Industrial Hygiene Engineering and the Process-Environment System

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A systems approach to industrial health would help integrate the concepts applied by engineers, industrial hygienists, toxicologists, and physicians, and organize them into a strategy for health maintenance that is compatible and measurable along common lines. The advantages of a systems approach to industrial health are viewed in terms of the application and refinement of industrial hygiene standards, participation of the engineering professions, communication among all members of the occupational health team, and transition we are enjoying with the increasing use of automation, process control and computer technology.

Introduction

IN HIS INTRODUCTION to *Industrial Hygiene Highlights,* Professor Theodore Hatch[1] reminds us that "it is the responsibility of industrial hygienists, toxicologists and physicians constantly to review the adequacy of the methods they employ to demonstrate health maintenance." This is a challenge to all of us who have sensed the broadening horizons of our profession. For if we are to apply the principles of industrial hygiene successfully in this time of rampant technological change, we must keep abreast of new developments in the basic disciplines that comprise our multidisciplinary profession.

Effective management of occupational health programs requires—more than ever—coordination and teamwork among those specialties that function within this broad field. We need to know and understand how each discipline that deals with occupational health can complement and interact with other members of the occupational health team.

One measure of the compatibility of an interdisciplinary approach to occupational health is the emphasis we place on the concepts and methods applied to industrial hygiene by several specialties—by engineers, industrial hygienists, toxicologists and physicians—concepts and methods which we have in common, and which can be reduced to quantities measurable along common lines.

One concept that relates to all the disciplines within the field of occupational health is that of an "acceptable exposure level" or an "industrial hygiene standard" for inhalation of materials in the work place.

We are familiar with threshold limit values (TLV's), maximum acceptable concentrations (MAC's), and, in more recent years, the multiple guidelines of the Z-37 Committee of the America National Standards Institute (ANSI). Much attention has been given to the development of these standards, but it appears that there has been less concern for the validation and refinement of those guidelines, and clearly, even less concern for the application of industrial hygiene standards in the work place.

Specifically, two aspects of the application of standards are glossed over to our disadvantage. First is the fact that TLV's and other hygienic standards are not easy to use properly. Second, many of the engineers in industry who could be, are not using the concept of an industrial hygiene standard in their decision making. Therefore, we do not benefit as fully as we could from the assistance the engineering profession could give us in the overall control of industrial health hazards. What can be done to improve this situation?

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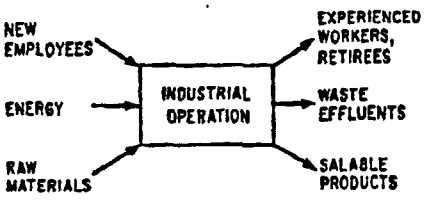

FIGURE 1. An industrial operation.

The Need for a Systems Approach

Clearly, the application of knowledge from engineering and medical research, industrial toxicology, and field experience in environmental control requires some communication system for the essential interplay to exist among the various parent disciplines within our field. If the communication is effective, that interaction can thrive.

On the other hand, if each discipline interested in occupational health attacks a particular problem independently, we likely will not meet the total need. Thus, we should adopt an integrated approach in organizing ourselves to deal with our common concerns.

In the integration of interdisciplinary interest which focuses on a complex problem, one promising technique is "systems analysis." Webster defines a system as a "regularly interacting or interdependent group of items forming a unified whole."[2] In simplest terms, a system consists of a set of components which, when combined, produce a useful result.

A "system" in terms of industrial health might be an organizational framework that defines the strategy for assuring the healthfulness of a worker population. To that end, the system might be composed of certain subsystems which could be examined and treated separately.

If we step back and look at an industrial operation and examine the various inputs and outputs from that industrial unit, we observe an interesting fact: From a larger viewpoint an industrial operation takes three inputs—new employees, raw materials, and energy—and converts them into three distinguishable products (see Figure 1). First, there are the salable products which are sold in the marketplace for profit. Second, there are waste effluents which take the form of solid, liquid, or gaseous materials—and in turn may contribute to the total environmental burden of air, water and soil pollution. Third, there is an output from the system which is of direct concern to those of us interested in occupational health—the exposed workers and retirees.

