---	Irritation is slight at 3.4 ppm; eyes, nose, throat affected
Ammonia	25 ppm	37.5 ppm	1-5 ppm	pungent	Eyes, throat, respiratory tract at 20 ppm in non-workers; 100 ppm for accustomed workers.
n-Amyl Acetate	100 ppm	125 ppm	7 ppm	fruity	Eyes, nose, respiratory tract irritation at 200 ppm
sec-Amyl Acetate Acetic Acid, 2-Pentyl Ester	125 ppm	156 ppm	7 ppm	fruity	Eyes, nose, respiratory tract irritation at 200 ppm
Aniline	5 ppm	10 ppm	0.5 ppm	aromatic amine-like	There may be some irritation between 7-53 ppm after several hours. Main systemic effect is cyanosis.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Benzyl Chloride alpha-Chloro-Toluene	1 ppm	2 ppm	0.01 ppm	unpleasant, very irritating	16 ppm is intolerable to eyes, nose, throat in 1 minute
Bromoform Tribromomethane	0.5 ppm	1.5 ppm	0.004 ppm	chloroform-like	Vapors are very irritating, but literature was not specific. No animal fatalities reported below 56,000 ppm for 1 hour
1,3-Butadiene Erythrene Vinyl Ethylene	1000 ppm	1250 ppm	0.16 ppm	mild, character- istic odor	Irritates skin, nose. 8000 ppm caused only slight irritation in animals
n-Butane Diethyl	500 ppm	625 ppm	5.5 ppm	---	10 min. exposure at 10,000 ppm can cause drowsiness
2-Butanone (MEK) Methyl Ethyl Ketone	200 ppm	250 ppm	14 ppm	ketonic	Affects eye, nose, throat. Some irritation possible at or slightly above current TLV, but only systemic effect located was low-grade intoxication from 300-600 ppm.
n-Butyl Acetate Butyl Acetic Ether	150 ppm	187 ppm	20.25 ppm (pure compd.) 10 ppm (esters)	fruity	Irritant level 200-300 ppm. Affects eyes, nose, throat, respiratory tract.
sec-Butyl Acetate Acetic Acid, sec-Butyl Ester	200 ppm	250 ppm	20.25 ppm (pure compd.) 10 ppm (esters)	fruity	Irritant level over 300 ppm. Affects eyes, nose, throat, respiratory tract.
tert-Butyl Acetate Acetic Acid, tert-Butyl Ester	200 ppm	250 ppm	20.25 ppm (pure compd.) 10 ppm (esters)	fruity	Irritant level over 300 ppm. Affects eyes, nose, throat, respiratory tract.
Butyl Alcohol n-Butanol	100 ppm	125 ppm	0.042 ppm 16.21 ppm 25 ppm	pungent	Irritates some persons' eyes at 50 ppm. Produces headaches at 200 ppm.
sec-Butyl Alcohol 2-Butanol Methyl Ethyl Carbinol	150 ppm	187 ppm	0.04 ppm 25 ppm	pungent	Nothing specific. Based on Butyl Alcohol, above.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
tert-Butyl Alcohol Trimethyl Carbinol	100 ppm	125 ppm	0.04 ppm 25 ppm	camphor-like	Based on n-Butyl Alcohol above; nothing else specific located.
n-Butyl Glycidyl Ether (BGE)	50 ppm	75 ppm	0.02 ppm (Heptanoic Acid-same mol.wght.)	irritating	Some persons affected slightly above 50 ppm. Affects, eyes, skin, respiratory tract, CNS depressant
Butyl Mercaptan 1-Butanethiol	0.5 ppm	1.5 ppm	0.001 ppm	heavy-skunk-like	Affects eyes. Irritates at 2.72 ppm after 3 hrs. daily
p-tert-Butyltoluene (p-TBT)	10 ppm	20 ppm	5 ppm	---	Affects respiratory tract. Mildly unpleasant at 80 ppm.
Carbon Disulfide	20 ppm	30 ppm	0.008 ppm 0.099 ppm	sweet,pleasing (pure compd.) foul,unpleasant (commercial)	Some headaches and mild intox- ication, 30-150 ppm.
Carbon Tetrachloride Tetrachloromethane	10 ppm	20 ppm	0.175 ppm	characteristic	Nausea, headache, dizziness repor- ted at 25 ppm.
Chlorine Dioxide	0.1 ppm	0.3 ppm	0.1 ppm 0.33 ppm	---	Severe irritation at 5 ppm. Affects eyes, respiratory tract.
Chlorobenzene Monochlorobenzene	75 ppm	112 ppm	60 ppm	---	Irritant level,200 ppm. Affects eyes, nose.
Cresol (all isomers)	5 ppm	10 ppm	0.0005 ppm 0.009 ppm	phenolic	Strong irritant, but no level reported. Mostly corrosive to skin.
Crotonaldehyde 2-Butenal Crotonal Methacrolein	2 ppm	4 ppm	0.03 ppm		At 45 ppm, extremely irritates eyes, skin, nose, respiratory tract.
Cumene Isopropylbenzene Propane, 2-Phenyl	50 ppm	75 ppm	0.007 ppm (Trimethyl- benzene at same mol.wght.)	sharp,penetra- ting,aromatic (Cumene)	Affects eyes, respiratory tract, but probably not harmful up to 400 ppm for humans/short expos.
Cyclohexane Hexahydrobenzene	300 ppm	375 ppm	0.41 ppm	solvent(pure) pungent(impure)	Slight irritation around 300 ppm to eyes, nose

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Cyclohexanone Pimelic Ketone	50 ppm	75 ppm	below 25 ppm	peppermint, acetone	Some irritation of throat at 50 ppm; affects eyes at 309 ppm. Levels that cause systemic effects not likely tolerated.
Cyclohexene 1,2,3,4-Tetrahydrobenzene	300 ppm	375 ppm	near 0.41 ppm noted for Cyclohexane	---	Affects nose, eyes, slightly above 300 ppm.
Diacetone Alcohol Diethyl Acetyl Carbinol 4-Hydroxy-4-Methyl-2-Pentanol Tyranton	50 ppm	75 ppm	0.007 ppm (for Hexanoic acid, same mol. weight)	faint, pleasant (for Diacetone Alcohol)	Irritation level is 100 ppm. Affects eyes, nose, throat.
1,2-Dibromoethane Ethylene Dibromide	20 ppm	30 ppm	below 25 ppm	chloroform-like	25 ppm-well tolerated. 50 ppm-dangerous to humans.
1,1-Dichloroethane Ethylidene Chloride	200 ppm	250 ppm	200.52 ppm	chloroform-like	No specific irritation located. May be narcotic in high concns.
1,2-Dichloroethane Ethylene Dichloride	50 ppm	75 ppm	0.185 ppm 47.04 ppm	pleasant with sweet taste	Between 50-100 ppm could cause some nausea, dizziness.
1,2-Dichloroethylene Acetylene Dichloride	200 ppm	250 ppm	1.09 ppm	etheral, acrid	No irritation below 1,000 ppm; may be narcotic in high concns.
Diethylamine	25 ppm	37 ppm	below 10 ppm	fish-like	Concns. dangerous to life not voluntarily tolerable. Around 50 ppm affected nose, skin, eyes in animals.
Diisobutyl Ketone 2,6-Dimethylheptanone-4 Valerone	25 ppm	37 ppm	50 ppm	ketonic	Affects eyes between 25-50 ppm
Diisopropylamine	5 ppm	10 ppm	0.85 ppm	characteristic	Irritant level-25-50 ppm. Affects eyes, nose, skin, respiratory tract.
Dimethylamine	10 ppm	20 ppm	0.02 ppm 0.15 ppm	fish-like characteristic	After 90 days continuous exp. to 5 ppm, can cause irritation. Will probably irritate nose, skin, eyes around 100 ppm.
Dimethylaniline N-Dimethylaniline Xylidine	5 ppm	10 ppm	0.005 ppm	---	Will cause irritation at 7-53 ppm after a few hours.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Dinitrobenzene (all isomers)	0.15 ppm	0.45 ppm	0.003 ppm 0.02 ppm 0.01 ppm	---	Only effects mentioned deal with blood involvement and that substance is readily absorbed thru skin, but no levels are given.
Dioxane Diethylene Dioxide	50 ppm	75 ppm	2.73 ppm	faint, pleasant	Can effect eyes, nose, respiratory tract. Only level reported was a human fatality at 470 ppm after a week of exposure.
Ethanolamine	3 ppm	6 ppm	2-3 ppm	ammoniacal, fishy	Affects skin, respiratory tract. Unpleasant slightly above 3 ppm.
2-Ethoxyethanol Cellosolve Oxitol Ethylene Glycol Monoethyl Ether	200 ppm	250 ppm	---	practically odorless	It can irritate slightly above 200 ppm; affects eyes, nose. In high concentrations, it is disagreeable.
Ethyl Acetate	400 ppm	500 ppm	0.06 ppm 10 ppm 200 ppm	fruity -very strong	Affects nose, eyes, throat; narcotic effects in high concns. Irritates at or slightly above 400 ppm.
Ethyl Acrylate (monomer)	25 ppm	37 ppm	0.00009 ppm 1 ppm	acrid, penetrating	4 ppm immediately irritating. Most workers find 25 ppm intolerable after a few minutes. Affects eyes, nose, skin.
Ethyl Alcohol Ethanol Grain Alcohol	1000 ppm	1250 ppm	4.63 ppm 51.05 ppm 366.94 ppm 1000 ppm	pleasant "vinous"	It affects humans (eyes, respiratory tract) around 5500 ppm.
Ethyl sec-Amyl Ketone (EAK) 5-Methyl-3-Heptanone Amyl Ethyl Ketone	25 ppm	37 ppm	0.12 ppm 6 ppm	mild, fruity	Irritates around 50 ppm; affects eyes, nose, respiratory tract.
Ethyl Benzene Phenylethane, EB	100 ppm	150 ppm	0.48 ppm (for p-Xylene at same mol. wght.)	pungent (Ethyl Benzene)	Affects eyes, nose skin; irritating around 200 ppm; very at 1000 ppm; intolerable at 2000 ppm.
Ethyl Butyl Ketone (EBK) 3-Heptanone	50 ppm	75 ppm	0.02 ppm (for 2-Heptanone)	penetrating, fruity	Affects nose, eyes slightly above 50 ppm.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Ethyl Ether Ethoxyethane	400 ppm	500 ppm	0.33 ppm 72.72 ppm	characteristic sweetish, pungent odor	At 300 ppm-objectionable odor. 400 ppm is "tolerable" in conditioned workers. Irritates some at 200 ppm (nose, eyes, skin, respiratory tract).
Ethyl Mercaptan Ethanethiol Ethyl Sulphydrate	0.5 ppm	1.5 ppm	1 part per billion	penetrating, leek-like	Affects the nose; may cause headache, nausea. Irritates at 4 ppm.
Ethyl Silicate Orthosilicic Acid, Tetraethyl Ester Tetraethoxysilane Tetraethyl Silicate	100 ppm	150 ppm	85 ppm	---	700 ppm is irritant level for humans. Being a lacrimator, most will find it intolerable after 30 minutes.
Ethylene Ethene	1000 ppm	1250 ppm	260 ppm (detectable) 700 ppm (most characteristic smell)	slightly sweet ammonia odor	It is a simple asphyxiant. MAC in workroom is 5500 ppm BECAUSE OF FIRE. No irritation located below that figure
Ethylenediamine 1,2-Diaminoethane 1,2-Ethanediamine	10 ppm	20 ppm	10 ppm	ammonia odor	100 ppm-tolerable for 5-10 seconds; 200 ppm-tingles skin and nose; 400 ppm is intolerable.
Ethylene Glycol (vapor) 1,2-Ethanediol	100 ppm	150 ppm	0.08 ppm	sweet taste	Mild irritation can occur at or near the TLV. Compd. is a CNS stimulant/depressant and can cause nausea, sleepiness.
Ethylene Glycol Monomethyl Ether Acetate Methyl Cellosolve Acetate	25 ppm	37 ppm	0.64 ppm	mild, ester-like	Slight nose irritation at 4500 ppm in animals.
N-(or 4-) Ethylmorpholine	20 ppm	30 ppm	0.25 ppm Under 25 ppm	ammonia-like	Affects eyes, nose, throat. Irritates at 100 ppm with subsequent odor fatigue.
Furfural Pyromucic Aldehyde 2-Furaldehyde	5 ppm	10 ppm	0.25 ppm 0.38 ppm 5 ppm (readily noticeable)	peculiar, irritating almond-like	Affects eyes, nose, throat, and is uncomfortable from 20-50 ppm.
Heptane	500 ppm	625 ppm	0.59 ppm	faint, characteristic	1000 ppm for 6 minutes will cause dizziness in humans.
2-Hexanone Methyl 2-Butyl Ketone	100 ppm	150 ppm	Detectable at low concns.	typical ketone odor	1000 ppm will cause irritation (eyes, nose) in humans after a few minutes.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Hexone Methyl Isobutyl Ketone Isopropylacetone 4-Methyl-2-Pentanone	100 ppm	150 ppm	Below 100 ppm	faint, ketonic	100 ppm irritates at initial exposure. 15 minutes at 200 ppm will irritate eyes, nose, throat.
Hydrogen Bromide	3 ppm	6 ppm	Below 2 ppm	acid	Irritates nose, throat, eyes, skin respiratory tract from 3-6 ppm.
Hydrogen Cyanide Hydrocyanic Acid Prussic Acid	10 ppm	20 ppm	0.91 ppm	bitter, almond-like	Effects are headache, vertigo, nausea. Symptoms are slight at 15-36 ppm after several hours.
Hydrogen Fluoride	3 ppm	6 ppm	Below 3 ppm	---	Highly corrosive; affects eyes, nose, respiratory tract, skin. Irritates at 120 ppm (0.1 mg/l) in man.
Hydrogen Sulfide	10 ppm	20 ppm	0.0081 ppm 0.791 ppm 0.13 ppm	nauseating, rotten-egg odor	Eyes can be irritated between 14-20 ppm, but mostly between 50-100 ppm. As the concentration increases, there is an odor fatigue that makes the smell unreliable as warning. But as concentration increases, so does chance of headache, nausea, lassitude, dizziness.
Indene Indonaphthene	10 ppm	20 ppm	0.004 ppm	---	Expected to irritate the nose and lungs by analogy to Naphthalene, but no data given below systemic effect level at 800 ppm.
Isoamyl Acetate Pear Oil Acetic Acid, Isopentyl Ester Isopentyl Alcohol, Acetate Butanol, 3-Methyl-Acetate 3-Methyl-1-Butyl Acetate	100 ppm	150 ppm	0.003 ppm	pear-like	Slight irritation in humans at 100 ppm; severe throat irritation at 200 ppm. Also can cause headache, fatigue, chest pressure
Isoamyl Alcohol Isopentyl Alcohol	100 ppm	150 ppm	0.02 ppm (for i-Pentanol)	Characteristic disagreeable odor; pungent repulsive taste	Can irritate (eyes, nose, throat) at 100 ppm in unacclimated persons. Has narcotic effect in high concns

