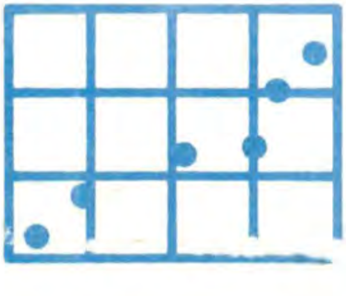
Division of Training and
Manpower Development
NIOSH

INDUSTRIAL HYGIENE MEASUREMENTS



550

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

INTRODUCTION

INDUSTRIAL HYGIENE MEASUREMENTS (550)

Conducted by
Division of Training and Manpower Development

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health
Cincinnati, Ohio 45226

August 1979

DISCLAIMER

ABSTRACT

The primary objective of this course is to provide the trainee with an understanding of routine sampling and measurement techniques. Approximately 50 percent of the course time consists of lectures which acquaint the trainee with various instruments and standards which govern their use. The remainder of the trainee's time is spent in laboratory sessions in the calibration and use of these sampling and measurement instruments. Some familiarization with the more general aspects of occupational health is included as introduction, and the evaluation of safety programs is briefly discussed. The training course manual has been specially prepared for the trainees attending the course and should not be included in reading lists of periodicals as generally available.

Reprinted May 1982

CONTENTS

Page

INTRODUCTION TO HAZARD EVALUATION

SECTION 1 — GAS AND VAPOR SAMPLING

SECTION 2 — AIR FLOW MEASUREMENTS

SECTION 3 — PARTICULATE SAMPLING

SECTION 4 — INDUSTRIAL VENTILATION

Page

SECTION 5 — HEAT STRESS

SECTION 6 — RADIATION

SECTION 7 — NOISE

SECTION 8 — SPECIAL TOPICS

GENERAL PRINCIPLES IN EVALUATING THE OCCUPATIONAL ENVIRONMENT

I WHY COLLECT AIR DUST SAMPLES?

A Purpose:

1 To determine the air dust exposures of individuals or groups of individuals in the performance of specific jobs and while in the general vicinity of sources of airborne material.

2 To determine the sources of air dust.

3 To supply information that will aid in preparing specific recommendations designed to minimize personnel exposures.

II CONDITIONS WHICH REQUIRE SPECIAL PRECAUTIONS

Before starting to collect samples, consider:

A Fire and Safety

1 There are areas where explosions may occur. Pumps with explosion-proof motors or other equipment are needed for survey work in these areas.

2 The surveyor shall practice good safety techniques and follow all safety rules whenever collecting samples.

B Health

1 The surveyor collecting samples in an area of high dust concentration should provide his own respiratory protective equipment which he will wear at all times in the area. In addition, he should wear eye protection, safety shoes and maybe even ear protection.

III EQUIPMENT CARE

A The care of the survey equipment is an important consideration in the survey work. Procedures and maintenance of survey equipment should be strictly adhered to.

IV WHAT KIND OF SPECIFIC EQUIPMENT WILL BE REQUIRED?

A Research - Read up on what has been done.

B Decide what equipment will do the best job for you.

C Personal Air Dust Sampler.

D Multiple Plate Elutriators.

E Total Dust Sampler

F Type of Filter

G Special Envelopes

H General Equipment

1 Velometer or manometer and pitot tube

2 Stopwatch

3 Extension cord (3-wire only)

4 Tweezers

5 Data sheets

6 Clipboard

I Special Equipment

Depending on circumstances special equipment (viz., Filtron Lapel Sampler, A.I.S.I. Tape Sampler, etc.) is also available for non-routine problems that might occur.

V TYPES OF SAMPLES

A Process Sample (P)

The process sample is collected to measure the amount of airborne contamination

---

Prepared by Edward D. Leininger, Industrial Hygienist, Division of Training, NIOSH, 6/72.

given off by a particular operation. It is collected as close as possible (within a few inches) to the work or action portion of the operation or visible or suspected source of dust.

B Breathing Zone Sample (BZ)

The breathing zone sample is collected within a few inches of the operator's nose for the purpose of determining the concentration of air dust which a person breathes in performing an operation. The breathing zone sample is also collected in the breathing zone while a person performs work adjacent to a source or sources of contamination.

C General Air Sample (GA)

The general air sample is collected in a room or area to measure the amount of radioactive air dust to which the people who occupy the room are exposed. The source of contamination may or may not be associated with what the people are doing in the area. Where general air samples are collected, the airborne concentration should be expected to remain fairly constant while the samples are being collected.