We have implied, then, that the work environment is only part of a larger system. Specifically, every work situation has three elements: a process (perhaps a limited operation or function task), a work environment, and a worker. Within an industrial unit the process, the work environment, and the worker are not totally independent entities. Each is affected, or could be affected, by the other two elements. In many cases, one cannot alter a process or even change a job procedure without changing the quality of the work environment. A worker often has enough latitude in his work procedure to create differences in the degree of exposure he will encounter on his job. All three of these items—the process, the work environment, and the worker—must receive attention in an occupational health program.

It is at this point that some of the functional differences within the occupational health team become important and necessary. Clearly, the physicians, the nurses, and the supportive role of toxicology must deal with the worker and his health; the industrial hygienists must deal primarily with the work environment; and the logical extension of this approach would have the engineers dealing with the process—which, after all, is causing the environmental stress in the first place.

The Need for Feedback

Control of health hazards in the work environment can be neither comprehensive nor complete unless we systematically use the information that such considerations yield. In a self-regulated system the key element for control is "feedback." This refers to a circularity of the flow among two or more parts of the system structure. Such an arrangement assures that the output of the system is maintained at a desired level. Typically, this requires constant monitoring of the system output, a comparison of the output with standards, evaluation of any discrepancies, and a flow of information concerning the abnormal deviations

back to other elements in the system structure so that the procedures may be changed if necessary. Figure 2 shows an example of a simple closed-loop system with feedback.

Likewise, in industrial health we have a critical need for feedback information. We must know the adequacy of specific environmental control techniques. We also must have feedback concerning our industrial hygiene standards. Useful standards should be continually verified or modified as our knowledge and experience grow.[2]

Figure 3 shows a system both for assuring environmental control—including feedback on the control techniques employed—and for validating industrial hygiene standards through systematic documentation of exposure together with systematic medical surveillance of the exposed worker. This combination industrial hygiene and medical survey is a simple application of a "systems analysis" because it integrates several functional specialties in our field into a unit that moves toward the same goal.

This particular approach centers upon the industrial hygiene standard that could be a basis but by no means the only basis for effective interaction among the parent disciplines represented in the overall system. Here then we have a strategy for harnessing the toxicological feedback that is available from the exposed worker in terms of the effect, if any, on his health at the levels of exposure measured in the work environment.

The engineering function is represented in that part of the overall system that deals with the Process and the Work Environment—as opposed to that part of the system which deals with the Worker.

If we separate out the Process-Environment portion of the overall system we notice a striking similarity with the typical engineering control network.

The Process–Environment System

Figure 4 depicts the Process–Environment System. This is represented as a closed-loop control network that stresses the engineering application of industrial hygiene standards. Most engineers are not primarily concerned with the requirements of industrial hygiene.

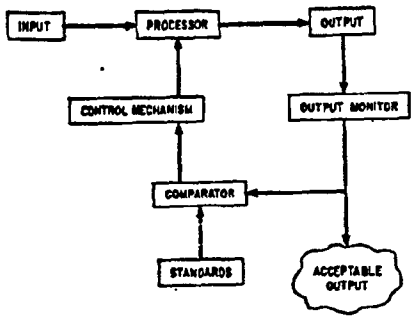

FIGURE 2. A typical control system with feedback.

Yet, effective communication on how engineering techniques can be utilized is an essential need and deserves more attention in practice.

The advantage we have in this respect is that engineers in general tend to deal with as large a system as they can handle from a computational standpoint. Therefore, the industrial hygiene standard could be used as an engineering standard in a larger system that includes the work environment.

Specifically, the *design* of a process should be directly related to the acceptable degree of environmental contamination by materials used or produced by the process. Environmental problems, unfortunately, are often created by poor engineering design. In other

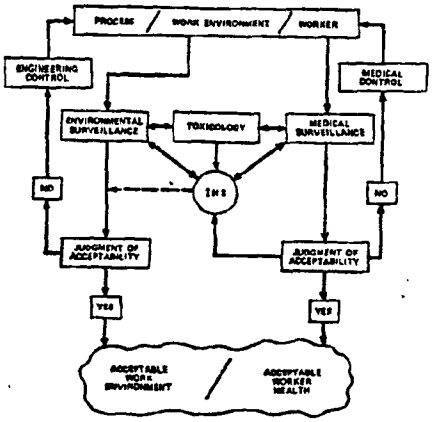

FIGURE 3. An overall system in occupational health.