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Isobutyl Acetate	150 ppm	187 ppm	0.23 ppm 20.25 ppm (for Butyl Acetate at same mol. weight)	--	n-Butyl Acetate irritates at 10-20 ppm. Isobutyl Acetate also effects nose, eyes, respiratory tract, but is less irritating and more toxic than Butyl Acetate. It has narcotic effects in high concentrations.
Isobutyl Alcohol Isopropyl Carbinol 2-Methyl-1-Propanol Isobutanol	100 ppm	150 ppm	11 ppm (for n-Butanol-sim. in tox.&comp.)	like Amyl Alcohol, but weaker (for Isobutyl Alcohol)	Affects skin and nose, and is narcotic in high concns.; but no data is given on irritation level. Minimum lethal concn. for rats was 8000 ppm/4 hrs.
Isophorone 3,5,5-Trimethyl-Cyclohexene-2-One-1	25 ppm	37 ppm	0.54 ppm	---	Affects eyes, nose, throat, at 25 ppm in unconditioned workers. Only useful warning level of odor is at 200 or 400 ppm. One study said that comfort concentration for 8-hrs was 10 ppm.
Isopropyl Acetate	250 ppm	312 ppm	0.0008 ppm 0.002 ppm (for Valeric Acid at same mol.weight)	unpleasant (for Isopropyl Acetate)	Affects the eyes at 200 ppm; higher for nose and throat, but nothing systemic located below 16,000 ppm.
Isopropyl Alcohol	400 ppm	500 ppm	0.27 ppm 0.45 ppm	slight odor resembling mix of Ethanol and Acetone	Affects eyes, nose, throat--mild at 400 ppm; intense at 800 ppm.
Isopropylamine 2-Aminopropane	5 ppm	10 ppm	0.0002 ppm 0.12 ppm (for Trimethylamine) 10-20 ppm odor of Isopropylamine is strong	ammonia odor (for Isopropylamine)	Affects eyes, nose, skin, throat at 10-20 ppm with short exposure. Nothing systemic below 8000 ppm.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Isopropyl Ether Diisopropyl Ether	250 ppm	312 ppm	0.005 ppm (for Hexanol at same mol. weight)	more irritating than Ethyl Ether (Isopropyl Ether)	Affects eyes and nose. Odor was unpleasant around 300 ppm, but not irritating until 800 ppm.
Isopropyl Glycidyl Ether (IGE) 1,2-Epoxy-3-Isopropoxy-Propane	50 ppm	75 ppm	Less than 10 ppm for Allyl Glycidyl Ether; 20.25 ppm for Butyl Acetate at same mol. weight.	-----	Noted some hemoglobin changes in rats at 400 ppm. It affects eyes, lungs, skin, but no level given.
Lithium Hydride	0.08 ppm	0.24 ppm	0.08 ppm (slightly over)	-----	0.154 ppm is initially objectionable, but adaptable. 1.54 ppm is maximum tolerable concn. for brief periods. 170 ppm can cause destruction of external nasal septum. High concns. can also cause permanent eye damage.
Maleic Anhydride	0.25 ppm	0.75 ppm	0.50 ppm	sharp, irritating	1.50-2 ppm-nose in 1 min.; eyes in 15 min. Around 2.50 would probably be intolerable.
Mesityl Oxide Methyl Isobutenyl Ketone 4-Methyl-3-Pentan-2-One	25 ppm	37 ppm	12 ppm	honey-like peppermint-like	25 ppm irritates most; 50 ppm irritates immediately. 100-800 ppm causes severe irritation with very unpleasant aftertaste. Affects eyes, nose, respiratory tract.
Methyl Acetate	200 ppm	250 ppm	200 ppm	pleasant	Narcotic effects in high concns. Only located data said LC for rat inhalation was 35000 ppm.
Methyl Acrylate Methyl Propenate Acrylic Acid, Methyl Ester	10 ppm	20 ppm	0.00004 ppm (detectable) 1 ppm (readily noticeable)	acid	Affects eyes, nose, skin. Based on data for Ethyl Acrylate: 4 ppm-most irritating; 25 ppm is intolerable after a few min.
Methylamine	10 ppm	20 ppm	0.02 ppm	-----	Affects eyes; skin, respiratory tract. Irritated some at 25 ppm. Cases of chemical bronchitis from 2-60 ppm noted.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Methyl 2-Cyanoacrylate 2-Cyanoacrylic Acid, Methyl Ester	2 ppm	4 ppm	1-3 ppm	-----	3 ppm irritates the nose; 5 ppm irritates the eyes.
Methyl Isoamyl Ketone 2-Hexanone, 5-Methyl-	100 ppm	150 ppm	0.02 ppm (for Methyl n-Amyl Ketone & same mol. weight)	faint, ketonic camphor odor (for Methyl Isoamyl Ketone)	Based on Methyl Isobutyl Ketone: Odor may be objectionable to some at 100 ppm, but until 200 ppm, no eye or nose irritation.
Methyl n-Amyl Ketone 2-Heptanone	100 ppm	150 ppm	0.02 ppm	penetrating, fruity	Noted some systemic effects in animals at 1,500 ppm. Affects the nose; narcotic in high concns.
Methyl Chloride Chloromethane	100 ppm	150 ppm	10 ppm (ACGIH Guides say practically NO odor)	ethereal odor; sweet taste	Can be narcotic in high concns w/ vision disturbances; but no apparent toxic effects have been found below 200 ppm.
Methylchloroform 1,1,1-Trichloroethane	350 ppm	437 ppm	20-100 ppm 330.54 ppm	aromatic, chloroform-like	500 ppm will cause slight eye &/ or nose irritation; 1000 ppm will irritate all and cause some dizziness (note: there was some growth depression in animals at 650 ppm)
Methylcyclohexane Cyclohexylmethane Toluene Hexahydride Hexahydrotoluene Sextone	500 ppm	625 ppm	0.41 ppm (for Cyclohexane)	-----	1200 ppm was reported to be innocuous to rabbits.
Methyl Isobutyl Carbinol (MIBC) Methyl Amyl Alcohol	25 ppm	37 ppm	0.002-0.005 ppm	-----	Eyes are irritated at 50 ppm, but odor is not objectionable at that point.
Methyl Mercaptan Methanethiol Mercaptomethane Thiomethyl Alcohol	0.5 ppm	1.5 ppm	0.001 ppm 0.008 ppm 0.041 ppm	odor of decayed cabbage or onions	No irritant level located; but it will cause nausea and narcotic effects at high concns. Lethal concn. for rats was 10000 ppm.
Methyl Methacrylate Methacrylic Acid	100 ppm	150 ppm	0.21 ppm 0.25 ppm	---	100 ppm is "comfort" limit; up to 200 ppm is tolerable with no real worker complaint, but 2300 ppm is totally unbearable to humans.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Methylene Chloride Dichloromethane	250 ppm	312 ppm	213 ppm 404 ppm Below 300 ppm	sweet	500 ppm on a chronic basis will cause irritation, but 1,000 ppm for 1/2 hour can cause dizziness and acute nausea.
Morpholine Diethyleneimine Oxide Tetrahydro-1, 4-Isioxazine	20 ppm	30 ppm	0.14 ppm	characteristic amine odor	12000 ppm causes severe irritation (eyes, nose, skin, throat, respiratory tract) with coughing after 90 seconds.
Naphthalene	10 ppm	20 ppm	0.03 ppm 0.3 ppm	moth-ball like	Irritates the eyes at 15 ppm; Eye lesions and general narcosis have been noted at very high concentrations.
Nitric Oxide Nitrogen Monoxide	25 ppm	37 ppm	1 ppm	-----	Becomes highly poisonous NO ₂ on contact with air, but only level mentioned was mouse fatality at inhalation of 350 ppm.
Nitromethane Nitrocarbol	100 ppm	150 ppm	100 ppm (very strong)	moderately strong, somewhat disagreeable odor.	At 200 ppm odor is irritating but unreliable as warning. 500 ppm will cause severe eye and respiratory irritation.
Octane	400 ppm	500 ppm	0.02 ppm	-----	Heptane cause dizziness at 1000 ppm. Octane is 1.2 to 2 times more toxic, so inferred level is 400-100 ppm (affects nose, too)
Pentane	500 ppm	625 ppm	2.17 ppm 1000 ppm	faint	5000 ppm for 10 min. had no effects. 90000-120000 ppm caused narcosis in animals.
2-Pentanone Methyl Propyl Ketone Ethyl Acetone	200 ppm	250 ppm	8 ppm	-----	1500 ppm is severely irritating to man-(eyes, nose, respiratory tract).
Perchloroethylene Tetrachloroethylene	100 ppm	150 ppm	4.73 ppm 50 ppm	ethereal	160 ppm-odor not objectionable; 216 ppm caused eye irritation; 280 ppm impaired motor coordination.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Phenol	5 ppm	10 ppm	0.02 ppm 0.042 ppm 0.065 ppm 4 ppm	characteristic definite odor	Affects nose, throat, eyes at 48 ppm.
Phenyl Ether (vapor) Diphenyl Ether Diphenyl Oxide	1 ppm	3 ppm	0.0001 ppm 0.101 ppm	characteristic	Complaints of disagreeable odor and nausea above 1 ppm.
Phenyl Ether-Diphenyl Mixture (vapor)	1 ppm	3 ppm	0.0001 ppm 0.101 ppm	characteristic	0.1 ppm is objectionable to sensitized persons; 7-10 ppm is extremely nauseating and irritating to eyes, respiratory tract.
n-Propyl Acetate	200 ppm	250 ppm	0.0006 ppm 0.002 ppm (for Valeric Acid or Methyl Butyrate)	pear odor for n-Propyl Acetate	2600 ppm caused salivation and eye irritation in cats. Can also affect nose, skin, respiratory tract.
n-Propyl Alcohol Propanol	200 ppm	250 ppm	0.23 ppm 0.45 ppm	alcoholic and slightly stupefying (easily masked)	Affects eyes, nose, but 800 ppm is tolerable with some discomfort
Propylene Dichloride 1,2-Dichloropropane	75 ppm	112 ppm	90 ppm	chloroform-like	Short periods of 400-500 ppm are tolerable with no ill effects. At 1600-2200 ppm there was severe lachrymation.
1,2-Propylene Oxide Methoxirane Propene Oxide Methy-Ethylene Oxide	100 ppm	150 ppm	35 ppm 200 ppm (not reliable)	----- as a warning)	Affects eyes, nose, skin, breathing, but only levels given-100 ppm caused no effects; 200 ppm seemed to cause increase in lung weight in 6 months.
Pyridine	5 ppm	10 ppm	0.01 ppm (unreliable exceeding 5 ppm because of odor fatigue)	characteristic,	General irritation caused by 6-12 ppm. At 30 ppm, odor is most objectionable.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Selenium Compounds (as Se)	0.06 ppm	0.18 ppm	---	like rotten horseradish (the Dioxide)	Affects eyes, nose, throat. Causes sweats, "garlic breath" and nervousness. Various complaints noted at 0.0021 to 0.02 ppm.
Sulfur Dioxide	5 ppm	10 ppm	3-5 ppm	suffocating smell	Affects throat at 8-12 ppm; Irritates eyes and causes coughing at 20 ppm.
Sulfuric Acid	0.25 ppm	0.75 ppm	0.75 ppm	---	1.25 ppm is tolerable for 5 min. with no irritation but will cause a rapid increase in respiratory rate. Affects nose, mouth, teeth (erosion) throat, lungs---corrosive.
Tetrahydrofuran Diethylene Oxide Tetramethylene Oxide	200 ppm	250 ppm	30 ppm	ether-like	17,000 ppm for 3 hours appeared safe. Can irritate skin, eyes, nose and be narcotic in high concentrations (25,000 ppm)
Tetranitromethane	1 ppm	3 ppm	---	pungent	0.4 ppm can cause some irritation Slightly over 1 ppm will cause lacrymation. Affects eyes, nose throat, lungs, skin.
Toluene Toluol Methylbenzene Methacide	100 ppm	150 ppm	40 ppm	benzene-like	200 ppm will cause narcotic effects in man.
1,2,3-Trichloropropane Trichlorohydrin	50 ppm	75 ppm	Under 50 ppm	very disagree- able odor	100 ppm is irritating to all and odor is very unpleasant.
Triethylamine	25 ppm	37 ppm	Under 10 ppm (for Methyl- amine)	strong, ammonia like	Irritant level is about 50 ppm for long exposure, but this may also cause some systemic effects (for Diethylamine) Affects nose, skin, eyes.

Group 1

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Turpentine (mixture of terpene hydrocarbons, mostly alpha-Pinene)	100 ppm	150 ppm	Below 75 ppm	characteristic Terpene odor	200 ppm can be moderately irritating to eyes; 750- 1000 ppm for several hours caused headache, dizziness, nausea, also.
Vinyl Acetate	10 ppm	20 ppm	Below 5 ppm	---	After 4 hours at 240 ppm, caused slight eye blinking in dogs, but at higher con- cns.; is a lacrimator.
Vinyl Toluene 4-Methyl Styrene	100 ppm	150 ppm	50 ppm	-----	Odor strong at 200 ppm, but irritation of eyes, nose noted at 400 ppm.
Xylenes Xylol	100 ppm	150 ppm	0.48 ppm (for p- Xylol)	aromatic; sim. to benzene, toluene	Affects eyes, nose, throat. 200 ppm is irritating enough to not be satisfactory for a work atmosphere at all.

Appendix E
Rationale for Group 2 Contaminants

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Acrolein Acrylaldehyde 2-Propenal	0.1 ppm	0.3 ppm	0.4 ppm	pungent	Affects nose, eyes (lacrimator), respiratory tract. Irritation noted at 0.25 ppm. 1 min. at 5 ppm is intolerable.
Acrylamide Propenamide	0.1 ppm	0.3 ppm	---	---	Readily toxic by contact, inhalation, ingestion, etc. Is a lacrimator, but no inhalation level located.
2-Aminopyridine	0.5 ppm	1.5 ppm	---	---	Incident of headache, nausea, raised blood pressure at 5 ppm for 5 hrs. Nothing else located.
Argon	1000 ppm	1250 ppm	---	odorless	Non-irritating. A simple asphyxiant in high concns.
Arsine Hydrogen Arsenide Arsenic Trihydride	0.05 ppm	0.15 ppm	---	disagreeable, garlic odor	Noted intoxication at 0.25 ppm, but is agreed that it is relatively non-irritating even at levels that may have systemic effects. Systemic effects have been noted at less than 0.5 ppm, and a few have been poisoned (non-fatal) at 10 ppm.
Boron Tribromide	1 ppm	3 ppm	Releases 3 moles of HBr on decomp.; Below 2 ppm is threshold for HBr.	---	Based on HBr, 5-6 ppm will irritate the nose mainly. Boron Tribromide also affects eyes, throat, skin, respiratory tract.
Bromine	0.1 ppm	0.3 ppm	0.31 ppm 0.46 ppm 1 ppm 3.5 ppm	---	Eyes, respiratory tract are excessively irritated at 1 ppm.
Bromine Pentafluoride	0.1 ppm	0.3 ppm	---	sweet, suffocating	Nothing specific located, but noted that current TLV will not lead to "excessive" respiratory irritation." Affects eyes, too.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
2-Butoxy Ethanol Butyl Cellosolve Ethylene Glycol Mono-n-Butyl Ether	50 ppm	75 ppm	---	---	At levels of 100 ppm and 200 ppm, skin affected first, but vapors are "uncomfortable."
Carbon Dioxide Carbonic Acid Gas	5000 ppm	6250 ppm	---	odorless	30,000 ppm can be slightly narcotic; 50,000 ppm will cause marked respiration increase; but continuous exposure to average of 15,000 ppm may alter physiological processes.
Carbon Monoxide	50 ppm	75 ppm	---	odorless	Continuous exposure at 500-1000 ppm will cause gradual asphyxia; also CO can cause headache, dizziness, nausea. Fatal in a few minutes at 5000 ppm.
Chlorine	1 ppm	3 ppm	0.010 ppm 4 ppm 10 ppm	suffocating	Irritates from 4-7 ppm; affects eyes, nose, throat, respiratory tract. Will cause a severe cough at 30 ppm.
Chlorobromomethane Methane, Chlorobromo-	200 ppm	250 ppm	---	---	No effects of consequence noted in expl. animals at 370 ppm. Acute inhal.exp. will cause headache, loss of consciousness, G.I. upsets, weight loss.
Chlorodiphenyl, 42% Chlorine	0.10 ppm	0.30 ppm	0.034 ppm (for Chloro-phenol)	chlorinated, aromatic odor (for Chlorodiphenyl)	Affects eyes, nose, throat, respiratory tract; 0.99 ppm is unbearably irritating.
Chlorodiphenyl, 54% Chlorine	0.04 ppm	0.12 ppm	0.034 ppm (for Chloro-phenol)	chlorinated, aromatic odor (for Chlorodiphenyl)	Affects eyes, nose, throat, and respiratory tract. 0.75 ppm is unbearably irritating immediately but over 150 days, 0.41 ppm had some systemic effects.
Chloropicrin Nitrochloroform Nitrochloromethane Trichloronitromethane	0.1 ppm	0.3 ppm	1.088 ppm	fly-paper odor	Affects eyes(lacrimator), skin, lungs. 0.3-0.37 ppm irritates; 4 ppm renders one unfit for activity and 15 ppm is intolerable.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Chloroprene 2-Chloro-1, 3-Butadiene	25 ppm	37.5 ppm	---	---	Lowest toxic concn. in air for humans noted located was 80 ppm. Is a CNS depressant, can cause conjunctivitis(eyes) and hair loss. (with topical application)
Cyanogen Ethanedinitrile Oxalic Acid Dinitrile	10 ppm	20 ppm	250 ppm	almond-like acid, pungent in lethal concns	Affects eyes and nose about 15 ppm, but animal expts. suggest it is 10 times LESS toxic than HCN
Cyclohexanol Hexahydrophenol Hexalin	50 ppm	75 ppm	---	camphor-like	Affects eyes, nose, throat at 100 ppm; immediate narcotic-like effects at 272 ppm.
1,3-Cyclopentadiene	75 ppm	112.5 ppm	---	irritating, terpene like; camphor-like in -dimer.	Definite eye, nose irritation at 250 ppm.
Decaborane (14) Boron Hydride Decaboron Tetradecahydride	0.05 ppm	0.15 ppm	---	---	Rats lost weight at 1 ppm at 4 wks and neurological incoordination noted at 6 months exposure to 0.2 ppm. Only irritation noted, was dizziness and nausea; no level given.
Diazomethane Azimethylene	0.2 ppm	0.6 ppm	---	---	It is very irritating, but specific level not indicated. Affects respiratory tract, eyes, nose--systemic effects are delayed. Fatal to cats in 10 min. at 175 ppm.
Diborane (6) Boroethane Diboron Hexahydride Dihydrodiborane	0.1 ppm	0.3 ppm	---	sickly sweet	Affects lungs; can produce metal fume fever, pulmonary edema. Only human experience is with CNS intoxication-no level given.
2-N Dibutylaminoethanol (DBAE) 2-(Dibutylamino)-Ethanol	2 ppm	6 ppm	---	---	"Information not available from which to determine whether or not 2 ppm will cause irritation. DBAE is a cholinesterase inhibitor-in vitro.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODGR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Dibutyl Phosphate	1 ppm	3 ppm	---	(Tributyl Phosphate is odorless).	Affects nose, respiratory tract; can cause headaches; irritation experienced by workers, but no levels given.
Dichlorodifluoromethane Fluorocarbon No. 12	1000 ppm	1250 ppm	---	practically odorless, but has faint, ether-like odor in high concns.	500 ppm will produce no effect. Humans exposed to 100,000 ppm for a few minutes will become unconscious.
Dichloroethyl Ether Chlorex 1-Chloro-2-(beta-Chloroethyl) Ethane	5 ppm	10 ppm	Easily noticeable at 0.0035%	pungent	At 0.0035% it is non-irritating and only slightly offensive in odor. It can affect the eyes at 2.5 ppm. Will also affect the skin and respiratory tract. It is a lacrimator.
Dichloromonofluoromethane Freon No. 21 Dichlorofluoromethane	1000 ppm	1250 ppm	---	---	Caused general irritation in animals around 5200 ppm.
Dichlorotetrafluoroethane Freon No. 114 Cryofluorane 1,2-Dichloro-1,1,2,2-Tetrafluoroethane	1000 ppm	1250 ppm	---	---	Concns. of 1% by vol. caused irritation in animals and increased respiration rate.
2-Diethylamino Ethanol 2-Hydroxytriethylamine	10 ppm	20 ppm	---	---	Irritates by contact, especially eyes, skin. No inhalation data located.
Difluorodibromomethane Freon No. 12B2	100 ppm	150 ppm	---	---	Continuous exposure of animals to 350 ppm for 7 mos., no intox. Animals exposed to 2,300 ppm for 3 days were irritated (respiratory tract, CNS damage).
1,1-Dimethylhydrazine (UDMH)	0.5 ppm	1.5 ppm	6 ppm	ammonia-like	Animals exposed to 5 ppm for 6 mos. showed weight loss, lethargy, mild anemia. It is highly corrosive and affects eyes, nose, skin and lungs. Repeated exposure to 25 ppm (animals) caused convulsions and death.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Dipropylene Glycol Methyl Ether	100 ppm	150 ppm	---	---	Affects CNS system; irritation inferred to be slightly above the TLV. Lowest human systemic effect located was at 300-400 ppm
Ethane Dimethyl Dimethyl Methylmethane	1000 ppm	1250 ppm	---	odorless	Non-irritating; simple asphyxi- ant in high concentrations.
2-Ethoxyethylacetate Cellosolve Acetate Ethylene Glycol Monoethyl Ether Acetate	100 ppm	150 ppm	---	pleasant	No human data located. Dogs were irritated (eyes, nose) at 600 ppm after 120-7 hr. exposures; BUT cats/rabbits died at 450 ppm after 12 times at 8 hrs. each.
Ethylamine Ethanamine Aminoethane	10 ppm	20 ppm	---	ammonia-like	Affects nose, eyes, skin, respir- atory tract. Both irritant and systemic effects noted at 50 ppm after 2 weeks' exposure.
Ethyl Bromide Bromoethane	200 ppm	250 ppm	Well above 200 ppm	ethereal odor/ burning taste	Affects eyes, lungs; can cause vertigo or narcosis--POSSIBLE DELAYED EFFECTS. Humans irritated at 6500 ppm in 5 min.
Ethyl Chloride Chloroethane Muriatic Ether	1000 ppm	1250 ppm	---	characteristic, ethereal odor/ burning taste	Affects nose, CNS (incoordination) Literature says some systemic effects may occur before notice- able irritation. Lowest human toxic concn. -13,000 ppm-caused intoxication.
Ethyl Formate Formic Ether Formosol	100 ppm	150 ppm	---	---	Affects nose, skin, eyes. Irritant level is 330 ppm. Narcotic in high concns.
Ethylene Chlorohydrin 2-Chloroethanol	5 ppm	10 ppm	---	faint, alcohol- ether-like, odor	Little or no margin between irritation and systemic effects. Poisoning can occur at 18 ppm. Most toxic by skin absorption. Warning properties poor and inadequate to prevent injury. No level given for actual irritation