D Personal or Lapel

E Grab

F Continuous

VI METHODS OF SAMPLING

When preparing to sample an area or a particular operation, first observe the area or operation to:

A See what operations are being performed within the sampling area. (This is to note whether there are any abnormal conditions existing such as fires, broken dust collector bags, or other factors which could produce abnormal air dust levels.)

B Observe the operation to note just what the operating personnel are doing, approximately how long it takes to do a certain phase of the operating, and to make note of the operator's movements. Complete sample data is very important. For example, ventilation on or off, (if on, measure with appropriate equipment), doors and windows open or closed, what equipment or machinery is operating within the area, maintenance work within the area. If a respirator is being worn by the operator, make note of this on the data sheet.

The following are two good examples of what is needed in the way of sample description data:

Example 1:

Plant 15 survey, Large Crusher, wet side, first floor, "98" material. No respiratory protection worn. On samples 9676, 9679, and 9692, the crusher overflowed causing large amounts of airborne dust in this area.

Sample No.	Sample Description	Result d/m/M^3
9676	GA - Smoking area, 1st floor, wet side	650
9679	GA - Smoking area, 1st floor, wet side	469
9692	GA - Smoking area, 1st floor, wet side	684

In checking the sample description, there is a very good reason given for the high sample results that were obtained.

Example 2:

Evaluation of UPA Furnace Drumming Station, Plant 15

Sample Description	Result d/m/M^3
BZ - Changing drums and scoop sampling oxide outside of station. The drums were old and the rings did not fit properly which forced the operator to pound it on with a hammer, causing a large amount of visible dusting. Dust-foe respirator worn.	1719
BZ - Changing drums and scoop sampling oxide while drum was	

	Result $d/m/M^3$
still under the influence of the station ventilation. The operator also slid the lid onto the drum before removing it from the station. These were fairly new drums which did not require pounding to secure the lids. Dust-foe respirator worn.	102

With the sample description given with each set of samples, it is very easy to determine the cause for the wide variance between the two sets of samples. Without information as complete as this, the two sets of samples would have been practically valueless so far as making appropriate recommendations is concerned.

VII FORMAT FOR THE PREPARATION OF PERIODIC REPORTS OF COMPLETE AIR DUST SURVEYS

A Abstract

This will be a brief summary consisting of a single sentence, or group of sentences, explaining the nature of the study and report. It may include findings and conclusions.

B Introduction

This will briefly state the objective of the study, together with such historical data as may be necessary in order to prepare the reader for the material to be presented.

C Methods

This will include a description of the various methods employed in collecting and analyzing samples, together with the method of determining exposure levels.

D Summary of Data

This will include:

1 A brief summary describing data contained herein and indicating any trend shown.

2 A table comparing, where possible, various exposure levels from previous years' surveys and the exposure levels found in the current survey.

3 A table showing the weighted exposures for the various groups.

4 A table showing the concentrations for the various operations and locations.

E Discussion

This is to be a brief, but thorough, description of the results of the study, causes of high samples and exposures, etc. Methods and operations will be discussed, where necessary, to indicate the reasons for high results.

F Conclusions

A brief and concise conclusion, which may be drawn from information contained in the report.

G Recommendations

This will include all recommendations which have been previously made, either in periodic or interim reports, and which are not completed at the time the report is written. It will also include all new recommendations. Where the recommendation is partially complete, an explanation of the progress made should be given. New recommendations are to be listed for the first time and are to be assigned, at this time, a recommendation number.

H Acknowledgements

Here credit will be given to those who contributed significantly to the report.

I Appendices

These will include such information as the process flow sheets, exposure evaluation sheets, etc. Graphs may be substituted from tables where the data can be presented in this manner. For each Appendix there should be some reference made in the body of the report to the material contained in the Appendix.

THRESHOLD LIMITS - THEIR USE AND MISUSE

This subject is particularly timely for a number of reasons. Never before in the history of air standards (since 1943) has there been such interest in them, both from industry which must employ them, and control agencies which use them. Moreover, at the present time the different standards in use in the U.S.A., threshold limit values (TLVs) and maximal acceptable concentrations (MACs), are undergoing extended technical scrutiny as to their basic concepts, definition and meaning.

This discussion is to be restricted to air standards for work-places in the U.S.A.