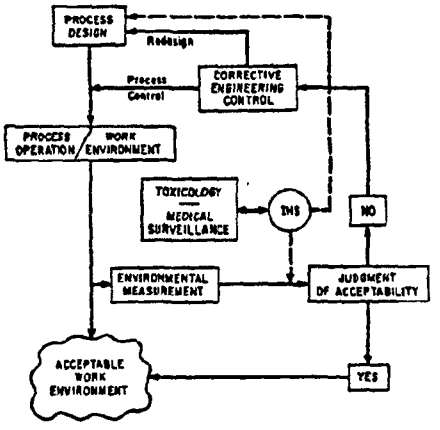

FIGURE 4. The Process–Environment System.

words, environmental control must start on the drawing board.

Second, the *operation* of the process can vary in a manner that will cause fluctuations in the level of contamination of the work environment. Again the acceptable exposure level serves as a guidepost toward which all future changes and improvements in the operation of the processes should be directed.

Third, the industrial hygiene standard directly affects the *measurement* of contamination in a particular work environment—such measurements to be used for judging acceptability of control, following comparison with the standard that applies in that particular case. With airborne chemical X, for example, there may be several ways to measure and monitor airborne concentrations of that contaminant in the work room air. The level of the threshold limit will often govern what type of instrument is used, and thereby the accuracy of the resulting information.

Fourth, we often think of a threshold limit value as the standard against which the estimate of the exposure is judged, but it is not enough to take such *judgment* for granted, for often the comparison of the measurement and the standard is made with inadequate information. Especially in the use of multiple guidelines, such as those of the Z-37 Committee of ANSI, we need a carefully planned approach—both to gather the proper information and then to use it meaningfully.

Finally, the measured deviation from the industrial hygiene standard frequently points the way to the type of *engineering control* or improvement that results when the measured concentration exceeds the standard. In other words, how far must we journey to arrive at the desired degree of contaminant control? If the deviation from the TLV is near zero, there is a different set of alternatives available than if the measured exposure exceeds the TLV by a gross amount.

Today's technological advances have brought us closer to the day when we can control the work environment just as we routinely control a manufacturing process. First we have seen the development of continuous monitoring, which can be an effective diagnostic tool for the identification of predominant sources of contamination in the work environment, the proper selection of contaminant control methods, and the documentation of occupational exposures.

The second development in this respect is the digital computer. When coupled to an environmental monitor the computer provides an effective means of reducing voluminous amounts of information into manageable form. These data, in turn, can be used to show both short-term and long-term trends of exposure. When correlated with day-to-day plant operation such information can result in even lower exposures.[4,5] In addition, such data can be used to describe the exposures of workmen in what is in effect a continuing industrial hygiene survey.

These two developments parallel the trend in the process industries where "on-stream process analyzers" and "computer applications" have mushroomed into prominence. Automatic regulation of product quality is commonplace—and the marriage of instrumentation and the computer has provided the engineering profession with some powerful new techniques.

This is important to our field because our allies in the engineering profession are increasingly well-versed in such techniques, and to the extent that engineers become engaged in environmental control, we can expect to take advantage of these and other technological advances in controlling the quality of the

work environment.

Advantages of Process–Environment System

Adequate Surveillance

A new process or facility should never be considered acceptable from our point of view until studies have proved the environmental control to be adequate. In view of the importance of process operation and its effect on the quality of the work environment, environmental surveillance often must be repeated regularly or, better yet, made a permanent feature of the Process–Environment System.

Frequency of environmental sampling is an important question, especially where we are confronted with variable concentrations or cyclic operations. A continuous monitor can be invaluable when we try to characterize the environment in such a way that our measurements are truly comparable with accepted hygienic standards. Also, the use of multiple guidelines in the control of the environment requires that a large number of regularly spaced samples be used to estimate the intensity of exposure.