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Ethylene Oxide Oxirane Aneprolene Carboxide 1,2-Epoxyethane	50 ppm	75 ppm	500 ppm 700 ppm	---	Most toxic by skin contact. Affects eyes and nose around 204 ppm after chronic exposure. Work conditions seldom exceed 5 ppm, and rarely over 50 ppm. 6 mos. exposure at 100 ppm caused light anemia in animals.
Fluorine (as F ₂)	1 ppm	3 ppm	---	sharp	Caustic to eyes, nose, skin, respiratory tract. 5 ppm caused eye irritation in rats; 25 ppm very briefly gave sore throat and chest pain to humans; and 50 ppm is intolerable to humans.
Fluorotrichloromethane Trichlorofluoromethane Freon NO. 11	1000 ppm	1250 ppm	---	faint, ethereal	At 1000 ppm, slight changes were noted in animals after 30 days. At 2000 ppm, there was evidence of some alveolar irritation after 30 days in animals. In high concentrations can cause stupor, incoordination and tremors.
Formic Acid	5 ppm	10 ppm	21-22 ppm	pungent	Caustic to nose, eyes, skin, respiratory tract; very irritating at 15 ppm.
Furfuryl Alcohol alpha-Furyl Carbinol	5 ppm	10 ppm	---	faint, burning odor w/bitter taste	Usually some eye irritation at 50 ppm.
Gasoline (Mixture of C ₄ to C ₁₂ hydrocarbons)	800 ppm For "light" gasoline, but is based on aromatic hydrocarbon content of each composition.	1000 ppm	---	characteristic	Inhalation can cause intense burning sensation in throat and lungs, but no levels located.
Germanium Tetrahydride Germane Germanium Hydride	0.2 ppm	0.5 ppm	---	---	Lethal concentrations for exptl. animals were 100-185 ppm for 1 hr. No irritant levels located; is apparently a hemo-lytic agent. No irritation mentioned.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Glycidol 2,3-Epoxy-1-Propanol	50 ppm	75 ppm	---	---	Slight irritation of nose, skin, eyes in animals at 400 ppm after 50 days.
Helium	1000 ppm	1250 ppm	---	odorless	Inert, non-irritating. Simple asphyxiant in high concns.
Hexafluoroacetone (HFA)	0.1 ppm	0.3 ppm	---	musty odor; acrid with impurities	No irritation levels mentioned; 1 ppm caused kidney disfunction and increased lung weight in animals.
sec-Hexyl Acetate	50 ppm	75 ppm	Odor is unpleasant at 100 ppm	unpleasant	Eyes are irritated at 100 ppm in addition to the unpleasant odor experience.
Hydrogen Protium	1000 ppm	1250 ppm	---	odorless	Inert, non-irritating. Simple asphyxiant in high concns.
Hydrogen Peroxide (90%) Hydrogen Dioxide Albone Hydroperoxide	1 ppm	3 ppm	---	essentially odorless, but w/bitter taste	Caustic to eyes, nose, skin, lungs, esp. undiluted. Probably 75-100 ppm for not more than 4 hrs. will be irritating to humans.
Hydrogen Selenide Selenium Hydride	0.05 ppm	0.15 ppm	0.30 ppm	disagreeable	Lowest irritation level for humans was below 0.2 ppm, affecting eyes, nose, throat, GI tract (most toxic).
Iron Pentacarbonyl Iron Carbonyl Pentacarbonyliron	0.01 ppm	0.03 ppm	---	---	Decomposes readily to form CO. Can cause headache, nausea, vertigo. Only level located was lowest LC(rats) of 15 ppm.
Ketene Ethenone Carbomethane Keto-Ethylene	0.5 ppm	1.5 ppm	---	penetrating	In animals, 1 ppm had no effect, but 17 ppm was fatal. Vapors are very irritating and can cause pulmonary edema.
L.P.G. Liquified Petroleum Gas (mainly Propane, C ₃ H ₈)	1000 ppm	1250 ppm	---	---	Narcotic effects in high concns.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Mercury (Alkyl Compounds) (Monomethyl and Monoethyl Mercury Salts; Dimethyl and Diethyl Mercury)	0.001 ppm	0.003 ppm	---	---	Research indicates "nothing consistent between 0.01-0.1 mgHg/m ³ ."
Mercury (all forms except Alkyls)	0.006 ppm	0.018 ppm	---	odorless	Humans have experience acute poisoning between 0.147-1.038 ppm, causing tightness in chest, breathing difficulty, coughing, tremors, salivation.
Methane Marsh Gas Methyl Hydride	1000 ppm	1250 ppm	---	odorless	Inert, non-irritating. A simple asphyxiant in high concns.
2-Methoxyethanol Methyl Cellosolve Ethylene Glycol Monomethyl Ether Methyl Oxitol Methyl Glycol	25 ppm	37 ppm	0.40 ppm	pleasant, sweet, alcoholic odor	No irritation noted at 20 ppm; toxic to humans at 60 ppm. Other reports of toxicity lower than that are being held in doubt.
Methyl Acetylene 1-Propyne	1000 ppm	1250 ppm	---	---	Can cause irritation of lungs, excitement, ataxia, salivation, tremors--but no levels given except 6 mos. MLD for rats of 28,700 ppm.
Methyl Acetylene-Propadiene Mixture MAPP Allene	1000 ppm	1250 ppm	---	---	Only level mentioned was at 5000 ppm after 4 mos. there was a decrease in lung weight in animals.
Methyl Acrylonitrile Methacrylonitrile	1 ppm	3 ppm	---	---	In a chronic study, 19.3-52.9 ppm was set at "no effect," but 36- 37 ppm was lethal to animals in 4 hrs. Literature calls for more information on substance and says brief excursions to 2 ppm may or may not be acceptable. Chief irritant effects are CNS disturbances and diarrhea.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Methylal Dimethoxymethane Methylene Dimethyl Ether Formaldehyde Dimethyl Acetal Methoxy-Methyl Ether	1000 ppm	1250 ppm	---	chloroform odor w/pungent taste	Seems to be narcotic in high concentrations. Lowest toxic level mentioned was 11,300 ppm(animals)
Methyl Alcohol Methanol Carbinol Wood Alcohol Wood Spirits	200 ppm	250 ppm	53.3 ppm 99 ppm 107 ppm 1,529 ppm 2,000 ppm 5,900 ppm	slight, alcoholic odor when pure; repulsive, pungent when crude.	Can cause headache, fatigue, nausea, visual impairment. Recommended max.level is 300 ppm.
Methylcyclohexanol Hexahydrocresol Methylanol Methyl Hexalin	50 ppm	75 ppm	---	---	The irritant level is about 500 ppm (affects eyes, respiratory tract, causes headaches), BUT slight tissue changes were noticed in exptl. animals at 120 ppm!
0-Methylcyclohexanone Methyl-Hexanone	50 ppm	75 ppm	---	---	Affects eyes and respiratory tract(animals) at 450 ppm. Is toxic mainly thru skin absorption. Narcotic in high concns.
2-Methylcyclopentadienyl Manganese-Tricarbonyl (as Mn)	0.1 ppm	0.3 ppm	---	faint, pleasant herbaceous odor	Substance leaves a "thick tongue" and metallic taste, causing nausea, headache, disturbed respiration, but only level mentioned was 39.3 ppm which was fatal to rats/1hr.
Methyl Formate Formic Acid, Methyl Ester Methyl Methanoate	100 ppm	150 ppm	2000 ppm	agreeable	Affects eyes, nose; but only irritant level located was 1600 ppm for inflammation of lungs(animals) after 1 hour.
Methyl Isocyanate	0.02 ppm	0.06 ppm	Probably between 2-4 ppm.	---	Highly corrosive to nose, eyes, skin. Eyes irritated(lacrima-tion) between 2-4 ppm. At 21 ppm was intolerable immediately.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Naphtha (Coal Tar) Solvent Naphthas Gas Naphthas	100 ppm	150 ppm	---	characteristic odor that varies with composition	Narcotic in high concentrations. Lowest toxic concentration located was 312 ppm for 7 days (rats). No irritation level located.
Neon	1000 ppm	1250 ppm	---	odorless	Inert, non-irritating. A simple asphyxiant in high concentrations
Nitric Acid Aqua Fortis	2 ppm	4 ppm	Mostly concerned w/ NO ₂ -detect- able at 1 ppm	characteristic, choking odor	At 62 ppm, throat is irritated, but from NO ₂ mostly. In slightly higher concentrations, effects of pulmonary edema may be delayed as much as 48 hours.
Nitrobenzene Nitrobenzol Essence or Oil of Mirbane	1 ppm	3 ppm	1.9 ppm 5.97 ppm	bitter almonds	1-5 ppm is recommended maximum safe level for daily exposures; because 6 ppm can cause head- aches and slight blood changes.
Nitroethane	100 ppm	150 ppm	---	pleasant odor, relatively mild.	Irritating to eyes and nose at concentrations above 100 ppm, but irritation not useful for warning. At 500 ppm there is strong eye and respiratory irritation.
Nitrogen	1000 ppm	1250 ppm	---	odorless	Inert, non irritating. A simple asphyxiant in high concentrations
Nitrogen Trifluoride Nitrogen Fluoride	10 ppm	20 ppm	---	Has a "moldy" odor, but has no odor warning properties at potentially hazardous levels	No irritant effects located. But prolonged absorption can cause teeth mottling and skeletal changes-no level given. Rats developed liver and kidney changes at 100 ppm after 18 weeks.
1- and 2-Nitropropane	25 ppm	37.5 ppm	300 ppm	---	Vapors can irritate the lungs; can cause anorexia, nausea, diarrhea. Some people develop symptoms at 50 ppm.
Nitrotoluene	5 ppm	10 ppm	---	---	No irritation effects located.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Nitrous Oxide Dinitrogen Monoxide Laughing Gas	1000 ppm	1250 ppm	---	odorless	Fairly chemically inert at room temperatures. May be narcotic in high concentrations. A simple asphyxiant.
Osmium Tetroxide Osmic Acid	0.0002 ppm	0.0006 ppm	0.002 ppm	acrid, chlorine-like odor	Highly irritating to eyes, nose, throat, respiratory tract, skin. 0.01-0.06 ppm caused general severe irritation. 0.1 ppm was tolerable for 1/2 hour. Over a 6 hr. period, highest tolerable concn. with no harmful effects was 0.00009 ppm.
Oxygen Difluoride Fluorine Oxide Fluorine Monoxide	0.05 ppm	0.15 ppm	0.1-0.5 ppm (fatigue develops rapidly-not reliable as warning)	peculiar, slightly irritating	0.1 ppm had no effect, but at 0.5 ppm and above it caused severe respiratory irritation. At 17 ppm it is more poisonous than Fluorine and symptoms may be delayed.
Pentaborane (9) Pentaboron Monohydride	0.005 ppm	0.015 ppm	1 ppm	characteristic pungent odor; garlicky or even sweet	5 min. exposure to 25 ppm is tolerable, but not without intoxication. Even at 0.2 ppm for 6 mos., weight loss, incoordination, tremors were noted.
Perchloromethyl Mercaptan	0.1 ppm	0.3 ppm	---	---	Lower concns. than 25 ppm caused strong eye, throat, chest irritation.
Perchloryl Fluoride Chlorine Fluoride Oxide Chlorine Oxyfluoride	3 ppm	6 ppm	---	---	At 24 ppm there was no irritation but there were systemic effects.
Petroleum Distillates (Naphtha) Petroleum Benzin Petroleum Ether Ligroin (mainly pentanes and hexanes)	based on individual aromatic hydrocarbon content of each composition.		---	characteristic	For most compositions, 4000-7000 ppm is tolerable for 1 hr. after which narcotic symptoms will probably develop.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Phenyl Glycidyl Ether (PGE) 1,2-Epoxy-3-Phenoxypropane	10 ppm	20 ppm	--- (but Allyl Glycidyl Ether is readily detectable just under 10 ppm)	---	Affects eyes and lungs. On a chronic basis, animals reacted at 100 ppm.
Phosdrin Mevinphos 3-Hydroxycrotonic Acid Methyl Ester Dimethyl Phosphate	0.01 ppm	0.03 ppm	---	mild odor	No irritant effects or levels mentioned. It is a cholinesterase inhibitor and the LC ₅₀ for rats was 14.4 ppm for 1 hour.
Phosgene Carbonyl Chloride	0.1 ppm	0.3 ppm	0.749 ppm 5.6 ppm	---	It will irritate the throat at 3 ppm. At 25 ppm it is dangerous immediately. Affects the eyes and causes severe coughing.
Phosphine Hydrogen Phosphide	0.3 ppm	0.9 ppm	2 ppm	decaying fish	Exposure to 5-10 ppm for a few days may lead to chronic or subacute poisoning. Main effects are diaphragm pains, feelings of coldness, weakness, vertigo. Lowest reported human fatality was 8 ppm.
Propane Dimethylmethane	1000 ppm	1250 ppm	---	odorless when pure	May be narcotic in high concen- trations, causing headache, numbness, chilliness.
Propargyl Alcohol 2-Propyn-1-ol	1 ppm	3 ppm	---	mild geranium odor	Only concentration located was 874 ppm which was lethal to mice. It can irritate the nose and skin and is a CNS depressant, but no level given.
n-Propyl Nitrate Nitric Acid, n-Propyl Ester	25 ppm	37.5 ppm	50 ppm	sweet, sickly odor	Only effects mentioned were slight hypotension in animals at 260 ppm after 6 mos.
beta-Propylene Glycol Monomethyl Ether 3-Methoxy-1-Propanol	100 ppm	150 ppm	---	---	Only level or effect mentioned was lethal concentration for rats was 4000 ppm after 4 hrs.

Group 2

COMPOUND	TLV		EXCURSION FACTOR		ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Stibine Antimony Hydride	0.1	ppm	0.3	ppm	---	disagreeable	Substance is intensely poisonous. No irritant level located, but it will cause headache, nausea, weakness. Only level located was a lethal concn. (animals) of 10 ppm in air.
Stoddard Solvent White Spirits Varno Spirits	200	ppm	250	ppm	---	characteristic	4000-7000 ppm is tolerable for 1 hour, but narcosis will develop
Sulfur Hexafluoride	1000	ppm	1250	ppm	---	odorless	Experiments (animals) showed that 24 hr exposure to 80% had no effect. Substance may be a simple asphyxiant in higher concentration
Sulfur Monochloride Sulfur Chloride	1	ppm	3	ppm	---	penetrating	Corrosive; affects eyes (lacrimator nose, throat, breathing. Is mildly irritating to humans at 2-9 ppm. Considered extremely toxic because it's possible for undecomposed vapor reach the lungs.
Sulfur Tetrafluoride	0.1	ppm	0.3	ppm	---	---	4 ppm for 12 days, 4 hrs. each, caused breathing trouble, nasal discharge (animals); no other levels located; substance is irritating and corrosive.
Sulfuryl Fluoride Sulfuric Oxyfluoride Vikane	5	ppm	10	ppm	---	odorless	Highly irritating to respiratory tract; may cause tooth mottling. Only level located was 6 mos. exposure (animals) at 20 ppm showed "significant" effects.
Tellurium Hexafluoride	0.02	ppm	0.06	ppm	---	repulsive	1 ppm for 1 hr. caused greatly accelerated respiration. Lethal concn. at 5 ppm caused pulmonary edema.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
TEPP Tetraethyl Pyrophosphate	0.004 ppm	0.012 ppm	---	agreeable	Mainly toxic by oral dose or skin absorption. A cholinesterase inhibitor, it can cause weakness, vomiting, blurred vision, muscle twitch. Single skin application of 10 mg/kg is dangerous to man.
1,1,1,2-Tetrachloro-2,2-Difluoroethane	500 ppm	625 ppm	---	---	10,000 ppm for 1-1/2-2 hrs. caused slight intoxication.
1,1,1,2-Tetrachloro-1,2-Difluoroethane	500 ppm	625 ppm	---	---	10,000 ppm for 1-1/2-2 hrs. caused slight intoxication, but continuous exposure at 5000 ppm (rats) was lethal, causing lung hemorrhage.
Tetraethyl Lead (as Pb) (TEL)	0.008 ppm	0.024 ppm	---	slightly sweet, but not adequate as a warning.	Irritating to eyes, no level located. 7.53 ppm for 1 hr caused illness in man.
Tetramethyl Lead (as Pb)	0.014 ppm	0.042 ppm	---	---	Toxic by inhalation or skin absorption. No irritant level located. 813 ppm was lethal for rats.
Tetramethyl Succinonitrile (TSN) Dinitrile Succinic Acid	0.5 ppm	1.5 ppm	---	almost no odor	Causes headaches, nausea; was lethal to rats by inhalation at 5.5 ppm after 31-46 hrs. 60 ppm was lethal for short-term exposure.
o-Toluidine 2-Aminotoluene o-Methylaniline	5 ppm	10 ppm	---	---	Affects the respiratory tract; causing headache, weakness, breathing difficulty, cyanosis; 6-23 ppm is tolerable for several hours without serious disturbance and 90-140 ppm is endurable for 1 hour.
Tributyl Phosphate	0.46 ppm	1.38 ppm	---	odorless	Heated vapors are very irritating to nose, causing severe general irritation, nausea, headache, but no levels located.

Group 2

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
1,1,2-Trichloroethane Vinyl Trichloride beta-Trichloroethane	10 ppm	20 ppm	400 ppm (for 1,1,1- Trichloro- ethane)	pleasant	Narcotic and irritating to eyes and nose in high concns. Only level located was a lethal dose to rats by inhalation at 2000 ppm.
Trichloroethylene Trichloroethene	100 ppm	150 ppm	60-100 ppm 400 ppm	chloroform-like	Anesthetic effects begin at 400 ppm.
1,1,1,2-Trichloro 1,2,2-Trifluoroethane Freon No. 113	1000 ppm	1250 ppm	---	nearly odorless	1,500 ppm had no effects on humans, but 2,500 was slightly narcotic.
Trifluoromonobromoethane Bromofluoroform Bromotrifluoromethane Freon No. 13B1	1000 ppm	1250 ppm	---	---	No irritation observed to date, and no real pertinent data located.
Trimethyl Benzene Mesitylene 1,3,5-Trimethylbenzene Pseudocumene 1,2,4-Trimethylbenzene	25 ppm	37.5 ppm	---	peculiar	35-50 ppm had no effect, but above that there is possibility of blood effects. Substance does irritate nose, but no level located.
Vinyl Bromide Caig Bromoethylene	250 ppm	312.5 ppm	---	---	Can irritate the eyes, but no level indicated. Rats lost some weight after 20 days exposure to 10,000 ppm, and others had recoverable anesthesia with no effects at 25,000 ppm.