Basis of Standards. All standards designed to safeguard the health and well-being of the worker rest on the premise that, although all chemical substances are toxic at some concentration experienced for a period of time, a concentration exists for all substances from which no toxicity may be expected no matter how long the exposure. A similar premise holds for substances producing irritation, discomfort and nuisance. Thus are differentiated chemical substances from ionizing radiation, which currently is commonly considered to have no threshold for injury.

A fact of importance to the basic concept also is that all toxicity is a response to dosage, and dosage is a concentration of a substance experienced over a period of time. (i.e., no one ever died from a concentration). This consideration of concentration and time has important bearing on the definition of hygienic standards to be discussed shortly.

Sponsoring Organizations. Currently there are two organizations that are recommending or proposing air standards for work places, the Threshold Limits Committee* of the American Conference of Governmental Industrial Hygienists, and the Z-37 Committee of the American Standards Association.** The composition of the committees may be differentiated on the basis that the T.L. Committee is composed of practicing industrial hygienists, toxicologists, industrial physicians, engineers, and chemists from governmental agencies and from universities, whereas the Z-37 Committee is composed mainly of representatives from industry or industry-connected organizations; some liaison members are from outside of industry. The American Industrial Hygiene Association sponsors the ASA Z-37 Committee, and has designated a technical group to review the standards prior to publication. The Z-37 Committee is large, requires membership approval of all Standards. As a consequence of this requirement and sponsor review, relatively few (20 or so) standards have been promulgated since its start in 1943. By contrast, the T.L. Committee has promulgated about 300 limits and is reviewing and revising the current list, and is adding new substances to the list annually.

Format of Standards. Important differences in the manner of presenting the published standards exist. The Z-37 Committee issues each standard as a separate document of six parts: The Meaning of Maximal Acceptable Concentration, Scope and Purpose of the Standards, Properties including Toxicity, the MAC, Sampling and Analysis Methods, and pertinent References. The standards are published on an irregular basis, and are proposed, voluntary values.

By contrast, the T.L. Committee publishes an annual booklet under the sponsorship of the ACGIH that lists alphabetically two types of limits, a recommended limit that comprises the bulk of the list, and a tentative value assigned for a period of years (at least two) to all newly added substances. In addition to the listed values the booklet contains a carefully worded preface that, like the sections in the American Standards publication, defines the T.L.V., its scope and purpose, its use and misuse. An appendix provides explanatory remarks for limits of those substances not amenable to a simple listing format.

A "Documentation of Threshold Limit Values" has been prepared by the T.L. Committee to supplement the T.L. list. The documentation provided the toxicologic basis for the committee selection of all the recommended values. Pertinent references to the literature and other sources of evidence for the recommendation are given. Supplements to the documentations will be published from time to time to maintain the listed values current.

---

*H.E. Stokinger, Chairman, 1014 Broadway, Cincinnati 2, Ohio.

**American Standards Assn., 10 E. 4th Street, New York 16, N.Y. H.H. Schrenk, Chairman

Presented by: H.L. Kusnetz, D.A. Holaday, B.F. Craft.

Hygienic Guides is a third publication that promulgates air standards for work places. For the most part individual values are taken from the T. L. list. Sponsored by the A. I. H. A., the Guides are not the product of a standard-developing group.

Definitions. Precise defining as to what the air standards apply is obviously a requisite for their proper application. At the present time the T. L. V.s and M. A. C.s are defined somewhat differently. Differing definitions are not in themselves a cause for concern if clearly understood, but in this instance, the same values are used as standards by both Committees, with a few exceptions. The T. L. Committee defines its limit as a "time-weighted average concentration for a normal workday." The Z-37 Committee defines its limit as a "ceiling" concentration below which it is understood all values are to fluctuate. Clearly, the same value permits a greater exposure on the T. L. definition than on the MAC definition, a confusing situation to those trying to comply with the standards. Actually, neither definition applies strictly to all substances alike, both those whose action is rapid and acute and those whose action is cumulative. Steps are being taken to resolve these difficulties.