Figure 5 shows a schematic representation of a multipoint continuous monitor that could be used to document exposures, and to aid in the control of air concentrations.[8] The several sampling probes extend into work areas where the worker spends his time during normal work activity. The concentrations at each of his work areas—or sampling locations—must be weighted according to the time spent there to estimate the time-weighted average concentration, the basis of most of the threshold limit values.

In addition, continuous monitors, if appropriately used, offer other important advantages. Among these are: (1) diagnostic air sampling, including time-dependent and location-dependent patterns, (2) efficient documentation, and (3) reduced material loss.

While controlling the air concentrations of a contaminant in the work room it is often possible to achieve an important savings from reduced material loss, especially if the contaminant is a raw material or product. Here is one area where it is very easy to enlist the help of the engineer. His prime concern with the economics of the operation of his process

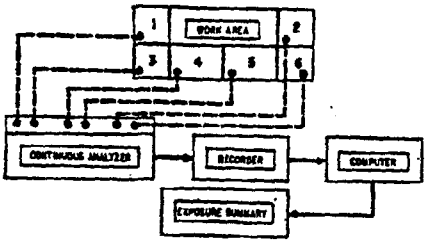

FIGURE 5. Schematic diagram of a continuous environmental monitoring system.

may help us to achieve our objective of limiting emissions into the work room. Sometimes it is possible to pay for a continuous monitoring system in a short time with the savings realized by its use.

Figure 5 indicates that the information from the schematic environmental monitor flows through a "computer." This again is indicative of the changing technology that bears on our field and at the same time opens new doors of opportunity for us to do a better job.

A continuous analyzer generates a great volume of information, and the full use of the data coming from such a device depends on how well we can reduce the output to meaningful terms. The digital computer offers us great help at this point because it can quickly translate a flood of concentration data into a comprehensive summary, including several parameters that may be of importance.

Proper Application of Standards

In a typical control system the error-detecting mechanism is critical. In the case of environmental surveillance, we are interested in comparing the estimated worker exposure with the appropriate industrial hygienic standards.

Whenever volatile substances are present in the work room, the concentrations will likely fluctuate so widely that it will be advantageous to monitor the environment continuously and test it repeatedly against the various standards that can be applied. In addition, the application of hygienic standards as they are defined virtually requires the use of continuous or semicontinuous sampling procedures, reduction of the measurements to the appropriate parameters, and then comparison with each of the appropriate guidelines.

For example, Table I shows the various in-

TABLE I
Industrial Hygiene Standard for Carbon Tetrachloride

TLV or "acceptable 8-hr TWA"	10 ppm
Acceptable ceiling concentration	25 ppm
Acceptable maximum concentration for peaks above acceptable ceiling	200 ppm
Acceptable number of peak concentrations of 5-minute duration for 8-hr period	2

dustrial hygiene standards that are available for carbon tetrachloride. To judge the acceptability of a particular work environment using these parameters, we would need a measurement in the worker's breathing zone at least every 5 minutes for 8 hours. This minimum of 96 samples would then have to be reduced to the various sampling statistics that could be compared with the standards.

Relatively little attention has been given to this problem of characterizing the work environment in a manner that will allow proper application of hygienic standards; it must receive more attention in the future. Table II shows one exposure summary that could be used to judge the intensity of exposure along several guidelines, both short-term and long-term. This exposure summary covers a 7-day period and reduces over 100,000 measurements to an informative, compact table. The information comes from a continuous environmental monitor linked directly to a digital computer.

Documentation and Feedback

The third advantage of the Process–Environment concept is that adequate environmental surveillance allows the use of feedback to provide a check on our environmental control efforts—to the extent that we correlate the environmental information with medical findings on the same worker population, we can use that feedback information to validate or refine our hygienic standards.