Appendix F
Rationale for Group 3 Contaminants

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Abate	0.82 ppm	2.46 ppm	---	---	Non-irritating.
Aldrin	0.02 ppm	0.06 ppm	---	mild, chemical	1.18 ppm for 84-214 hrs. caused no ill effects. No other levels located; however, it is toxic by all routes and serious effects begin with acute intoxication.
Octalene 1,2,3,4,10,10-Hexachloro-1,4,4a,5,8, 8a-Hexahydro-Endo-Exo-1,4: 5,8- Dimethanonaphthalene					
Ammonium Chloride, fume Sal Ammonia	4.76 ppm	9.52 ppm	---	odorless	No irritant level located. Large ingestion doses can cause nausea, acidosis. LD ₅₀ (rats) was 30 mg/kg
Ammonium Sulfamate Ammate	2.13 ppm	4.26 ppm	---	odorless	Non-irritating. 2% oral dose (rats) for 105 days caused some growth retardation.
Antimony and Compounds (as Sb) (except Stibine)	0.10 ppm	0.30 ppm	---	most cmpds. are odorless	Irritant level is 14.09 ppm (for mg/Sb. Affects skin, respiratory tract.
ANTU Alpha Naphthyl Thiourea 1-(1-Naphthyl)-2-Thiourea	0.036 ppm	0.108 ppm	---	variable	Non-irritating to date. LD ₅₀ (animals) from oral dose of 4,250 mg/kg caused pulmonary edema.
Arsenic and Compounds (except Arsine)	0.163 ppm	0.489 ppm	---	some are odorless; As ₂ O ₃ smells garlic-like	Affects skin, nose, throat, eyes. Some irritation noted at current TLV. Serious effects are delayed and result from chronic exposures (no level given).
Azinphos-Methyl Guthion o,o-Dimethyl-5-(4-Oxobenzotriazino-3-Methyl)Phosphorodithioate Phosphorodithioic Acid, o,o-Dimethyl Ester 5-Ester with 3-(Mercaptomethyl)-1,2,3-Benzotriazin-4(3H)-One	0.02 ppm	0.06 ppm	---	some say odorless, but others say it is definite, "chemical-like"	Toxic to skin and questionable as to respiratory effects. Exposure to 20 ppm (rats) had questionably slight effects.
Barium (soluble compounds)	0.089 ppm	0.267 ppm	---	---	Dusts of Barium Oxide can affect nose and skin, but no levels given. Barium Sulfate dust has caused Baritosis (no level). 5mg/kg given subcutaneously to animals was lethal (Barium Chloride)

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Benzoyl Peroxide Lucidol	0.51 ppm	1.53 ppm	---	---	1.23 ppm can irritate the nose, throat.
Bismuth Telluride Tellurobismuthite	0.306 ppm	0.918 ppm	---	---	Considered inert
Bismuth Telluride (Selenium-doped)	5 mg/m ³	10 mg/m ³	---	---	Animals exposed for 1 yr. to 15 mg/m ³ (1.04 μ particle dia.) had mild and reversible granu- lomatous lesions without fibrosis. No other effect found.
Boron Oxide Boron Monoxide	10 mg/m ³	20 mg/m ³	---	---	470 mg/m ³ caused some nasal irritation in animals.
Cadmium <u>METAL DUSTS ONLY!</u>	0.04 ppm	0.12 ppm	---	---	Irritation is usually latent, but progressive if established. Effects are throat dryness, cough, irritability, chest pain-no level located. Humans developed systemic effects after 20 yrs exposure to 0.65-3.27 ppm.
Calcium Carbonate	2.448 ppm	4.896 ppm	---	odorless	Considered inert, non-irritating, "nuisance" particulate.
Calcium Arsenate Pencal Tricalcium Arsenate	0.06 ppm	0.18 ppm	---	slight lime odor	Contains approx. 20% Arsenic; and Arsenic Trioxide can irritate skin and nose at 0.06 ppm. It is known definitely to cause itching, nausea, headache, but no level located.
Calcium Oxide Lime	2.18 ppm	4.36 ppm	---	---	Affects skin, nose (septum perforation possibly), eyes, respiratory tract. No levels given, but TLV low enough to prevent "undue" irritation.
Carbaryl Sevin®	1.65 ppm	3.3 ppm	---	---	Systemic effects possible before irritation; urinary metabolite (1-Naphthol) noted.

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Carbon Black (amorphous) Channel Black Furnace Carbon Black	3.5 mg/m ³	7 mg/m ³	---	---	No irritation effects or levels located. Animals exposed to 2.5 mg/m ³ for 1,000-1,500 hrs. had some mild ECG changes.
Cellulose (paper fiber)	10 mg/m ³	20 mg/m ³	---	odorless	Non-irritating, inert; classed as a "nuisance" particulate.
Chlordane 1060 Octachlor 1,2,4,5,6,7,8-Octachloro-3a,4,7,7a-Tetrahydro-4, 7-Methapoidan	0.03 ppm	0.09 ppm	---	---	Unable to locate any immediate irritant properties or levels. 5 ppm or less in animal diets for 15-18 mos. caused liver damage. Is toxic also by inhalation, causing irritability, convulsions, depression in acute stage.
Chlorinated Camphene Toxaphene Synthetic 3956 Octachlorocamphene	0.03 ppm	0.09 ppm	---	pleasant, mild piney odor	Absorbed thru skin. No irritant properties or levels located. Oral LD ₅₀ (rats) in 1% oil was 40 mg/kg. Acute poisoning causes convulsions and death due to respiratory failure.
o-Chlorobenzylidene Malonitrile (OCBM)	0.05 ppm	0.15 ppm	0.195 ppm (experienced subjects aware after 1 minute)	---	Irritates eyes(lacrimator), causes headache rapidly, sore throat, salivation; affects skin. Irritation level is 0.19 ppm, and by 0.56-0.87 ppm it is no longer tolerable.
Cotton dust (raw)	0.2 mg/m ³	0.6 mg/m ³	---	odorless	Some people become irritated at 1 mg/m ³ . Lowest reported systemic effect for human was 2.5 mg/m ³ . Affects lungs; may cause byssinosis.
Crag Sesone Sodium 2,4-Dichlorophenoxyethyl Sulfate	0.790 ppm	2.37 ppm	---	odorless	Toxic mainly by ingestion or skin contact; no immediate irritation properties. LD ₅₀ (rats) 730 mg/kg-(kidney and liver).

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
2,4-D Hedonal 2,4-Dichlorophenoxyacetic Acid	1.11 ppm	2.22 ppm	---	---	No human data to date. Can affect the eyes, but no level located. LD ₅₀ /oral/mice was 375 mg/kg.
DDT Pentech Santobane 1,1,1-Trichloro-2,2-Bis(p-Chloro-phenyl) Ethane	0.069 ppm	0.207 ppm	---	---	29.23 ppm began to irritate the eyes of humans after 6 days exp. for 1 hr. daily. Human lethal dose was 250 mg/kg(liver) Early systemic signs are weakness, giddiness, vomiting, tremors, nervousness.
Diazinon Phosphorothioic Acid o,o-Diethyl o-(2-Isopropyl-6-Methyl-4-Pyrimidinyl) Ester	0.008 ppm	0.024 ppm	---	faint, ester-like odor	No irritant properties/levels located. Skin application of 1.1 mg/kg(humans) caused serious poisoning characterized by weakness, headache, nausea, blurred vision, sweating.
Dibrom Naled o,o-Dimethyl-o-(1,2-Dibromo-2,2-Dichloroethyl) Phosphate	0.154 ppm	0.462 ppm	---	---	No unusual human response reported to date. 2.16 ppm for 6 weeks (animals) caused decreased cholinesterase activity, lethargy and obvious discomfort.
Dibutylphthalate n-Butyl Phthalate Phthalic Acid, Dibutyl Ester	0.44 ppm	1.32 ppm	---	odorless	Because of low vapor pressure, any significant inhalation would have to be with spray or mist exposures. Affects eyes(lacrimator, photophobia), nose-no level indicated. 140 mg/kg of ingestion caused nausea, dizziness, eye lacrimation.
1,3-Dichloro-5,5-Dimethyl Hydantoin DCDMH Dactin Halane	0.025 ppm	0.075 ppm	---	---	At 0.24 ppm can irritate the eyes, nose respiratory tract.

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Dieldrin Compound 497 Octalox 1,2,3,4,10,10-Hexachloro-6,7-Epoxy-1, 4,4a,5,6,7,8,8a-Octahydro-Endo- Exo-1,4:5,8-Dimethanonaphthalene	0.02 ppm	0.06 ppm	---	mild, chemical	Can cause headache, nausea, irritability, but no level given. 2.5 ppm(rats) caused increase in liver size.
Dinitrotoluene	0.202 ppm	0.606 ppm	---	---	Can cause headache, fatigue, nau- sea, chest pain, weight loss, but no levels given.
Diphenyl Biphenyl Phenyl Benzene	0.2 ppm	0.6 ppm	---	pleasant, peculiar odor	Irritates eye, nose, throat. Maximum safe level(animals) was below 0.79 ppm.
Diphenyl Amine Phenyl Aniline	1.46 ppm	2.92 ppm	---	floral odor	Can irritate the nose, and bladder symptoms have been noted, but no levels located.
Diquat Reglone 6,7-Dihydrodipyrido(1,2-a:2',1'-c) Pyrazidiinium Dibromide	0.036 ppm	0.108 ppm	---	---	Has produced cataracts in humans, caused respiratory distress, weakness, but no levels indica- ted. Animals exp. to 1.7 mg/ kg/day for 4 years developed NO cataracts.
Emery Natural Corundum Aluminum Oxide alpha-Alumina	10 mg/m ³	20 mg/m ³	---	odorless	Non-irritating, inert; classed as a "nuisance"particulate.
Endosulfan Thiodan 1,4,5,6,7,7-Hexachloro-5-Norbornene- 2,3-Dimethanol Cyclic Sulfite	0.006 ppm	0.018 ppm	---	---	No particular immediate irritant properties, but systemic onset can occur rapidly(convulsions) Inhalation lethal dose for rats was 21.07 ppm in 4 hours.
Endrin 1,2,3,4,10,10-Hexachloro-6,7-Epoxy-1, 4,4a,5,6,7,8,8a-Octahydro-Endo-Endo- 1,4: 5,8-Dimethanonaphthalene	0.006 ppm	0.018 ppm	---	mild, chemical	Mostly absorbed thru skin; can cause hyperirritability, nausea, headache, but no human data level located. 25 ppm in animals' diets for 2 years had moderate toxic effects.0.36ppm inhaled(animals) was fatal after 26 weeks'exp.

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
EPN Phenylphosphonothioic Acid, o-Ethyl o-p-Nitrophenyl Ester.	0.038 ppm	0.114 ppm	---	characteristic, aromatic odor	Can cause sweating, excessive salivation, headache, restlessness, muscle twitch, but no levels given. Humans tolerated 6 mg per day in their diet for 44 days with no effect.
Ethylene Glycol (particulate) 1,2-Ethanediol	3.95 ppm	7.9 ppm	---	sweet taste	Humans exposed to 11.05 ppm for 4 weeks developed sore throat, headache, backache.
Ferbam Ferric Dimethyldithiocarbamate Carbamate Tris(Dimethyldithiocarbamate)Iron	0.588 ppm	1.764 ppm	---	---	Lethal dose for animals was 700-3000 mg/kg-caused damage to upper respiratory tract, skin, nose, kidney damage. No inhal- ation data, irritant properties or other levels located.
Ferrovanadium (dust) Iron meta-Vanadate	1 mg/m ³	3 mg/m ³	---	---	Can affect the lungs, but no immediate irritation levels located. Animals showed no acute intoxication even as high as 10,000 mg/m ³ .
Glass (fibrous, dusts)	10 mg/m ³	20 mg/m ³	---	odorless	No effects at any level found so far with non-respirable particles of 5-7 micrograms. But skin and nose can be irri- tated by non-respirable parti- cles from 9-22 micrograms.
Glycerin Mist Glycerol	10 mg/m ³	20 mg/m ³	---	odorless	No irritant properties/levels located. Classified as a "nuisance" particulate.
Graphite (synthetic)	10 mg/m ³	20 mg/m ³	---	odorless	No irritant properties/levels located. Classified as a "nuisance particulate."
Gypsum Calcium Sulfate (dihydrate)	10 mg/m ³	20 mg/m ³	---	odorless	No irritant properties/levels located. Classified as a "nuisance particulate."

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Heptachlor	0.033 ppm	0.099 ppm	---	mild-camphora- ceous	Toxic by all routes. 1-3 g. on human skin can cause serious symptoms-tremors, ataxia, convulsions, etc.
Hexachloronaphthalene (62% Chlorine)	0.015 ppm	0.045 ppm	---	---	Can cause dermatitis. Human exp. to 0.073-0.146 ppm of mixed penta and hexachloronaphthalene had liver damage.
Hydroquinone p-Dihydroxybenzene 1,4-Benzenediol Hydroquinol Quinol Tecquinol	0.445 ppm	1.335 ppm	---	---	Can cause eye irritation above the TLV, but it is mild and reversible. Human ingestion of 5 g. was fatal. Staining and corneal opacity occurs in workers exposed for prolonged period to vapor concns not high enough to cause systemic effects.
Indium and Compounds, (as In)	0.009 ppm (for In ₂ O ₃ most repre- sentative)	0.027 ppm	---	---	Sol. salts will affect the eyes; metal dusts will affect the lungs. Rats exp. to 2.118-8.56 ppm for 224 hrs. developed lung damage.
Iron salts, soluble, as Fe (Ferric Chloride and Ferric Sulfate are most representative)	0.151 ppm (for Ferric Chloride)	0.453 ppm	---	---	Respiratory tract can be irritated and ingestion can cause severe GIT irritation; the estimated fatal human oral dose is 30 grams.
Kaolin Bolus Alba China Clay (essentially a hydrated aluminum silicate)	10 mg/m ³	20 mg/m ³	---	odorless	Non-irritating, inert; classed as a "nuisance" particulate and a simple asphyxiant.
Lead (inorganic fumes and dusts)	0.018 ppm	0.054 ppm	---	---	In chronic conditions, there have been vague G.I. and CNS complaints (no levels given). Acute poisoning can cause permanent brain damage. Fatal human dose noted at 10 grams (oral).

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Lead Arsenate Schultenite	0.011 ppm	0.033 ppm	---	odorless	Can produce either lead or arsenic intoxication. Only level noted was oral LD ₅₀ (rats) of 100 mg/kg.
Limestone Natural Calcium Carbonate	2.488 ppm	4.896 ppm	---	odorless and tasteless	Non-irritating, inert; classed as a "nuisance" particulate; a simple asphyxiant.
Lindane 1,2,3,4,5,6-Hexachlorocyclohexane	0.042 ppm (but TLV for vapor space treatment as an insecticide is 0.004 ppm)	0.126 ppm AND 0.012 ppm	---	alpha isomer- persistent, acrid odor; beta- isomer, slight musty odor	Irritates eyes, nose throat, may cause dizziness, headache, nausea 50% soln. accidentally sprayed on cattle was fatal. Oral LD ₅₀ (rats) was 125 mg/kg.
Magnesite Magnesium Carbonate Hydroxide	10 mg/m ³	20 mg/m ³	---	odorless	Non-irritating, inert; classed as a "nuisance" particulate, a simple asphyxiant.
Magnesium Oxide fume Magnesia Calcined Magnesia Magcal Magnesia Usta Maglite	5.076 ppm	12.155 ppm	---	odorless and tasteless	No immediate irritation located, but human toxic level (for fibrile reactions and leukocytosis) was 243 ppm.
Malathion 5-(1,2-Dicarbethoxyethyl)0,0-Dimethyldithiophosphate	0.742 ppm	2.16 ppm	---	characteristic, unpleasant	6.289 ppm in the aerosol form irritated the eyes and nose.
Marble Limestone Calcium Carbonate	10 mg/m ³	20 mg/m ³	---	odorless	Non-irritating, inert; classed as a "nuisance particulate."
Methoxychlor Marlate 1,1,1-Trichloro-2,2-Bis(Paramethoxy-phenyl) Ethane	0.709 ppm	2.127 ppm	---	fruity	Some skin irritation has been noted from compd. in solution, but no level indicated. Est. fatal dose for man is 450 gm.
Molybdenum, soluble and insoluble compds.	1.277 ppm (for Mo)	2.554 ppm (for Mo)	---	---	No immediate irritant properties/levels located for humans, but oral doses in cattle caused diarrhea, debilitation, fading of hair color.

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Nicotine	0.075 ppm	0.225 ppm	---	acid, burning taste, odor of pyridine or tobacco	An oral dose of 2-5 mg can be toxic, causing such things as nausea, diarrhea, confusion, twitching. Readily absorbed thru mucous membranes in intact skin.
p-Nitroaniline Fast Red Base GG Diaz Fast Red GG	1 ppm	3 ppm	---	---	Mainly absorbed thru skin, causing cyanosis(acute) and liver damage (chronic). 250 mg/kg was fatal(mouse) by injection.
p-Nitrochlorobenzene 1-Chloro-4-Nitrobenzene	0.155 ppm	0.465 ppm	---	---	0.559 ppm has produced slight toxic effects in humans. Effects are headaches, drowsiness, nau- sea, vomiting, cyanosis.
Octachloronaphthalene Perchloronaphthalene	0.006 ppm	0.018 ppm	---	---	Skin irritation and liver is noted, but no levels have been located.
Oxalic Acid Ethanedioic Acid	0.272 ppm	0.816 ppm	---	---	5-10% solns. irritating to skin after prolonged exposure. Also toxic by ingestion (nausea, diarrhea, gastroenteritis) Est. human fatal oral dose is 700 mg/kg.
Paraquat 1,1'-Dimethyl-4,4'-Bipyridinium Di- chloride or Dimethosulfate	0.5 mg/m ³	1.5 mg/m ³	---	---	No serious injuries reported for 8 years of use-(some nose- bleeds). Toxicity of aerosols is a function of particle size: 0.4 mg/m ³ of particles of respiratory size caused lung irritation, but agricultural use as herbicide would involve primarily non- respirable particles.

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Pentaerythritol Tetramethylolmethane	1.799 ppm	3.598 ppm	---	odorless	No immediate irritating properties /levels located. Acute toxicity can cause diarrhea, ataxia, tremors, vestibular upsets, but only level located was 5 g.toxic (rats) and 16 g. was lethal.
Phenylhydrazine Hydrazinobenzene	5 ppm	10 ppm	---	faint, aromatic odor	Active skin poison. Only level located was an oral LD(rats) of 550 mg/kg.
Phosphoric Acid	0.25 ppm	0.75 ppm	---	---	0.9-2.83 ppm will cause cough; 25 ppm unendurable to all but hardened workers. Also affects skin, nose, eyes.
Phosphorus Pentachloride Phosphoric Chloride	0.118 ppm	0.354 ppm	---	pungent, unpleasant	The hydrolysis product, H_3PO_4 will cause a cough at 0.9 ² 4 2.83 ppm. Also affects eyes, nose.
Phosphorus Pentasulfide	0.11 ppm	0.33 ppm	---	peculiar	In air the compd. forms Phosphorus Pentoxide & Phosphoric Acid which will cause coughing at 0.9-2.83 ppm. In water the compd. forms Hydrogen Sulfide which can irritate the eyes below 20 ppm.
Pival Tri-Ban Pindone 2-Pivalyl-1,3-Indandione	0.011 ppm	0.033 ppm	---	---	Toxicity based on ingestion (oral LD ₅₀ (rats) 280 mg/kg). No apparant immediate irritant properties/levels located.
Plaster of Paris Calcium Sulfate, Hemihydrate	10 mg/m ³	20 mg/m ³	---	odorless	Non-irritating, inert; classed as a "nuisance particulate."
Platinum(soluble salts, as Pt)	0.00025 ppm	0.00075 ppm	---	---	2-20 micrograms/m ³ was blamed for asthma cases in 4 plants.
Pyrethrum Buhach Insect Powder Pyrethrin II Dried Flowers of Chrysanthemum Cinerarefolium, containing about 0.9% Pyrethrins	0.329 ppm	0.987 ppm	---	---	Rats exp. to 395 ppm in oil for 30 mins. developed slight lung congestion. Est. fatal human dose is 1430 mg/kg for a 70 kg. man.