Bases of Limits. There are three sources of information from which hygienic air standards are developed. 1) Industrial plant experience. 2) Experimental animal toxicologic studies, and 3) Experimental human exposure studies. On first thought it might seem that the first source would provide the best data for standard development. As a matter of experience, data from animal studies have yielded air standards that have not been revised with any greater frequency than those based on worker experience. (Slide 1)

A survey of the 148 threshold limit values up to 1953 according to informational source shows as good a record of stable values from animal sources as from man (67% and 65% unchanged values, resp.) In passing, the high rate of revision of those limits, either human or animal should be noted, when the data are derived from short-term studies, as would be expected. It is interesting to note also that Slide 1 shows that a T. L. value derived by analogy with some related substance had the lowest rate of revision of any group. Whether the proper inference from this finding is that T. L. values derived by analogy are better than those from other sources is not at all clear. Obviously analogies must have been drawn from other groups with a lower rate of stability so that one is forced to conclude that these analogies happened to be selected from among the most stable of the T. L. V. s. In general, unless considerable is known about relative metabolism and mechanism of action of a substance, T. L. V. derivation by analogy is beset with high risk, should be done only in emergency, chemical structural similarity notwithstanding. For example, would the T. L. V. of tetrachlorethane, Cl_2C-CCl_2, of 5 ppm have been derived by analogy with tetrachlorethylene, Cl_2C-CCl_2, with a T. L. V. of 100 ppm? It is highly doubtful.

Technical Advantages of Animal Research. The difficulties attendant on translating the results of animal toxicity studies to man have been so repeatedly emphasized that sight has been all but lost of the real advantages of animal experimentation is estimating the toxic potential of a chemical. By comparison with information obtainable from a study of industrial worker exposure, the following factors decidedly favor animal experimentation: 1) Strict control of exposure concentrations. By comparison, in industry it is rare to obtain continuously monitored reasons. Also, more often than not the worker experiences a mixed exposure that greatly complicates or precludes interpretation. Moreover, the duration that the worker experiences even a moderately well-monitored concentration is rarely known with the desired certainty. Lack of precise knowledge of the most fundamental factor in the environmental animal approach. 2) Strict control of duration of exposure. In contrast to industrial exposures that are more commonly than not, sporadic or intermittent, animal exposures can be controlled to be regular and of almost any duration. The toxic potential of most substances is directly a function of the duration of the exposure; a study of the toxic response from a intermittent or irregular exposure in general will be misleading. 3) More detailed study permitted. Study of the response to exposure of the industrial worker may be hampered at times by poor cooperation of the worker or management, but more importantly by the sheer inability to perform certain types of examination (X-ray, biopsy, blood tests) with sufficient frequency to be of value, if such desirable examinations are permitted at all. No such limitation is imposed by animal studies, blood tests, biopsies and sacrifices may be made almost without limitation to afford a serial view of the course of the response with exposure intensity.

Limitations of Animal Experimentation. It is clear from the foregoing that animal experimentation offers several advantages that can rarely if ever be completely met by similar studies made in the industrial environment. There are, however, at least two limitations to animal studies; 1) The obvious fact that animals are not people and thus may respond in varying degrees differently than man to the same exposure. As previously noted, however, the probability of reproducing the human response in animals increases as the number and judicious selection of animal species increase. 2) Animals, being essentially mute, serve best as test subjects for systemically toxic substances; substances whose primary response is sensory are best tested in man who can describe subtle irritations and discomfitures and relate them to the experienced concentration.

Kinds of Data - Human. The ideal information for developing a hygienic standard for air is, of course, a long-term environmental and medical study of a significant number of healthy workers exposed eight hours daily to a single, known substance. Few such studies have been made because of the rarity that such ideal situations present themselves. Accordingly, more often than not, evaluating committees must content with something less than the ideal either compromising on something less than adequate group size, exposure concentration, and nutritional control, medical supervision, or other factors crucial to an adequately controlled study.

Experimental studies on human beings are being made however, with increasing frequency of late. Toxic substances for which the kinds of data required relate to sensory effects, short-term, or single exposure repeated studies are adequate if performed under controlled conditions on groups of ten or twenty individuals. 1) On the other hand, long-term inhalation studies of man of two or more years in duration are confined by necessity of cost to an almost statistically unacceptable number of exposed subjects; careful control of environment and of the subject are in part vitiated by questionable representativeness of the exposed subjects.

Animal Data. By contrast, the kinds and types of data obtainable on animals is limited only by the experience and ingenuity of the toxicologist. Only one exception exists, as already mentioned - the muteness of animals limits their use of testing substances whose primary action is the production of sensory effects. Obviously, man is the subject of choice for this type of substance. The most valuable fund of information derived from animal studies is the relative degree of response obtained from a series of test inhalation exposure levels. From the degree of response at a known level in respect to a "no effect" level, a judgement can be formed as to the spread between an effect - and a no-effect level, a most important determination because it establishes a safety factor. Unequivocal information on the course of the response at each exposure level is supplied by periodic assays of the response by biochemical, pharmacologic, hematologic, physiologic and histochemical procedures.