As the problems of concern in the work room from environmental stresses become more subtle and complex, the need for systematic studies on the relationship between exposure and consequence increases, and we need more than ever to complement the results from laboratory studies with planned systematic findings on groups of people exposed to the suspected agent under real conditions.[5,6,7]

Summary

Progress in our field—occupational health—will continue to depend on a "team approach." As Professor Hatch[1] pointed out, we must continually examine the methods we use to achieve results. Surely we must go beyond that and be willing to apply new techniques to our field whenever it can be demonstrated that such application will enable us to do a better job in conserving the health of the worker in the industrial environment. The development of our profession will depend on how well we integrate the common interests that each discipline brings to the field of occupational health. Our progress will also

TABLE II
Data Summary from a Continuous Environmental Monitor
Department—chemical plant
Material —methyl chloride
Date —2/17/69 to 2/25/69

	Sampling Location (raw data)						Job Classification (time-weighted)
	1	2	3	4	5	6	A
Mean concentration	14.3	29.5	38.8	42.8	61.3	79.3	26.8
Standard deviation	13.9	9.5	19.4	9.1	22.4	21.0	19.3
Frequency distribution							
25 ppm	8.5	49.4	60.5	100.0	100.0	100.0	39.6
50 ppm	1.9	9.1	20.4	16.4	51.4	100.0	13.5
100 ppm	0.5	0.2	3.4	0.2	6.7	14.5	1.4
200 ppm	0.2	0.0	0.4	0.0	1.1	0.3	0.1
300 ppm	0.1	0.0	0.3	0.0	0.1	0.0	0.0
Maximum concentration							
5 minutes	93.3	66.2	107.0	91.6	164.7	170.3	76.2
10 minutes	74.9	62.7	98.8	82.2	145.0	150.2	67.6
30 minutes	45.7	51.1	86.6	63.0	109.7	121.4	51.0
1 hour	30.7	43.0	73.7	54.9	94.9	107.9	41.5
4 hours	17.3	33.4	47.8	45.6	69.8	87.8	30.5

be measured by how well we find compatible, systematic methods of using the newest tools available to each basic discipline in our field.

A systems approach to industrial health would help us to take advantage of the transition we will enjoy with increasing use of automation, process control, and the digital computer. From a systems engineering point of view there is really little difference between controlling the process and controlling the work environment associated with it. A logical point of reference for the transition ahead would be the Process–Environment System.

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Gordon Research Conference

The 1970 Gordon Research Conference on Toxicology and Safety Evaluations will be held at Kimball Union Academy, Meriden, New Hampshire, July 27-31. This conference has been of considerable interest to industrial hygienists for a number of years because of the close relationship of problems encountered in industrial health work. This year the Chairman is J. Wesley Clayton, Jr. and Vice-Chairman is Edward D. Palmes. The program is as follows:

July 27. (R. A. Scala, discussion leader): H. H. Cornish, "Serum isozymes and organ damage"; J. L. Radomski, "The metabolism of 1- and 2-naphthylamine as related to carcinogenesis." (S. L. Friess, discussion leader): J. M. Barnes, "Toxic substances and the nervous system."

July 28. (S. Epstein, discussion leader): C. Jacobson, "Test systems for the reproductive evaluation of mutagens"; D. J. Kilian, "The role of cytogenics in evaluating the toxicity of chemical compounds." (H. V. Malling, Discussion leader): C. Valenti, "Effects of psychotropic drugs on mammalian chromosomes in vitro and in vivo observations."

July 29. (C. H. Hine, discussion leader): R. E. Hodges, "The role of human studies in evaluating potentially hazardous agents"; L. H. Schmidt, "What nonhuman primates have taught us relative to the action of chemicals on living systems." (Sidney Leskovitz, discussion leader): B. Pernis, "Immunological problems in toxicology."

July 30. (W. B. Ennis, discussion leader): D. O. King, "Rational Management of the environment"; K. C. Barrons, "Benefits of agricultural chemicals." (J. P. Frawley, discussion leader): L. Cole, "The chemical threat to our environment."

July 31. (E. D. Palmes, discussion leader): T. Foin, "Technology, population and the environment."

Attendance at the Conference is by application only. Application forms and full information regarding requirements for attendance may be obtained by writing to Dr. Alexander M. Cruickshank, Director Gordon Research Conference, Pastore Chemical Laboratory, University of Rhode Island, Kingston, Rhode Island 02881 (Telephone: 401-783-4011). Applications for this Conference should be submitted before June 1, 1970.