F-11

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
RDX Cyclonite Cyclotrimethylenenitramine Hexahydro-1,3,5-Trinitro-5-Triazine	0.165 ppm	0.495 ppm	---	---	Acute poisoning can cause nausea, convulsions. No readily apparent irritant properties/levels located. Oral LD ₅₀ (rats) was 200 mg/kg.
Rhodium (metal fume, dusts, soluble salts, as Rh)	0.024 ppm (for fumes, dusts) 0.001 mg/m ³ (for soluble salts)	0.072 ppm (for fumes, dusts) 0.003 mg/m ³ (for soluble salts)	---	---	No significant data/reports indicating trouble from any compounds for man.
Ronnel o,o-Dimethyl o-(2,4,5-Trichlorophenyl) Phosphorothioate	0.762 ppm	2.286 ppm	---	---	It is a cholinesterase inhibitor. One oral LD ₅₀ (rats) reported was 1.74 mg/kg.
Rouge Ferric Oxide	10 mg/m ³	20 mg/m ³	---	odorless	Classed as a "nuisance" particulate. No levels given, but benign pneumoconiosis has been noted.
Silicon	8.722 ppm	17.444 ppm	---	---	Considered an inert material. Intracheal injections (animals) of 21.8 ppm caused some pulmonary lesions.
Silicon Carbide	6.114 ppm	12.114 ppm	---	odorless	There were pulmonary effects in humans exposed to 34 mppcf (average 1 micron particle size) for 15 years.
Starch Amylum	10 mg/m ³	20 mg/m ³	---	odorless	Non-irritating, inert; classed as a "nuisance" particulate.
Strychnine	0.011 ppm	0.033 ppm	---	odorless, but bitterness threshold is 1:130,000	Inhalation toxic levels not located, but oral lethal dose for humans is 30-60 mg.
Sucrose Sugar, Cane or Beet	0.755 ppm	2.265 ppm	---	odorless, sweet taste	Non-irritating, inert; classed as a "nuisance" particulate.

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
2,4,5-T 2,4,5-Trichlorophenoxy Acetic Acid	0.959 ppm	2.877 ppm	---	---	Can irritate eyes and cause G.I. disturbances, but no occupational illnesses reported. Oral LD ₅₀ (rats) is 300 mg/kg.
Tantalum (metal and oxide dusts)	0.677 ppm	2.031 ppm	---	---	No occupational illnesses reported. Significant pulmonary effects were caused when oxide dust of 100 mg was administered intratracheal (animals).
TEDP Thiopyrophosphoric Acid, Tetraethyl Ester	0.015 ppm	0.045 ppm	---	---	No immediate irritant properties or levels located. It is a cholinesterase inhibitor. 180 ppm (equiv. to 630 mg/man/day) caused illness and tissue change.
Tellurium	0.019 ppm	0.057 ppm	---	Te is odorless, but H ₂ Te has a strong, offensive odor. Warning of over-exposure could be dry, metallic taste in the mouth.	The current TLV may not be low enough to prevent characteristic "garlic" breath. Main effects are nausea, vomiting-some are irritated at 0.01-0.1 mg/m ³ with repeated exposure.
Tetryl Nitramine 2,4,6-Trinitrophenyl-Methylnitramine	0.128 ppm	0.384 ppm	---	---	The TLV should be low enough to prevent systemic effects, but some sensitization occurs. Main irritant property is contact dermatitis.
Thallium (soluble compounds)	0.1 mg/m ³	0.3 mg/m ³	---	Tl ₂ SO ₄ is odorless	Lowest toxic dose (animals) of Tl was oral, 0.8 mg/kg. Signs of over-exposure include nausea, diarrhea, tingling pain in extremities.
Thiram Bis(Dimethylthiocarbamoyl)Disulfide	0.509 ppm	1.527 ppm	---	odorless	Can irritate nose, throat, skin, but no levels located. LD ₅₀ (rats) was 865 mg/kg; (rabbits) was 210 mg/kg.

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Tin (inorganic cmpds., except SnH_4 and SnO_2 , as Sn)	2 mg/m ³	4 mg/m ³	---	---	Tin Tetrachloride can cause cough at 8.5 ppm. Dose of 25 mg/kg body weight can cause tremors. Most compounds do not show immediate irritant properties before getting to levels of systemic effects.
Tin (organic compounds) Dibutyltin Dilaurate (representative) Tributyltin Chloride (representative)	0.1 mg/m ³	0.3 mg/m ³	---	---	Affects skin; may cause sore throat, cough, vomiting after general exposure in some persons.
Tin Oxide Stannous Oxide	1.819 ppm	3.638 ppm	---	odorless	Non-irritating, inert; classed as a "nuisance" particulate.
Titanium Dioxide Unitane	3.066 ppm	6.132 ppm	---	odorless	It may be a possible respiratory irritant, but no data or levels were located. It is classed as a "nuisance" particulate.
Trichloronaphthalene	0.529 ppm	1.587 ppm	---	---	Noticable effect is a type of dermatitis. Lowest located human inhalation data was systemic effects at 3.175 ppm.
Triorthocresyl Phosphate Tri-o-Tolyl Phosphate Tri-o-Cresyl Phosphate	0.007 ppm	0.021 ppm	---	odorless	Evidently no characteristic irritant properties of a warning type nature. Ingestion causes nausea, diarrhea and can progress to polyneuritis and extremity paralysis. A lethal dose of 1000 mg/kg (oral) has been reported for humans.
Warfarin 3-(alpha-Acetylbenzyl)-4, Hydroxy Coumarin	0.008 ppm	0.024 ppm	---	very faint odor; salty taste	It depresses formation of prothrombin; increases capillary fragility, leading to hemorrhage. Only levels indicated were oral LD ₅₀ (rats) of 25.825 ppm and a MLD (animals) of 1 mg/kg for 5 days.

Group 3

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Zinc Oxide fume	1.505 ppm	3.01 ppm	---	odorless and tasteless	15 mg/m ³ frequently causes chills in humans related to "metal fume fever. Lowest lethal inhalation dose (rats) located was 120 ppm.
Zirconium Compounds, as Zr	1.343 ppm (powder and dust forms) (5 mg/m ³)	2.686 ppm (10 mg/m ³)	---	odorless	No effects located. A lethal injection dose (animals) was given for Zirconium Oxides at 87 mg/m ³ , but no systemic effects noted and no irritant properties or levels located.

Appendix G
Rational for Group 4 Contaminants

Group 4

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
Dimethyl Phthalate (DMP) Phthalic Acid, Dimethyl Ester Dimethyl 1,2-Benzenedicarboxylate	0.631 ppm	1.893 ppm	---	some say none, others say slightly aromatic	Can irritate the nose and eyes, but no levels located. Only figure located was oral LD ₅₀ for rats of 7 ml/kg.
Di-sec Octyl Phthalate (DOP) Di(2-Ethylhexyl)Phthalate Octoil Dioctyl Phthalate Bis(2-Ethylhexyl)Phthalate	0.314 ppm	0.942 ppm	---	---	No irritation found. Expl. fatalities noted, but no levels determined. Dietary ingestion of 0.4% caused some growth retardation.
Methyl Demeton Meta-Systox o-(2(Ethylthio)Ethyl)o,o-Dimethyl Phosphorothioate	0.053 ppm	0.159 ppm	---	---	An alkylsulfonium compd-very high intravenous, skin absorption toxicity. LD ₅₀ -rats-intravenous- 0.02-0.07 mg/kg. No irritation located.
Methyl Parathion Phosphorothioic Acid, o, o-Dimethyl o-p-Nitrophenyl Ester	0.019 ppm	0.057 ppm	---	pungent, garlic-like	Toxic by all routes; irritates eyes, causes headache, dizziness, nausea, labored breathing, but only level located was an oral LD ₅₀ (rats) of 9-25 mg/kg.
Oil Mist (mineral) (vapors&particulate)	5 mg/m ³ (each composition classed according to aromatic hydrocarbon content)	10 mg/m ³	---	---	Some lung-type illness reported from inhalation at average concns below 15 mg/m ³ in industry.
Phthalic Anhydride Phthalic Acid, Anhydride Phthalandione	2 ppm	4 ppm	---	characteristic, choking odor	Irritates the nose at 4.14 ppm; the eyes at 4.96 ppm. Will also affect the throat and cause coughing and sneezing
Quinone 1,4-Benzoquinone 1,4-Cyclohexadienedione	0.1 ppm	0.3 ppm	Not "readily apparent" at 1 ppm and odor fatigue occurs	penetrating chlorine odor	Irritating to eyes above 0.1 ppm; Chronic exposures to 1-2 ppm may cause chronic eye injury.

Group 4

COMPOUND	TLV	EXCURSION FACTOR	ODOR THRESHOLD	ODOR DESCRIPTOR	LOWEST TOXIC LEVEL AND EFFECT LOCATED
2,4,6-Trinitrotoluene (TNT) 1,Methyl-2,4,6-Trinitrobenzene	0.2 ppm	0.6 ppm	---	---	Can cause dermatitis, headaches, weakness, anemia, blue lines on gums and stains on skin and hair Only level located was changes in human hematology noted at 2 mg/m ³ .
Tungsten (soluble & insoluble cmpds) Wolfram	0.666 ppm (for W)	1.998 ppm (for W)	---	---	Only expts. done were by inject- tion, causing incoordination, anorexia, colic, etc. which gave an LD ₅₀ (animals) 105 mg/kg. No irritation or levels located.

Appendix H
Recommendations for Air Cleaners
and
Summary of Air Cleaning and Air Monitoring Equipment
Including
Categorization by Chemical Classes

Abbreviation Code for Contaminant
Detection and Analysis Techniques and Equipment*

1.	Absorption Spectroscopy.....	ABS/SPEC
2.	Amperometric.....	AMP
3.	Chemiluminescence	CHEMILUM
4.	Colorimetry.....	COLORIM
5.	Combustion	CMBST
6.	Correlation Spectroscopy	COR/SPEC
7.	Coulometry.....	COU
8.	Diffusion.....	DIF
9.	Electrical Conductivity	EC
10.	Gas Chromatography/Flame Ionization Detection	GC/FID
11.	Gas Chromatography/Flame Photometric Detection.....	GC/FPD
12.	Gas Chromatography/Helium Ionization.....	GC/HEION
13.	Hydrogen Flame Ionization Detection.....	HFID
14.	Infrared.....	IR
15.	Infrared Spectroscopy	IR/SPEC
16.	Non-Dispersive Infrared.....	NDIR
17.	Non-Dispersive Spectroscopy.....	ND/SPEC
18.	Non-Dispersive Ultra Violet.....	NDUV
19.	Nucleogenic	NUC
20.	Photoionization	PHION
21.	Photometric	PMET
22.	Thermal Conductivity	THERCON
23.	Wet Chemical.....	WCHEM

*Note that the analysis techniques and sensitivities for specific compounds are based on information supplied by manufacturers of air monitoring equipment.

Additional Abbreviation Coding
for
Appendix H

Column 4.....Details of the rationale code for air
cleaning equipment recommendations
are included in Section II of this report.

Columns 9 and 10 "ppm" = "parts per million."
"mdc" = "minimum detectable
concentration."
"fs" = "full scale"

Column 11.....The asterisk, "*" notes which of those
compounds have applicable, available
air cleaning equipment AND air moni-
toring/analysis equipment that met the
criteria outlined in this report.

AC..... Air cleaner

AM Air monitor

Distribution of Group 1, 2, 3, 4 Contaminants
by Chemical Classification

	Group. 1	Group. 2	Group. 3	Group. 4	Total Chem. Class Types
Acids/Anhydrides	2	1	1	1	5
Alcohols	12	6	3	-	21
Aldehydes	3	1	-	-	4
Amines/Imines	8	1	2	-	11
Esters	17	4	1	2	24
Ethers	12	8	1	-	22
Halogen Derivatives	13	21	15	-	49
Hydrocarbons	19	11	1	1	32
Inorganics	6	26	40	1	73
Keto-Esters	-	-	1	-	1
Ketones	12	3	3	1	17
Nitrogen Compounds, Misc.	13	20	13	1	47
Nitrogen and/or Phosphorus and/or Sulfur Combinations	-	-	12	2	14
Organo-Metallic Compounds	1	4	1	-	6
Phenols	2	-	-	-	2
Phosphorus Compounds, Misc.	-	5	3	-	8
Polysaccharides	-	-	4	-	4
Sulfur Compounds	8	5	2		15
Group Totals	128	116	103	9	356

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B. P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Acetaldehyde	none	Adsorber	A-1(c)	44.05	21.0 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Aldehydes
Acetic Acid	7	Adsorber	A-1(b)(c)	60.05	118.0 °C	4	GC/FID HFID IR PHION	0.1 ppm(mdc)	20 ppm(fs)	Acids/Anhydrides *
Acetone	2	Adsorber Absorber	A-1(b)(c) B-1	58.08	56.5 °C	5	GC/FID IR NDIR PHION EMET	0.09 ppm(mdc)	3000 ppm(fs)	Ketones *
Acetonitrile	none	Adsorber	A-1(b)	41.05	81.5 °C	4	EC/WCHEM GC/FID HFID IR	0.1 ppm(mdc)	40 ppm(fs)	N Compounds, Misc.
Acetylene	4	Adsorber	A-1(a)	26.04	-83.6 °C	4	GC/FID IR IR/SPEC NDIR	0.0002ppm (mdc, est)	500 ppm(fs)	Hydrocarbons *
Acrylonitrile	2	Adsorber	A-1(b)(c)	53.06	77.3 °C	5	EC/WCHEM GC/FID IR NDIR	0.1 ppm(mdc)	1000 ppm(fs)	N Compounds, Misc. *
Allyl Alcohol	1	Adsorber	A-1(b)	58.08	96.0 °C to 97.0 °C	4	GC/FID HFID IR PHION	0.1 ppm(mdc)	10 ppm(fs)	Alcohols *
Allyl Glycidyl Ether (AGE)	none	Adsorber	A-1(b)	114.14	153.9 °C	3	GC/FID HFID IR	0.07 ppm(mdc)	5 ppm(fs)	Ethers
Allyl Propyl Disulfide	none	Adsorber	A-1(b)	148.30	-	3	GC/FID HFID PHION	0.1 ppm(mdc)	5 ppm(fs)	Sulfur Compounds

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Ammonia	12	Adsorber	A-1(c)-2-3	17.03	-33.35 °C	11	EC/WCHEM IR IR/SPEC NDIR NDIR/NDUV NUC PHION	0.002 ppm(mdc)	300 ppm(fs)	N Compounds, Misc. *
n-Amyl Acetate	1	Adsorber	A-1(b) (c)	130.18	149.0 °C	4	GC/FID IR NDIR PHION	0.01 ppm(mdc)	1000 ppm(fs)	Esters *
sec-Amyl Acetate	none	Adsorber	A-1(b) (c)	130.18	133.0 °C	3	GC/FID NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Esters
Aniline	1	Adsorber	A-1(b) (c)	93.12	184.0 °C to 186.0 °C	5	GC/FID HFID IR PHION PMET	0.1 ppm(mdc)	11 ppm(fs)	N Compounds, Misc. *
Benzyl Chloride	2	Adsorber	A-1(b)	126.58	179.0 °C	4	EC/WCHEM GC/FID HFID IR	0.1 ppm(mdc)	"Low" ppm	Halogen Deriv. *
Bromoform	none	Adsorber	A-1(b)	252.77	149.0 °C to 150.0 °C	2	EC/WCHEM GC/FID	0.1 ppm(mdc)	"Low" ppm	Halogen Deriv.
1,3-Butadiene	2	Adsorber	A-1(c)	54.09	-4.4 °C	5	GC/FID IR NDIR PHION PMET	0.1 ppm(mdc)	1000 ppm(fs)	Hydrocarbons *
n-Butane	2	Adsorber	A-1(a)	58.12	-0.5 °C	3	GC/FID IR NDIR	0.1 ppm(mdc)	500 ppm(fs)	Hydrocarbons *
2-Butanone	none	Adsorber	A-1(b) (c)	72.10	79.6 °C	4	GC/FID IR NDIR PHION	0.08 ppm(mdc)	1000 ppm(fs)	Ketones

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range			General Chemical Classification
n-Butyl Acetate	none	Adsorber	A-1(b) (c)	116.2	125.0 °C tol 126.0 °C	4	GC/FID IR NDIR PHION	0.1	ppm(mdc)	1000 ppm(fs)	Esters
sec-Butyl Acetate	none	Adsorber	A-1(b) (c)	116.2	112.0 °C tol 113.0 °C	4	GC/FID IR NDIR PHION	0.1	ppm(mdc)	1000 ppm(fs)	Esters
tert-Butyl Acetate	none	Adsorber	A-1(b) (c)	116.2	97.8 °C	4	GC/FID IR NDIR PHION	0.1	ppm(mdc)	1000 ppm(fs)	Esters
Butyl Alcohol	1	Adsorber	A-1(b) (c)	74.12	117.0 °C tol 118.0 °C	4	GC/FID IR NDIR PHION	0.1	ppm(mdc)	1000 ppm(fs)	Esters *
sec-Butyl Alcohol	1	Adsorber	A-1(b) (c)	74.12	99.5 °C	4	GC/FID IR NDIR PHION	0.05	ppm(mdc)	1000 ppm(fs)	Alcohols *
tert-Butyl Alcohol	none	Adsorber	A-1(b) (c)	74.12	82.41 °C	4	GC/FID IR NDIR PHION	0.07	ppm(mdc)	1000 ppm(fs)	Alcohols
n-Butyl Glycidyl Ether (BGE)	none	Adsorber	A-1(b)	130.09	164.0 °C	2	GC/FID NDIR	0.1	ppm(mdc)	500 ppm(fs)	Ethers
Butyl Mercaptan	none	Adsorber	A-1(b), -2	90.19	98.2 °C (@766 mmHg)	4	GC/FID HFID IR PHION	0.08	ppm(mdc)	5 ppm(fs)	Sulfur Compounds
p-tert-Butyltoluene (p-TBT)	none	Adsorber	A-1(b)	148.27	197.0 °C (approx.)	4	GC/FID HFID IR PHION	0.1	ppm(mdc)	10 ppm(fs)	Hydrocarbons

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Carbon Disulfide	none	Adsorber	A-1(c)	76.14	46.3 °C	6	EC/WCHEM IR NDIR PHION	0.1 ppm(mdc)	500 ppm(fs)	Sulfur Compounds
Carbon Tetrachloride	4	Adsorber	A-1(b) (c)	153.94	76.8 °C	5	EC/WCHEM GC/FID IR NDIR	0.06 ppm(mdc)	50 ppm(fs)	Inorganics *
Chlorine Dioxide	5	Absorber	B-2	67.5	11.0 °C	1	WCHEM	Not Given	Same	Inorganics *
Chlorobenzene	1	Adsorber	A-1(b) (c)	112.56	131.0 °C to 132.0 °C	6	EC/WCHEM GC/FID IR NDIR PHION PMET	0.1 ppm(mdc)	750 ppm(fs)	Halogen Deriv. *
Cresol (all isomers)	none	Adsorber	A-1(b) (c)	108.13	117.7 °C to 202.0 °C	4	GC/FID HFID IR PHION	0.1 ppm(mdc)	5 ppm(fs)	Phenols
Crotonaldehyde	none	Adsorber	A-1(b) (c)	70.09	67.7 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	2 ppm(fs)	Aldehydes
Cumene	none	Adsorber	A-1(b)	120.19	152.0 °C to 153.0 °C	5	GC/FID IR NDIR PHION PMET	0.1 ppm(mdc)	500 ppm(fs)	Hydrocarbons
Cyclohexane	1	Adsorber Absorber	A-1(a) (b) (c) B-1	84.16	80.74 °C	4	GC/FID IR NDIR PHION	0.03 ppm(mdc)	1000 ppm(fs)	Hydrocarbons *
Cyclohexanone	none	Adsorber	A-1(b) (c)	98.14	155.6 °C	5	GC/FID HFID IR PHION PMET	0.1 ppm(mdc)	50 ppm(fs)	Ketones