Proper design of the chronic inhalation studies is generally contingent on prior determination of the acute single dose LC_{50} by inhalation and the LD_{50} values by mouth, skin, and eye, all sources of contact and routes of entry of industrial chemicals into the body. More often than not a 30 to 60 day subacute study is also needed to obtain the range of animal tolerance of the chemical upon repeated, daily exposures, to characterize the response, to try out definitive tests of toxic response and to obtain some sort of estimate of the most suitable times for periodic assay of the response. The subacute study is made purposely to bridge the gap between acute and chronic studies.

Evaluation of Data. Assuming average to good data will be derived according to guidelines proposed in "Principles and Procedures for Developing Experimental Animal Data for Threshold Limit Values for Air"(2), the next step is the evaluation of the data by the (Threshold Limits) Committee and the recommendation of a limit. One of the items of major importance is the "spread" between the no-effect or the borderline levels, and that producing frank injury. The next consideration of importance is the character of the disease, for from this is determined the seriousness of the response. For example, a substance from which overexposure could result in permanent injury or death (cyanides, silica, carbon tetrachloride) requires an obviously greater safety factor incorporated in the limit than a substance whose primary action is narcosis, (aliphatic hydrocarbons). Depending on the seriousness of the response, a safety factor of ten or more might be added to the level that produced no effect, whereas a factor of two might be added to the no-effect level of a narcotizing agent.

The importance of the safety factor cannot be overestimated; first, because it provides a "cushion" against the event that human susceptibility is considerably greater than that determined in animals; and secondly, it provides one of the bases for the prohibited use of TLVs as relative toxicity ratings. Clearly, if different safety factors are incorporated in the values, the true toxicity of a substance is not precisely expressed by a varying factor-incorporated value and thus ratios of TLVs cannot be struck between two limits to obtain a relative toxicity rating. There are other reasons for this also (see Misuse of Limits).

Interpretation of Limits. Following adoption of the air standards, it is most important that they be properly interpreted, not used blindly as a mystic number without reference to their bases. General guidelines to the proper interpretation of the standards are to be found in the preface to the T. L. list and in the MAC pamphlet. The first statement in the former document states that the TLVs are to be considered as guides in the control of health hazards, and not to be regarded as fine lines separating safe and dangerous concentrations. (This obviously follows from the recognition of the inclusion of the safety factor in the limit.) The next statement of importance concerns the inclusion of nearly, but not all workers; the occasional worker that is hypersusceptible or hypersensitive by reason of peculiar genetic or environmental conditions may not always be included in even those limits provided with large safety factors.

Confining our remarks for the moment to the TLVs whose definition of a limiting value is a time-weighted concentration averaged throughout a working day, a moment's reflection will raise the question of how much of a fluctuation above the limit is permissible in developing the average. It is precisely here that the interpretation of an experienced industrial hygienist is required. As a first step in correct interpretation, obviously fluctuation above the average value should be balanced by an equivalent fluctuation below the average. But, the factor that must be critically evaluated is the maximal fluctuation above the value permitted at any time. And the time factor is important. Here, the interpretation is based on the degree of response say for a period not to exceed 30 minutes, for the particular substance in question. Often such information is in the toxicologic literature or can be deduced from it. If, for example, the substance in question is ozone, a permissible above the limit (0.1 ppm) fluctuation for 30 minutes is twice the limit, or 0.2 ppm. On the other hand, a permissible above-the-limit fluctuation for 30 minutes for crystalline silica might be five or even ten times the limit for the dust of a given silica content; in this instance the magnitude of the excess permitted depends on the duration of prior exposure; the longer the past exposure, the larger the excess permitted.

If in practice excesses beyond these reasonable fluctuations of concentration and time have occurred, a hazardous condition is interpreted to exist, and operations should be curtailed or shut down pending correction of the situation.