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Cyclohexene	none	Adsorber	A-1 (b) (c)	82.14	-83.0 °C	4	GC/FID IR NDIR PHION	0.02 ppm(mdc)	2000 ppm(fs)	Hydrocarbons
Diacetone Alcohol	none	Adsorber	A-1 (b)	116.16	164.0 °C to 166.0 °C	4	GC/FID HFID IR PHION	0.08 ppm(mdc)	50 ppm(fs)	Alcohols
1,2-Dibromoethane	none	Adsorber	A-1 (b) (c)	187.88	131.0 °C to 132.0 °C	4	EC/WCHEM GC/FID NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.
1,1-Dichloroethane	1	Adsorber	A-1 (b) (c)	98.97	57.0 °C to 59.0 °C	4	EC/WCHEM GC/FID IR NDIR	0.1 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.
1,2-Dichloroethane	none	Adsorber	A-1 (b) (c)	98.97	83.0 °C to 84.0 °C	3	EC/WCHEM GC/FID NDIR	0.1 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.
1,2-Dichloroethylene	none	Adsorber	A-1 (b) (c)	94.93	55.0 °C	5	EC/WCHEM GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.
Diethylamine	none	Adsorber	A-1 (b) (c)	73.4	55.5 °C	4	GC/FID IR NDIR PHION	0.05 ppm(mdc)	25 ppm(fs)	Amines/Imines
Diisobutyl Ketone	none	Adsorber	A-1 (b)	142.24	169.4 °C	3	GC/FID NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Ketones
Diisopropylamine	none	Adsorber	A-1 (b)	101.19	84.0 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	5 ppm(fs)	Amines/Imines

Group 1

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Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range				General Chemical Classification
Dimethylamine	none	Adsorber Absorber	A-3 B-2	45.08	7.0 °C	4	GC/FID HFID PHION WCHEM	0.1 ppm(mdc)	10 ppm(fs)			Amines/Imines
Dimethylaniline	none	Adsorber	A-1(b) (c)	121.18	192.0 °C to 194.0 °C	4	GC/FID HFID PHION PMET	0.1 ppm(mdc)	5 ppm(fs)			N Compounds, Misc.
Dinitrobenzene (all isomers)	none	Adsorber	A-1(b)	168.11	299.0 °C to 319.0 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	5 ppm(fs)			N Compounds, Misc.
Dioxane	none	Adsorber	A-1(b) (c)	88.10	101.0 °C	4	GC/FID IR NDIR PHION	0.05 ppm(mdc)	200 ppm(fs)			Ethers
Ethanolamine	1	Adsorber	A-1(b)	61.08	170.8 °C	2	GC/FID HFID	0.1 ppm(mdc)	10 ppm(fs)			Amines/Imines
2-Ethoxyethanol	none	Adsorber Absorber	A-1(b) (c) B-1	90.12	135.0 °C	3	GC/FID IR NDIR	0.06 ppm(mdc)	1000 ppm(fs)			Ethers
Ethyl Acetate	1	Adsorber	A-1(b) (c)	88.10	77.0 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	400 ppm(fs)			Esters
Ethyl Acrylate (monomer)	none	Adsorber	A-1(b) (c)	100.11	99.4 °C	3	GC/FID IR NDIR	0.04 ppm(mdc)	1000 ppm(fs)			Esters
Ethyl Alcohol	4	Adsorber Absorber	A-1(b) (c) B-1	46.07	78.5 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)			Alcohols
Ethyl sec-Amyl Ketone	none	Adsorber	A-1(b)	128.21	157.0 °C to 162.0 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	25 ppm(fs)			Ketones

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Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range				General Chemical Classification
Ethyl Benzene	none	Adsorber	A-1(a) (b) (c) B-1	106.16	136.0 °C	3	GC/FID NDIR PMET	0.1 ppm (mdc)	1000 ppm (fs)			Hydrocarbons
Ethyl Butyl Ketone (EBK)	none	Adsorber	A-1(b)	114.18	150.0 °C	4	GC/FID HFID IR PHION	0.1 ppm (mdc)	50 ppm (fs)			Ketones
Ethyl Ether	1	Adsorber	A-1(c)	74.12	34.6 °C	4	GC/FID IR NDIR PHION	0.06 ppm (mdc)	1000 ppm (fs)			Ethers *
Ethyl Mercaptan	none	Adsorber	A-1(b) (c) -3	62.13	34.7 °C to 35.04 °C	3	GC/FID HFID PHION	0.1 ppm (mdc)	10 ppm (fs)			Sulfur Compounds
Ethyl Silicate	none	Adsorber	A-1(b)	208.33	165.0 °C to 166.0 °C	2	IR NDIR	0.02 ppm (mdc)	500 ppm (fs)			Organo-Metallics
Ethylene	3	Adsorber	A-1(a)	28.05	103.9 °C	4	GC/FID IR IR/SPEC NDIR	0.1 ppm (mdc)	1000 ppm (fs)			Hydrocarbons *
Ethylene Diamine	none	Adsorber	A-1(b)	60.10	116.0 °C to 117.0 °C	3	GC/FID HFID PHION	0.1 ppm (mdc)	10 ppm (fs)			Amines/Imines
Ethylene Glycol (vapor)	4	Adsorber	A-1(b)	62.07	197.6 °C	2	GC/FID HFID	0.1 ppm (mdc)	100 ppm (fs)			Alcohols *
Ethylene Glycol Monomethyl Ether Acetate	none	Adsorber	A-1(b) (c)	118.13	143.0 °C	3	GC/FID HFID IR	0.02 ppm (mdc)	25 ppm (fs)			Esters
n-Ethylmorpholine	none	Adsorber	A-1(b)	115.18	138.0 °C to 139.0 °C (@763 mmHg)	2	GC/FID HFID	0.1 ppm (mdc)	20 ppm (fs)			N Compounds, Misc.
Furfural	1	Adsorber	A-1(b)	96.08	161.8 °C	5	GC/FID HFID IR PHION PMET	0.1 ppm (mdc)	5 ppm (fs)			Aldehydes *

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Heptane	2	Adsorber Absorber	A-1(a)(b)(c) B-1	100.20	98.4 °C	5	GC/FID IR NDIR PHION	0.01 ppm(mdc)	500 ppm(fs)	Hydrocarbons *
2-Hexanone	none	Adsorber	A-1(b)(c)	100.16	127.5 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Ketones
Hexone	none	Adsorber	A-1(b)(c)	100.16	117.0 °C to 118.0 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Ketones
Hydrogen Bromide	none	Adsorber Absorber	A-1(c), -3 B-2	80.92	-66.8 °C	2	EC/WCHEM	<0.1 ppm(mdc)	"low" ppm	Inorganics
Hydrogen Cyanide	6	Adsorber Absorber	A-1(c), -3 B-2	27.03	26.0 °C	4	AMP EC/WCHEM IR	<0.1 ppm(mdc)	50 ppm(fs)	N Compounds, Misc. *
Hydrogen Fluoride	5	Adsorber Absorber	A-3 B-2	20.01	19.7 °C	4	EC/WCHEM PMET	<0.1 ppm(mdc)	"low" ppm	Inorganics *
Hydrogen Sulfide	13	Adsorber Absorber	A-3 B-2	34.08	-60.7 °C	16	AMP DIF EC/WCHEM GC/FID GC/FPD IR/SPEC NDIR/NDUV PHION PMET	0.0025 ppm(mdc)	50 ppm(fs)	Sulfur Compounds *
Indene	none	Adsorber	A-1(b)	116.15	181.6 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	10 ppm(fs)	Hydrocarbons
Isoamyl Acetate	none	Adsorber	A-1(b)	130.09	120.0 °C 145.0 °C (commercial)	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Esters

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range				General Chemical Classification
Isoamyl Alcohol	none	Adsorber	A-1(b)	88.15	132.0 °C	4	GC/FID IR NDIR PHION	0.1	ppm(mdc)	1000	ppm(fs)	Alcohols
Isobutyl Acetate	none	Adsorber	A-1(b)	116.16	118.0 °C	4	GC/FID IR NDIR PHION	0.02	ppm(mdc)	1000	ppm(fs)	Esters
Isobutyl Alcohol	none	Adsorber	A-1(b)	74.12	108.0 °C	4	GC/FID IR NDIR PHION	0.1	ppm(mdc)	1000	ppm(fs)	Alcohols
Isophorone	none	Adsorber	A-1(b) (c)	138.22	210.0 °C to 215.0 °C	3	GC/FID HFID IR	0.1	ppm(mdc)	25	ppm(fs)	Ketones
Isopropyl Acetate	none	Adsorber	A-1(b) (c)	102.13	89.0 °C	4	GC/FID IR NDIR PHION	0.02	ppm(mdc)	1000	ppm(fs)	Alcohols
Isopropyl Alcohol	2	Adsorber Absorber	A-1(b) (c) B-1	60.09	82.5 °C	4	GC/FID IR NDIR PHION	0.1	ppm(mdc)	1000	ppm(fs)	Alcohols *
Isopropylamine	none	Adsorber	A-1(b)	59.08	33.0 °C to 34.0 °C	4	GC/FID IR NDIR PHION	0.1	ppm(mdc)	10	ppm(fs)	Amines/Imines
Isopropylether	1	Adsorber	A-1(b) (c)	102.17	68.0 °C to 69.0 °C	4	GC/FID IR NDIR PHION	0.07	ppm(mdc)	500	ppm(fs)	Ethers *
Isopropyl Glycidyl Ether (IGE)	none	Adsorber	A-1(b)	116.16	137.0 °C	2	GC/FID NDIR	0.1	ppm(mdc)	500	ppm(fs)	Ethers
Lithium Hydride	none	-	-	7.95	-	none	-	-	-	-	-	Inorganics

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range				General Chemical Classification
Maleic Anhydride	3	Adsorber	A-1(b)	98.06	202.0 °C	3	GC/FID HFID PHION	0.1 ppm (dc)	5	ppm (fs)		Acids/Anhydrides *
Mesityl Oxide	none	Adsorber	A-1(b) (c)	98.14	129.5 °C	4	GC/FID HFID IR PHION	0.08 ppm (mdc)	25	ppm (fs)		Ethers
Methyl Acetate	none	Adsorber Absorber	A-1(b) (c) B-1	74.08	57.0 °C to 59.0 °C	4	GC/FID IR NDIR PHION	0.1 ppm (mdc)	1000	ppm (fs)		Esters
Methyl Acrylate	none	Adsorber	A-1(b) (c)	86.09	70.0 °C	4	GC/FID HFID IR PHION	0.003 ppm (mdc)	10	ppm (fs)		Esters
Methylamine	none	Adsorber Absorber	A-3 B-2	31.06	-6.3 °C	5	GC/FID HFID IR PHION WCHEM	0.1 ppm (mdc)	20	ppm (fs)		Amines/Imines
Methyl 2-Cyanoacrylate	none	Adsorber	A-1(b)	110.10	47.0 °C to 49.0 °C (@1.8 mmHg)	2	GC/FID HFID	0.1 ppm (mdc)	5	ppm (fs)		Esters
Methyl Isoamyl Ketone	none	Adsorber	A-1(b)	114.20	-	3	GC/FID HFID PHION	0.1 ppm (mdc)	10	ppm (fs)		Ketones
Methyl n-Amyl Ketone	none	Adsorber	A-1(b)	114.18	151.5 °C	4	GC/FID IR NDIR PHION	0.1 ppm (mdc)	1000	ppm (fs)		Ketones
Methyl Chloride	1	Adsorber	A-1(c)	50.49	-24.0 °C	5	EC/WCHEM GC/FID IR NDIR	0.1 ppm (mdc)	500	ppm (fs)		Halogen Deriv. *
Methyl Chloroform	none	Adsorber	A-1(b) (c)	133.42	74.1 °C	4	EC GC/FID IR NDIR	0.05 ppm (mdc)	350	ppm (fs)		Halogen Deriv.

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range				General Chemical Classification
Methyl Cyclohexane	none	Adsorber	A-1(b)(c)	98.07	-	4	GC/FID IR NDIR PHION	0.04 ppm(mdc)	500	ppm(fs)		Hydrocarbons
Methyl Isobutyl Carbinol (MIBC)	none	Adsorber	A-1(b)	102.06	132.0 °C	4	GC/FID HFID IR PHION	0.1 ppm(mdc)	25	ppm(fs)		Alcohols
Methyl Mercaptan	none	Adsorber	A-1(c)	48.11	5.95°C	5	GC/FID GC/FPD HFID IR PHION	0.001 ppm(mdc)	10	ppm(fs)		Sulfur Compounds
Methyl Methacrylate	1	Adsorber	A-1(b)	100.01	100.0 °C to 101.0 °C	4	GC/FID IR NDIR PHION	0.03 ppm(mdc)	500	ppm(fs)		Esters *
Methylene Chloride	1	Adsorber	A-1(b)(c)	84.94	39.75°C	4	EC GC/FID IR NDIR	0.1 ppm(mdc)	500	ppm(fs)		Halogen Deriv. *
Morpholine	none	Adsorber	A-1(b)	87.12	128.9 °C	3	GC/FID HFID IR	0.1 ppm(mdc)	20	ppm(fs)		N Compounds, Misc.
Naphthalene	none	Adsorber	A-1(a)(b)(c)	128.16	217.9 °C	3	GC/FID HFID PMET	0.1 ppm(mdc)	10	ppm(fs)		Hydrocarbons
Nitric Oxide	7	Adsorber Absorber	A-3 B-2	30.01	-151.7 °C	19	CHEMILUM COLORIM EC/WCHEM IR IR/SPEC NDIR/NDUV ND/SPEC PHION	0.002 ppm(mdc)	25	ppm(fs)		N Compounds, Misc. *

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Nitromethane	none	Adsorber	A-1 (b) (c)	61.04	101.2 °C	3	GC/FID IR NDIR	0.1 ppm(mdc)	200 ppm(fs)	N Compounds, Misc.
Octane	none	Adsorber Absorber	A-1 (a) (b) (c) B-1	114.22	125.6 °C	4	GC/FID IR NDIR PHION	0.02 ppm(mdc)	400 ppm(fs)	Hydrocarbons.
PenLane	1	Adsorber Absorber	A-1 (a) (b) (c) B-1	72.15	36.1 °C	4	GC/FID IR NDIR PHION	0.02 ppm(mdc)	500 ppm(fs)	Hydrocarbons *
2-Pentanone	none	Adsorber	A-1 (b) (c)	86.13	101.7 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Ketones
Perchloroethylene	none	Adsorber	A-1 (b) (c)	165.85	121.0 °C	5	EC GC/FID IR NDIR PHION	0.05 ppm(mdc)	200 ppm(fs)	Halogen Deriv.
Phenol	3	Adsorber	A-1 (b) (c)	94.11	182.0 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	5 ppm(fs)	Phenols *
Phenyl Ether (vapor)	none	Adsorber	A-1 (b)	170.20	259.0 °C	4	GC/FID HFID IR PHION	0.02 ppm(mdc)	2 ppm(fs)	Ethers
Phenyl Ether-Di- phenyl Mixture	none	Adsorber	A-1 (b)	170.20	253.0 °C to 259.0 °C	2	GC/FID HFID	0.1 ppm(mdc)	2 ppm(fs)	Ethers
n-Propyl Acetate	none	Adsorber	A-1 (b)	102.14	101.6 °C	4	GC/FID IR NDIR PHION	0.02 ppm(mdc)	1000 ppm(fs)	Esters
n-Propyl Alcohol	2	Adsorber Absorber	A-1 (b) (c) B-1	60.09	97.0 °C to 98.0 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Alcohols *

Group 1

Compound	No. AC Mfgs.	AC Type Recommen- dation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Propylene Di- chloride	1	Adsorber	A-1(b) (c)	112.99	95.0 °C to 96.0 °C	4	EC GC/FID IR NDIR	0.1 ppm(mdc)	500 ppm(fs)	Halogen Deriv. *
1,2-Propylene Oxide	none	Adsorber	A-1(a) (b)	58.08	35.0 °C	3	GC/FID IR NDIR	0.1 ppm(mdc)	1000 ppm(fs)	Ethers
Pyridine	1	Adsorber	A-1(a) (b) (c)	79.10	115.0 °C to 116.0 °C	5	GC/FID HFID IR PHION FMET	0.1 ppm(mdc)	5 ppm(fs)	N Compounds, Misc. *
Selenium Cmpds. (as Se)	none	-	-	78.96 (Se)	685.0 °C (red form)	1	PHION	0.1 ppm(mdc)	Same	Inorganics
Sulfur Dioxide	29	Adsorber Absorber	A-2, -3 B-2	64.07	-10.0 °C	17	ABS/SPEC COLORIM COR/SPEC COU GC/FID GC/FPD IR IR/SPEC NUC WCHEM/EC	0.001 ppm(mdc)	"low" ppm	Sulfur Compounds *
Sulfuric Acid	18	Adsorber Absorber	A-1(b) (c), -2, -3 B-2	98.08	209.0 °C	2	EC/WCHEM	"low" ppm	Not Given	Sulfur Compounds *
Tetrahydrofuran	none	Adsorber Absorber	A-1(b) B-1	72.10	66.0 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Ethers
Tetranitromethane	none	Adsorber	A-1(a) (b)	196.04	126.0 °C	1	GC/FID	0.1 ppm(mdc)	Same	N Compounds, Misc.
Toluene	2	Adsorber	A-1(a) (b) (c)	92.13	109.0 °C 111.0 °C (commercial)	5	GC/FID IR NDIR PHION	0.1 ppm(mdc)	500 ppm(fs)	Hydrocarbons *

Group 1

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
1,2,3-Trichloropropane	none	Adsorber	A-1(b)	177.44	156.0 °C	4	EC GC/FID IR NDIR	0.1 ppm(mdc)	500 ppm(fs)	Halogen Deriv.
Triethylamine	none	Adsorber	A-1(b)	101.19	89.0 °C to 90.0 °C	4	GC/FID HFID IR PHION	0.1 ppm(mdc)	25 ppm(fs)	Amines/Imines
Turpentine	1	Adsorber	A-1(b)	136.23	156.0 °C to 170.0 °C	3	GC/FID NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Hydrocarbons *
Vinyl Acetate	none	Adsorber	A-1(b)	86.09	72.0 °C to 73.0 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	10 ppm(fs)	Esters
Vinyl Toluene	none	Adsorber	A-1(b)	118.19	-	3	GC/FID NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Hydrocarbons
Xylene	none	Adsorber	A-1(a) (b) (c)	106.16	137.0 °C 140.0 °C	5	GC/FID IR NDIR PHION PMET	0.1 ppm(mdc)	500 ppm(fs)	Hydrocarbons

Group 2

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range			General Chemical Classification
Acrolein	none	Adsorber	A-1(b) (c)	56.06	52.7 °C	3	GC/FID IR PHION	0.1 ppm (mdc)	Same		Aldehydes
Acrylamide	none	Adsorber	A-1(b)	71.08	125.0 °C (@25 mmHg)	2	GC/FID PHION	0.1 ppm (mdc)	Same		N Compounds, Misc.
2-Aminopyridine	none	Adsorber	A-1(b)	94.11	210.6 °C	2	GC/FID PHION	0.1 ppm (mdc)	Same		N Compounds, Misc.
Argon	none	-	-	39.948	87.29°K	none	-	-	-		Inorganics
Arsine	1	Adsorber	A-1(b), -3	77.93	-55.0 °C to -62.5 °C	none	-	-	-		Inorganics
Boron Tribromide	none	Adsorber	A-1(b)	250.57	90.0 °C	none	-	-	-		Inorganics
Bromine	2	Adsorber	A-1(b)	160.0	59.0 °C	4	EC/WCHEM PHION	0.005 ppm (mdc)	"low" ppm (mdc)		Inorganics *
Bromine Penta-fluoride	none	Adsorber	A-1(b)	174.92	40.5 °C	2	EC/WCHEM	"low" ppm (mdc)	not given		Inorganics
Butoxy Ethanol	none	Adsorber	A-1(b) (c)	118.17	171.2 °C	4	GC/FID HFID IR PHION	0.08 ppm (mdc)	50 ppm (fs)		Ethers
Carbon Dioxide	9	Absorber	B-1	44.01	-78.5 °C (sublimes)	6	GC/FID IR NDIR WCHEM	0.05 ppm (mdc)	5000 ppm (fs)		Inorganics *
Carbon Monoxide	3	Adsorber	A-3	28.01	-197.0 °C	16	CMBST EC GC/FID GC/FPD IR IR/SPEC NDIR THERCON	0.001 ppm (mdc)	50 ppm (fs)		Inorganics *
Chlorine	14	Adsorber	A-1(b) (c)	70.906	-34.6 °C	6	EC/WCHEM AMP	0.005 ppm (mdc)	5 ppm (fs)		Inorganics *
Chlorobromomethane	none	Adsorber	A-1(b)	129.39	68.11 °C	none	-	-	-		Halogen Deriv.

Group 2

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Chlorodiphenyl (42% Chlorine)	none	Adsorber	A-1 (b)	247.53	325.0 °C to 366.0 °C (distillation range)	none	-	-	-	Halogen Deriv.
Chlorodiphenyl (54% Chlorine)	none	Adsorber	A-1 (b)	326.45	365.0 °C to 390.0 °C (distillation range)	none	-	-	-	Halogen Deriv.
Chloropicrin	none	Adsorber	A-1 (b) (c)	164.39	112.0 °C	1	GC/FID	0.1 ppm(mdc)	Same	N Compounds, Misc.
Chloroprene	none	Adsorber	A-1 (b)	88.54	59.4 °C	5	EC GC/FID IR NDIR PHION	0.1 ppm(mdc)	500 ppm(fs)	Halogen Deriv.
Cyanogen	5	Absorber Adsorber	E-1, -2 A-1 (c)	52.04	-21, 17 °C	2	EC WCHEM	<1 ppm(mdc)	"low" ppm(mdc)	N Compounds, Misc. *
Cyclohexanol	none	Adsorber	A-1 (b) (c)	100.16	160.0 °C to 165.0 °C	4	GC/FID HFID IR PHION	0.1 ppm(mdc)	50 ppm(fs)	Alcohols
Cyclopentadiene	none	Adsorber	A-1 (b)	66.10	41.5 °C to 42.0 °C	4	GC/FID HFID PHION PMET	0.1 ppm(mdc)	75 ppm(fs)	Hydrocarbons
Decaborane (14)	none	Adsorber	A-1 (b)	122.31	213.0 °C	none	-	-	-	Inorganics
Diazomethane	none	Adsorber	A-3	42.04	-23.0 °C	none	-	-	-	N Compounds, Misc.
Diborane (6)	none	Adsorber	A-1 (c)	27.69	-92.5 °C	none	-	-	-	Inorganics
2-n-Dibutylamino-ethanol (DBAE)	none	Adsorber	A-1 (b)	173.34	-	3	GC/FID HFID PHION	0.1 ppm(mdc)	5 ppm(fs)	N Compounds, Misc.
Dibutyl Phosphate	none	Adsorber	A-1 (b)	210.20	-	none	-	-	-	P Compounds, Misc.
Dichlorodifluoromethane	1	Adsorber	A-1 (b) (c)	120.92	-29.8 °C	4	EC GC/FID IR NDIR	0.08 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.

Group 2

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range				General Chemical Classification
Dichloroethyl Ether	none	Adsorber	A-1(b) (c)	143.02	143.02 °C	5	EC GC/GID HFID IR PHION	0.06	ppm (mdc)	10	ppm (fs)	Ethers
Dichloromono-fluoromethane	none	Adsorber	A-1(b) (c)	102.91	9.0 °C	4	EC GC/FID IR NDIR	0.08	ppm (mdc)	1000	ppm (fs)	Halogen Deriv.
Dichlorotetra-fluoroethane	none	Adsorber	A-1(b) (c)	170.88	3.55 °C	4	EC GC/FID IR NDIR	0.02	ppm (mdc)	1000	ppm (fs)	Halogen Deriv.
2-Diethylamino Ethanol	none	Adsorber	A-1(b)	117.19	163.0 °C	3	GC/FID HFID PHION	0.1	ppm (mdc)	10	ppm (fs)	N Compounds, Misc.
Difluorodibromomethane	none	Adsorber	A-1(b)	209.79	24.5 °C	3	EC GC/FID NDIR	0.1	ppm (mdc)	100	ppm (fs)	Halogen Deriv.
1,1-Dimethylhydrazine	none	Adsorber	A-1(b)	60.10	63.3 °C	2	HFID PHION	0.5	ppm (mdc)	10	ppm (fs)	N Compounds, Misc.
Dipropylene Glycol Methyl Ether	none	Adsorber	A-1(b)	148.20	-	2	GC/FID NDIR	0.1	ppm (mdc)	1000	ppm (fs)	Ethers
Ethane	1	Adsorber	A-1(a), -3	30.07	-88.0 °C	3	GC/FID IR NDIR	0.1	ppm (mdc)	1000	ppm (fs)	Hydrocarbons *
2-Ethoxyethylacetate	none	Adsorber	A-1(b) (c)	132.16	156.4 °C	3	GC/FID IR NDIR	0.03	ppm (mdc)	1000	ppm (fs)	Esters
Ethylamine	none	Adsorber	A-1(c)	45.08	16.6 °C	4	GC/FID HFID IR PHION	0.1	ppm (mdc)	20	ppm (fs)	Amines/Imines

Group 2

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Ethyl Bromide	none	Adsorber	A-1(b) (c)	108.98	38.4 °C	5	EC GC/FID NDIR PHION WCHEM	0.1 ppm(mdc)	5000 ppm(fs)	Halogen Deriv.
Ethyl Chloride	none	Adsorber	A-1(b) (c)	54.52	12.3 °C	5	EC/WCHEM GC/FID IR NDIR	0.1 ppm(mdc)	5000 ppm(fs)	Halogen Deriv.
Ethyl Formate	none	Adsorber	A-1(b) (c)	74.08	54.3 °C	4	GC/FID HFID IR PHION	0.06 ppm(mdc)	100 ppm(fs)	Esters
Ethylene Chloro- hydrin	none	Adsorber	A-1(b)	80.52	128.7 °C	5	EC GC/FID HFID IR PHION	0.08 ppm(mdc)	20 ppm(fs)	Halogen Deriv.
Ethylene Oxide	none	Adsorber Absorber	A-1(c) B-1	44.05	10.7 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	500 ppm(fs)	Ethers
Fluorine (as F ₂)	3	Adsorber	A-1(b) (c)	56.995	-188.0 °C	2	EC	0.005 ppm(mdc)	"low" ppm	Inorganics *
Fluorotrichloro- methane	none	Adsorber	A-1(b) (c)	137.38	23.8 °C	5	EC/WCHEM GC/FID IR NDIR	0.01 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.
Formic Acid	2	Adsorber	A-1(b) (c)	46.02	100.5 °C	3	HFID IR IR/SPEC	0.0008 ppm(mdc) (est)	25 ppm(fs)	Acids/Anhydrides *
Furfuryl Alcohol	1	Adsorber	A-1(b)	98.10	170.0 °C	4	GC/FID HFID IR PHION	0.1 ppm(mdc)	20 ppm(fs)	Alcohols *

Group 2

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Gasoline	1	Adsorber	A-1(b)(c)	various	39.0 °C (initial) 204.0 °C (final)	3	GC/FID NDIR PHION	0.1 ppm(mdc)	800 ppm(fs)	Hydrocarbons *
Germanium Tetrahydride	none	Adsorber	A-1(b)	76.63	-90.0 °C	none	-	-	-	Inorganics
Glycidol	none	Adsorber Absorber	A-1(b) B-1	74.08	167.0 °C (decomposes)	3	GC/FID HFID IR	0.1 ppm(mdc)	50 ppm(fs)	Alcohols
Helium	1	-	-	4.003	-268.94 °C	1	GC/HEION	0.1 ppm(mdc)	Same	Inorganics *
Hexafluoroacetone (HFA)	none	Adsorber	A-1(b)	166.03	-	none	-	-	-	Ketones
sec-Hexyl Acetate	none	Adsorber	A-1(b)	144.12	-	4	GC/FID GC/HEION HFID IR PHION	0.1 ppm(mdc)	50 ppm(fs)	Esters
Hydrogen	4	Adsorber	A-3	1.008	-252.7 °C	1	GC/HEION	0.1 ppm(mdc)	Same	Inorganics *
Hydrogen Peroxide (90%)	4	Absorber	B-1	34.02	140.0 °C (calc.)	1	WCHEM	0.1 ppm(mdc)	Same	Inorganics *
Hydrogen Selenide	none	Adsorber	A-1(b)(c)	80.98	-42.0 °C	1	PHION	0.1 ppm(mdc)	Same	Inorganics
Iron Pentacarbonyl	none	Adsorber	A-1(b)	195.90	103.0 °C	none	-	-	-	Inorganics
Ketene	none	Absorber	B-1,-2	42.04	-56.0 °C	2	HFID PHION	0.3 ppm(mdc)	10 ppm(fs)	Ketones
L.P.G.	none	Adsorber Absorber	A-1(c) B-1	various	-	3	GC/FID IR NDIR	0.1 ppm(mdc)	1000 ppm(fs)	Hydrocarbons
Mercury (Alkyl Compounds)	none	Adsorber	A-1(b)	various	Various	none	-	-	-	Organo-Metallics
Mercury (All forms except Alkyls)	2	Adsorber	A-3	200.57 (Hg)	356.58 °C (Hg)	1	PMET	0.0018 ppm(fs)	Same	Inorganics *
Methane	1	Adsorber	A-1(a),-3	16.04	-161.4 °C	7	GC/FID GC/FPD IR IR/SPEC NDIR	0.02 ppm(fs)	1000 ppm(fs)	Hydrocarbons *

Group 2

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
2-Methoxyethanol	none	Adsorber	A-1(b) (c)	76.09	124.5 °C	4	GC/FID HFID IR PHION	0.05 ppm(mdc)	25 ppm(fs)	Ethers
Methyl Acetylene	none	Adsorber	A-1(c)	40.06	-27.5 °C	4	GC/FID IR NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Hydrocarbons
Methyl Acetylene-Propadiene Mixture (MAPP)	none	Adsorber	A-1(c)	40.06	-34.3 °C (Propadiene)	2	GC/FID NDIR	0.1 ppm(mdc)	1000 ppm(fs)	Hydrocarbons
Methyl Acrylonitrile	none	Adsorber	A-1(b)	68.11	-	3	GC/FID HFID PHION	0.1 PPM(mdc)	10 ppm(fs)	N Compounds, Misc.
Methylal	none	Adsorber	A-1(b)	76.09	42.3 °C	3	GC/FID IR NDIR	0.1 ppm(mdc)	1000 ppm(fs)	Ethers
Methyl Alcohol	4	Adsorber Absorber	A-1(b) (c) B-1	32.04	64.7 °C	3	GC/FID IR NDIR	0.1 ppm(mdc)	500 ppm(fs)	Alcohols *
Methylcyclohexanol	none	Adsorber	A-1(b) (c)	114.18	165.0 °C to 173.0 °C	4	GC/FID HFID IR PHION	0.1 ppm(mdc)	50 ppm(fs)	Alcohols
o-Methyl Cyclohexanone	none	Adsorber	A-1(b) (c)	112.18	163.0 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	50 ppm(fs)	Ketones
2-Methylcyclopentadienyl Manganese Tri-carbonyl (as Mn)	none	Adsorber	A-1(b)	218.10	-	none	-	-	-	Organo-Metallics
Methyl Formate	none	Adsorber	A-1(b) (c)	60.05	31.8 °C	3	GC/FID IR NDIR	0.1 ppm(mdc)	1000 ppm(fs)	Esters

Group 2

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Methyl Isocyanate	none	Adsorber	A-1(b)	57.05	43.0 °C to 45.0 °C	1	PHION	0.2 ppm (mdc)	Same	N Compounds, Misc.
Naphtha (Coal Tar)	1	Adsorber	A-1(c)	various	-	2	NDIR PHION	0.5 ppm (mdc)	1000 ppm (fs)	Hydrocarbons *
Neon	none	-	-	20.183	-245.92 °C	1	GC/HEION	0.1 ppm (mdc)	Same	Inorganics
Nitric Acid	13	Adsorber	A-3	53.02	86.0 °C (anhydrous)	2	IR/SPEC WCHEM	0.6 ppm (mdc) (est)	Not Given	N Compounds, Misc. *
Nitrobenzene	1	Adsorber	A-1(b) (c)	123.11	210.9 °C	4	GC/FID HFID IR PHION	0.1 ppm (mdc)	10 ppm (fs)	N Compounds, Misc. *
Nitroethane	none	Adsorber	A-1(b) (c) (USE EXTREME CAUTION W/ACTIVATED CARBON OR HOPCALITE)	75.07	114.0 °C	3	GC/FID IR NDIR	0.1 ppm (mdc)	500 ppm (fs)	N Compounds, Misc.
Nitrogen	none	-	-	14.008	-195.80 °C	1	GC/HEION	0.1 ppm (mdc)	Same	Inorganics
Nitrogen Tri-fluoride	none	Adsorber	A-1(b)	71.01	-129.0 °C	3	GC/WCHEM NDIR	"low" ppm	50 ppm (fs)	N Compounds, Misc.
1-,2-Nitropropane	none	Adsorber	A-1(b) (c)	89.09	120.0 °C to 132.0 °C	2	GC/FID HFID	0.1 ppm (mdc)	25 ppm (fs)	N Compounds, Misc.
3- or m-Nitrotoluene	none	Adsorber	A-1(b) (c)	137.13	231.9 °C	4	GC/FID HFID IR PHION	0.1 ppm (mdc)	5 ppm (fs)	N Compounds, Misc.
Nitrous Oxide	1	Absorber	B-1,-2	44.02	-88.46 °C	5	IR NDIR NDIR/NDUV WCHEM	<1 ppm (mdc)	1000 ppm (fs)	N Compounds, Misc. *
Osmium Tetroxide	none	Adsorber	A-1(b)	254.20	131.2 °C	none	-	-	-	Inorganics

Group 2

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Oxygen Difluoride	none	Absorber	B-1	54.0	-145.0 °C	none	-	-	-	Inorganics
Pentaborane (9)	none	Absorber	A-1(b)	63.17	58.4 °C	none	-	-	-	Inorganics
Perchloromethyl Mercaptan	none	Absorber	A-1(b)	151.43	-	1	GC/FID	0.1 ppm(mdc)	Same	Sulfur Compounds
Perchloryl Fluoride	none	Absorber	A-1(b)	102.46	-46.8 °C	1	EC	"low" ppm	Same	Inorganics
Petroleum Distillates (Naphtha)	none	Absorber	A-1(b) (c)	various	60.0 °C to 160.0 °C	3	IR NDIR PHION	0.02 ppm(mdc)	500 ppm(fs)	Hydrocarbons
Phenyl Glycidal Ether (PGE)	none	Absorber	A-1(b)	150.19	-	2	GC/FID HFID	0.1 ppm(mdc)	10 ppm(fs)	Ethers
Phosdrin	none	Absorber	A-1(b)	224.16	106.0 °C to 107.5 °C (@1 mmHg)	none	-	-	-	P Compounds, Misc.
Phosgene	2	Absorber	A-1(b) (c)	144.01	8.3 °C	4	EC/WCHEM IR/SPEC	0.001 ppm(mdc)	"low" ppm	Halogen Deriv. *
Phosphine	none	Absorber	B-1	34.0	-87.4 °C	none	-	-	-	P Compounds, Misc.
Propane	2	Absorber Absorber	A-1(b) (c) B-1	44.09	-42.28 °C	4	GC/FID IR NDIR	0.03 ppm(mdc)	500 ppm(fs)	Hydrocarbons *
Propargyl Alcohol	1	Absorber	A-1(b)	56.06	114.0 °C to 115.0 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	10 ppm(fs)	Alcohols *
n-Propyl Nitrate	none	Absorber	A-1(b)	105.18	110.0 °C (@762 mmHg)	3	GC/FID HFID IR	0.1 ppm(mdc)	25 ppm(fs)	N Compounds, Misc.
beta-Propylene Glycol Mono-methyl Ether	none	Absorber	A-1(b)	90.14	-	3	GC/FID HFID PHION	0.1 ppm(mdc)	100 ppm(fs)	Ethers
Stibine	1	Absorber	A-1(b), -3	124.78	-17.0 °C	none	-	-	-	Inorganics
Stoddard Solvent	none	Absorber Absorber	A-1(a) (b) (c) B-1	-	150.0 °C to 210.0 °C	3	IR NDIR PHION	0.01 ppm(mdc)	200 ppm(fs)	Hydrocarbons

Group 2

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Sulfur Hexa-fluoride	none	Adsorber	A-1(b)	146.07	-63.8 °C (sublimes)	5	EC/WCHEM IR NDIR	0.02 ppm(mdc)	1000 ppm(fs)	Sulfur Compounds
Sulfur Mono-chloride	none	Adsorber	A-1(b)	135.03	130.0 °C	none	-	-	-	Sulfur Compounds
Sulfur Tetra-fluoride	none	Adsorber	A-1(b)	108.07	-40.0 °C	1	WCHEM	Not Given	Same	Sulfur Compounds
Sulfuryl Fluoride	none	Adsorber	A-1(b)	102.07	-55.4 °C	3	EC/WCHEM IR	0.1 ppm(mdc)	"low" ppm	Sulfur Compounds
Tellurium Hexa-fluoride	none	Adsorber	A-1(b)	241.61	-38.90 °C (sublimes)	1	WCHEM	Not Given	Same	Inorganics
TEPP	none	Adsorber	A-1(b)	290.20	104.0 °C to 110.0 °C (at 0.08 mmHg)	none	-	-	-	P Compounds, Misc.
1,1,1,2-Tetra-chloro-2,2-Di-fluoroethane	none	Adsorber	A-1(b)	203.80	-	2	GC/FID NDIR	0.1 ppm(mdc)	500 ppm(fs)	Halogen Deriv.
1,1,2,2-Tetra-chloro-1,2-Di-fluoroethane	none	Adsorber	A-1(b)	203.80	93.0 °C	3	EC GC/FID NDIR	0.1 ppm(mdc)	500 ppm(fs)	Halogen Deriv.
Tetraethyl Lead	1	Adsorber	A-1(b)	323.45	198.9 °C	none	-	-	-	Organo-Metallics
Tetramethyl Lead	none	Adsorber	A-1(b)	267.35	-	none	-	-	-	Organo-Metallics
Tetramethyl Succinonitrile	none	Adsorber	A-1(b)	136.22	-	1	PHION	0.5 ppm(mdc)	Same	N Compounds, Misc.
o-Toluidine	none	Adsorber	A-1(b)	107.15	200.0 °C to 202.0 °C	4	GC/FID HPID IR PHION	0.1 ppm(mdc)	10 ppm(fs)	N Compounds, Misc.
Tributyl Phosphate	none	Adsorber	A-1(b)	266.32	289.0 °C (w/decomp.)	2	GC/FID PHION	0.1 ppm(mdc)	0.5 ppm(mdc)	P Compounds, Misc.
1,1,2-Trichloro-ethane	none	Adsorber	A-1(b) (c)	133.42	113.65 °C	4	EC GC/FID HPID IR	0.1 ppm(mdc)	25 ppm(fs)	Halogen Deriv.

Group 2

Compound	No. AC Mfgs.	AC Type Recommen- dation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Trichloroethylene	none	Adsorber	A-1(b) (c)	131.40	87.1 °C	5	EC GC/FID IR NDIR PHION	0.1 ppm(mdc)	200 ppm(fs)	Halogen Deriv.
1,1,2-Trichloro 1,2,2-Trifluoro- ethane	none	Adsorber	A-1(b)	187.37	47.6 °C	4	EC GC/FID IR NDIR	0.02 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.
Trifluoromono- bromomethane	none	Adsorber	A-1(b)	148.92	-57.8 °C	3	EC GC/FID NDIR	0.1 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.
Trimethyl Benzene	none	Adsorber	A-1(b)	120.19	164.7 °C	3	GC/FID HFID PHION	0.1 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.
Vinyl Bromide	none	Adsorber	A-1(b)	105.94	16.0 °C	5	EC/WCHEM GC/FID NDIR PHION	0.1 ppm(mdc)	1000 ppm(fs)	Halogen Deriv.

Group 3

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Abate	none	Process Dependent	-	298.23	-	none	-	-	-	NPS Combinations
Aldrin	none	Process Dependent	-	364.93	-	none	-	-	-	Halogen Deriv.
Ammonium Chloride (fume)	9	Process Dependent	-	53.46	337.8 °C	none	-	-	-	N Compounds, Misc.
Ammonium Sulfamate	none	Process Dependent	-	115.1	160.0 °C (decomposes)	none	-	-	-	NPS Combinations
Antimony & Cmpds. (as Sb) (except Stibine)	2	Process Dependent	-	121.75 (Sb)	1380.0 °C (Sb)	none	-	-	-	Inorganics
ANTU	none	Process Dependent	-	202.27	-	none	-	-	-	NPS Combinations
Arsenic & Cmpds. (except Arsine)	2	Process Dependent	-	74.9 (As)	615.0 °C (sublimes) (As)	none	-	-	-	Inorganics
Azinphos-Methyl (Guthion)	none	Process Dependent	-	317.34	-	none	-	-	-	NPS Combinations
Barium (sol.cmpds)	1	Process Dependent	-	134.34 (Ba)	1140.0 °C (Ba)	none	-	-	-	Inorganics
Benzoyl Peroxide	none	Process Dependent	-	242.22	(explodes before)	none	-	-	-	Ethers
Bismuth Telluride	none	Process Dependent	-	800.83	-	none	-	-	-	Inorganics
Bismuth Telluride (Se-doped)	none	Process Dependent	-	-	-	none	-	-	-	Inorganics
Boron Oxide	none	Process Dependent	-	-	1300.0 °C to 1500.0 °C (vaporizes)	none	-	-	-	Inorganics
Cadmium (METAL DUSTS ONLY!)	none	Process Dependent	-	112.40 (Cd)	767.0 °C	none	-	-	-	Inorganics
Calcium Carbonate	6	Process Dependent	-	100.09	825.0 °C (decomposes)	none	-	-	-	Inorganics

Group 3

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Calcium Arsenate	3	Process Dependent	-	398.06	-	none	-	-	-	Inorganics
Calcium Oxide	10	Process Dependent	-	56.08	2850.0 °C	none	-	-	-	Inorganics
Carbaryl Sevin Dust	none	Process Dependent	-	74.04	-	none	-	-	-	N Compounds, Misc.
Carbon Black (amorphous)	12	Process Dependent	-	12.01	4200.0 °C	none	-	-	-	Inorganics
Cellulose (paper fiber)	3	Process Dependent	-	-	-	none	-	-	-	Polysaccharides
Chlordane	none	Process Dependent	-	409.80	-	none	-	-	-	Halogen Deriv.
Chlorinated Cam- phene	none	Process Dependent	-	414.6	155.0 °C (decomposes)	none	-	-	-	Halogen Deriv.
o-Chlorobenzyl- dene Malonitrile (OCBM)	none	Process Dependent	-	188.60	310.0 °C to 315.0 °C	none	-	-	-	N Compounds, Misc.
Cotton Dust (raw)	1	Process Dependent	-	-	-	none	-	-	-	Polysaccharides
Crag Sesone	none	Process Dependent	-	309.13	245.0 °C (decomposes)	none	-	-	-	Sulfur Compounds
2,4-D Hedonal	none	Process Dependent	-	221.04	160.0 °C	none	-	-	-	Halogen Deriv.
DDT	none	Process Dependent	-	354.50	110.0 °C (decomposes)	none	-	-	-	Halogen Deriv.
Diazinon	none	Process Dependent	-	304.36	83.0 °C to 84.0 °C (@0.002 mmHg)	none	-	-	-	NPS Combinations
Dibrom	none	Process Dependent	-	476.88	-	none	-	-	-	Halogen Deriv.
Dibutylphthalate	none	Process Dependent	-	278.34	330.0 °C to 340.0 °C	none	-	-	-	Esters

Group 3

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
1,3-Dichloro-5,5-Dimethyl Hydantoin	none	Process Dependent	-	197.03	100.0 °C (sublimes)	none	-	-	-	N Compounds, Misc.
Dieldrin	none	Process Dependent	-	380.93	-	none	-	-	-	Halogen Deriv.
Dinitrotoluene	1	Process Dependent	-	182.11	300.0 °C (approx.)	none	-	-	-	N Compounds, Misc.
Diphenyl	1	Process Dependent	-	154.20	256.1 °C	none	-	-	-	Hydrocarbons
Diphenyl Amine	none	Process Dependent	-	169.22	302.0 °C	none	-	-	-	Amines/Imines
Diquat	none	Process Dependent	-	344.07	320.0 °C (decomposes)	none	-	-	-	N Compounds, Misc.
Emery	3	Process Dependent	-	101.96	2920.0 °C to 3140.0 °C	none	-	-	-	Inorganics
Endosulfan	none	Process Dependent	-	406.95	-	none	-	-	-	Sulfur Compounds
Endrin	none	Process Dependent	-	390.93	245.0 °C (decomposes)	none	-	-	-	Halogen Deriv.
EPN	none	Process Dependent	-	323.31	-	none	-	-	-	NPS Combinations
Ethylene Glycol (particulate)	none	Process Dependent	-	62.07	197.6 °C	none	-	-	-	Alcohols
Perbam	none	Process Dependent	-	416.50	180.0 °C (decomposes)	none	-	-	-	NPS Combinations
Ferrovanadium Dust	none	Process Dependent	-	352.67	-	none	-	-	-	Inorganics
Glass (fibrous, dusts)	3	Process Dependent	-	-	-	none	-	-	-	Inorganics
Glycerin Mist	3	Process Dependent	-	92.09	290.0 °C (decomposes)	none	-	-	-	Alcohols
Graphite (synthetic)	6	Process Dependent	-	12.01	2820.0 °C (commercial grades can withstand up to that temp)	none	-	-	-	Inorganics

Group 3

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Gypsum	7	Process Dependent	-	172.18	-	none	-	-	-	Inorganics
Heptachlor	none	Process Dependent	-	373.35	135.0 °C to 145.0 °C (0.1-1.5 mm Hg)	none	-	-	-	Halogen Deriv.
Hexachloronaphthalene (62% Chlorine)	none	Process Dependent	-	334.82	344.0 °C	none	-	-	-	Halogen Deriv.
Hydroquinone	none	Process Dependent	-	110.11	286.0 °C	none	-	-	-	Ketones
Indium & Compds., (as In)	none	Process Dependent	-	114.82 (In)	2000.0 °C (In)	none	-	-	-	Inorganics
Iron Salts, sol. (as Fe)	none	Process Dependent	-	-	-	none	-	-	-	Inorganics
Kaolin	4	Process Dependent	-	-	-	none	-	-	-	Inorganics
Lead (inorganic fumes and dusts)	6	Process Dependent	-	207.19 (Pb)	1613.0 °C (Pb)	none	-	-	-	Inorganics
Lead Arsenate	2	Process Dependent	-	347.13	280.0 °C (decomposes)	none	-	-	-	Inorganics
Limestone	7	Process Dependent	-	100.09	825.0 °C (decomposes)	none	-	-	-	Inorganics
Lindane	none	Process Dependent	-	290.85	-	none	-	-	-	Halogen Deriv.
Magnesite	3	Process Dependent	-	-	Greater than 700.0 °C (converted to MgO)	none	-	-	-	Inorganics
Magnesium Oxide (fume)	3	Process Dependent	-	40.32	3600.0 °C	none	-	-	-	Inorganics
Malathion	none	Process Dependent	-	330.36	156.0 °C to 157.0 °C (0.7 mmHg)	none	-	-	-	NPS Combinations

Group 3

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Marble	1	Process Dependent	-	100.09	-	none	-	-	-	Inorganics
Methoxychlor Mariate	none	Process Dependent	-	345.65	-	none	-	-	-	Halogen Deriv.
Molybdenum (sol. & insol. cmpds)	3	Process Dependent	-	95.94 (Mo)	3700.0 °C (Mo)	none	-	-	-	Inorganics
Nicotine	1	Process Dependent	-	162.23	247.0 °C	none	-	-	-	N Compounds, Misc.
p-Nitroaniline	none	Process Dependent	-	138.12	332.0 °C (calc.)	none	-	-	-	N Compounds, Misc.
p-Nitrochlorobenzene	none	Process Dependent	-	157.58	242.0 °C	none	-	-	-	N Compounds, Misc.
Octachloronaphthalene	none	Process Dependent	-	403.70	440.0 °C to 442.0 °C	none	-	-	-	Halogen Deriv.
Oxalic Acid	none	Process Dependent	-	90.04	102.0 °C (sublimes)	none	-	-	-	Acids/Anhydrides
Paraquat	none	Process Dependent	-	-	-	none	-	-	-	N Compounds, Misc.
Pentaerythritol	1	Process Dependent	-	136.15	276.0 °C (@30 mmHg) (sublimes)	none	-	-	-	Alcohols
Phenyldiazine	none	Process Dependent	-	108.14	243.5 °C (decomposes)	none	-	-	-	N Compounds, Misc.
Phosphoric Acid	8	Process Dependent	-	98.0	261.0 °C	none	-	-	-	P Compounds, Misc.
Phosphorus Pentachloride	none	Process Dependent	-	208.27	160.0 °C	none	-	-	-	P Compounds, Misc.
Phosphorus Pentasulfide	none	Process Dependent	-	222.29	523.0 °C (in inert gas)	none	-	-	-	NPS Combinations
Pival	none	Process Dependent	-	230.3	-	none	-	-	-	Ketones
Plaster of Paris	none	Process Dependent	-	145.15	-	none	-	-	-	Inorganics

Group 3

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Platinum (sol. salts, as Pt)	none	Process Dependent	-	195.09 (Pt)	4530.0 °C (Pt)	none	-	-	-	Inorganics
Pyrethrum	2	Process Dependent	-	372.45	192.0 °C to 193.0 °C	none	-	-	-	Keto-Esters
RDX	none	Process Dependent	-	222.15	-	none	-	-	-	N Compounds, Misc.
Rhodium (metal fume, dusts, sol salts, as Rh)	none	Process Dependent	-	102.91 (Rh)	2500.0 °C (Rh)	none	-	-	-	Inorganics
Rommel	none	Process Dependent	-	321.57	-	none	-	-	-	NPS Combinations
Rouge	none	Process Dependent	-	159.70	-	none	-	-	-	Inorganics
Silicon	none	Process Dependent	-	28.09	2600.0 °C	none	-	-	-	Inorganics
Silicon Carbide	3	Process Dependent	-	40.07	2200.0 °C (sublimes)	none	-	-	-	Inorganics
Starch	6	Process Dependent	-	162.14 (approx.)	(decomposes w/heat)	none	-	-	-	Polysaccharides
Strychnine	none	Process Dependent	-	334.30	270.0 °C (85 mmHg)	none	-	-	-	N Compounds, Misc.
Sucrose	6	Process Dependent	-	324.30	160.0 °C to 186.0 °C (decomposes)	none	-	-	-	Polysaccharides
2,4,5-T	none	Process Dependent	-	255.49	-	none	-	-	-	Halogen Deriv.
Tantalum (metal & oxide dusts)	none	Process Dependent	-	180.95 (Ta)	4100.0 °C (Ta)	none	-	-	-	Inorganics
TEDP	none	Process Dependent	-	322.34	-	none	-	-	-	NPS Combinations
Tellurium	none	Process Dependent	-	127.60	1390.0 °C	none	-	-	-	Inorganics
Tetryl	none	Process Dependent	-	287.15	180.0 °C to 190.0 °C (explodes)	none	-	-	-	Amines/Imines

Group 3

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol.Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Thallium (sol. compounds)	none	Process Dependent	-	204.37 (Tl)	1457.0 °C (Tl)	none	-	-	-	Inorganics
Thiram	none	Adsorber	A-(b)w/Filter System	240.44	-	none	-	-	-	NPS Combinations
Tin (inorganic cmpds, except SnH_4 , SnO_2 , as Sn)	2	Adsorber	A-(b)w/Filter System	118.69 (Sn)	2260.0 °C (Sn)	none	-	-	-	Inorganics
Tin (organic compounds)	none	Adsorber	A-(b)w/Filter System	-	-	none	-	-	-	Organo-Metallics
Tin Oxide	1	Adsorber	A-(b)w/Filter System	134.70	1080.0 °C (decomposes) (6600 mmHg)	none	-	-	-	Inorganics
Titanium Dioxide	6	Adsorber	A-(b)w/Filter System	79.90	1640.0 °C (decomposes)	none	-	-	-	Inorganics
Trichloronaphthalene	none	Adsorber	A-(b)w/Filter System	231.50	-	none	-	-	-	Halogen Deriv.
Triorthocresyl Phosphate	none	Adsorber	A-(b)w/Filter System	368.36	410.0 °C	none	-	-	-	P Compounds, Misc.
Warfarin	none	Adsorber	A-(b)w/Filter System	308.32	-	none	-	-	-	Ketones
Zinc Oxide (fume)	6	Adsorber	A-(b) w/Filter System	81.38	1800.0 °C (sublimes)	none	-	-	-	Inorganics
Zirconium Cmpds., (as Zr)	1	Adsorber	A-(b)w/Filter System	91.2	3577.0 °C	none	-	-	-	Inorganics

Group 4

Compound	No. AC Mfgs.	AC Type Recommendation	Rationale	Mol. Wt.	B.P.	No. AM Mfgs.	Technique	Sensitivity Range		General Chemical Classification
Dimethylphthalate	none	Adsorber w/Filter System	A-1(b)	194.19	282.0 °C 285.0 °C	none	-	-	-	Esters
di-sec, Octyl Phthalate	none	Adsorber w/Filter System	A-1(b)	390.54	-	none	-	-	-	Esters
Methyl Demeton	none	Adsorber w/Filter System	A-1(b)	230.30	74.0 °C 89.0 °C	none	-	-	-	NPS Combinations
Methyl Parathion	none	Adsorber w/Filter System	A-1(b)	265.23	-	none	-	-	-	NPS Combinations
Oil Mist (mineral)	18	Adsorber w/Filter System	A-1(b)	-	-	none	-	-	-	Hydrocarbons
Phthalic Anhydride	2	Adsorber w/Filter System	A-1(b)	148.11	284.5 °C (sublimes)	1	PHION	0.3 ppm (MDC)	Same	Anhydrides *
Quinone	none	Adsorber w/Filter System	A-1(b)	108.09	115.7 °C (sublimes)	1	PHION	0.2 ppm (MDC)	Same	Ketones
2,4,6-Trinitro-toluene (TNT)	none	Adsorber w/Filter System	A-1(b)	277.13	150.0 °C (decomposes)	1	PHION	0.2 ppm (MDC)	Same	N Compounds, Misc.
Tungsten (as W) (sol. & unsol. compounds)	none	Adsorber w/Filter System	A-1(b)	183.85	5900.0 °C	none	-	-	-	Inorganics

Appendix I
Excerpts From User Questionnaire

III. FATE OF AIR CLEANER EFFLUENT

1. Is the cleaned air recirculated to the work area?

(Yes) (No)

2. If so, what are the properties of the cleaner effluent and the system discharge into the work area?

a. Concentration _____ (mg/m³ or ppm)

b. Particle size distribution _____

3. If the cleaned air is recirculated to the work area, is additional make-up air required for proper ventilation?

(Yes) (No)

4. If yes, in what quantity (cfm) is the make-up air supplied?

5. Are there any existing provisions for elimination of negative pressure buildup in work area? (pressure relief valves, blast gates, etc.)

(Yes) (No)

6. If yes, briefly describe these provisions.

IV. MONITORING OF CLEANER PERFORMANCE

1. Flow monitoring instrumentation:

- a. Pressure gauges (type and location relative to cleaner)

- b. Method and equipment used to determine inlet flow rate.

- c. Location of flow probe relative to cleaner.

- d. Pressure drop across cleaner as a function of duty cycle (time).

2. Concentration monitoring instrumentation:

- a. Method and quipment used to obtain contaminant sample from moving air stream _____.
- b. Locations at which samples are taken _____.
- c. Number of samples taken _____.
- d. How often is sampling conducted? _____.
- e. Analytical method used to analyze sample (UV, IR, GC, gravimetric, etc.) _____.
- f. Is sampling and analysis an on-line, automatic operation or is laboratory analysis of sample required?
_____.
- g. If laboratory analysis is required, what is the elapsed time between sampling and return of analysis results (hours, days) _____.

3. Collection efficiency _____ based on (Check one)

- a. Weight flow _____
- b. Particle size distribution _____

V. RELIABILITY AND MAINTAINABILITY

1. Efficiency quoted by equipment manufacturer_____.
2. Installation date_____.
3. Is process and loading the same as when cleaner was installed?
(Be specific)
_____.
4. If a backup cleaning system exists, indicate type of collector
_____ and mode of activation (manual, automatic).
5. Estimated total hours of cleaner operation since installation.
_____.
6. How many failures has the cleaner experienced since installation?
_____.
7. Types of failures. _____

_____.
8. Average off-line time per failure_____.
9. Please fill out the table below to describe the preventative maintenance actions which you perform on the cleaner.

Maintenance Action	Frequency (hours/days)	Avg. Time Required to Perform Maintenance

10. Is an electromechanical schematic of the system available for inspection or reproduction?

(Yes) (No)

11. Number of work shifts/day that air cleaning is required.

- a. One
- b. Two
- c. Three

12. Is a warning or alarm system connected to the air cleaner?

(Yes) (No)

13. If the response to the previous question is positive, specify the operating parameters that are monitored by the warning system (i.e., pressure transducers, flow probes, system power, etc.).

_____.

14. Is the warning panel capable of initiating corrective action?

- a. Yes_____, specify corrective action taken

_____.

- b. No_____

15. Estimated hours of operation of performance monitoring system.

_____.

16. How many failures has the monitoring system experienced since installation?_____.