Misuse of Standards. The preface to the T.L. list also contains guidelines on the improper use of air standards. 1) The standards should not be used as a common denominator of toxicity. The reasons in part for this prohibition have already been given. An additional reason is that many limits are based not on toxicity (health) considerations, but on irritation and discomfort, that have no direct relation to toxicity per se. e.g. SO_2, T.L.V., 5 ppm
HCN T.L.V. 20 ppm

One cannot conclude that SO_2 is 4 times more toxic than HCN; SO_2 limit is based on irritation; HCN on systemic toxicity. 2) The standards should not be used directly for limiting concentrations of substances in community air; the standards are based on the healthy adult worker, do not take into account populations of all ages and in varying states of health. 3) The standards should not be mathematically manipulated by applying physical constants for the derivation of relative hazard; exceptions are very closely related substances. The reasons given above are differing safety factors and bases for selection; if these two factors are not identical, then the standards may not be mathematically manipulated. e.g. Dividing two standards by some respective physical constant such as vapor pressure will lead to an erroneous estimation of relative hazard, unless the above-stated conditions hold.

Other prohibited uses are given in (3).

REFERENCES

1 Keplinger, M.L. The Use of Man for Toxicity Evaluation, Ind. Hyg. Foundation Meeting, October 24, 1962.

2 Principles and Procedures for Developing Experimental Animal Data for Threshold Limit Values for Air, Threshold Limits Committee, Am. Conf. Govtl. Ind. Hygienists, October 1962.

VALID REPRESENTATIVE AIR SAMPLES — LOCATION, TIME, DURATION, WORK CYCLES, PEAKS AND TIME WEIGHTED AVERAGE CONCENTRATIONS

The preface of the Threshold Limit Values of Airborne Contaminants, the document from which most of the standards for airborne contaminants promulgated by OSHA under Title 29, Code of Federal Regulations, Part 1910, were drawn, states that "They (the TLV's) should be used as guides in the control of health hazards and should not be used as fine lines between safe and dangerous concentrations." Certain exceptions are noted.

A recent statement by a committee of the American Industrial Hygiene Association proposed that the AIHA Journal publish the following; "Threshold limit values for airborne particulates which were developed as guidelines for estimating potential hazard to the individual worker are now being used as absolute standards to define safe and unsafe conditions. Frequently this interpretation transforms the eight-hour time weighted concentration (inherent in the TLV definition) into a maximum ceiling level for air sampling purposes. In light of (1) the limited precision of currently used particulate air sampling procedures, (2) the temporal variability in working-environment air concentrations and (3) the statistical extrapolation of air sampling data to estimate risk to the worker, the AIHA-ACGIH Aerosol Hazards Evaluation Committee wishes to re-emphasize that TLV's should not be used as exact dividing lines between safe and unsafe work conditions."

From the preceding statements, it is apparent that industrial hygienists are concerned now, as in the past, with the use of threshold limit values and that they are especially concerned about their use as enforceable standards. The problem with both of the preceding statements is that they are negative. They tell us what not to do, but they do not tell us what we should do. In the next few minutes I am going to discuss some of the positive things we can do to take into account the limitations in the TLV's insofar as we are able and at the same time get on with the work of protecting the health of workers exposed to harmful air contaminants. Specifically, I will examine the reasons why there are objections to the use of the TLV's, or any other number for that matter, as standards and what we can do to deal with these objections when TLV's are used as standards.

The two basic problems in using TLV's as standards concern the accuracy of the TLV as an index of biological risk and the accuracy of measurements of air concentrations in assessing exposure. These are separate problems and I will consider them, each in turn.

The philosophy underlying the use of the TLV has always been that it is better to have a number which is not known to be a perfectly accurate representation of the safe level of exposure than to have no number. Consequently, it has always been the practice of this standard setting group (ACGIH), when it was known that there was a potential hazard, to adopt a number based on the best information available. Sometimes the best was not very good. Only rarely was a detailed dose-response relationship based on human exposure over a sufficiently long period of time available for the purpose of setting standards. We should consider ourselves fortunate that it was not, since in order for data of this kind to occur it is necessary that there be a significantly large number of people exposed to such a degree that a measurable amount of disease is occurring. Fortunately, there are few large populations of workers who are getting frank occupational diseases. In most cases, it is necessary to use animal data and I will not dwell on the difficulties in extrapolating from the results of animal experiments to

---

Prepared by Jeremiah Lynch, Sanitary Engineer, Director, Division of Training, NIOSH, 9/73.

humans, except to say that animals are quantitatively different in a great number of respects, most important of all perhaps in that they do not live as long. It is, therefore, not possible to estimate the effect of life-long exposures lasting 20, 30, or 40 years. Further, some of the TLV's were set by analogy to some other compound of known toxicity. Some of them were set based on such matters as irritation and general plant housekeeping. Smyth analyzed the ACGIH Documentation to answer the question of what each TLV attempts to present. He found "30% of the values guard against irritation, 7% are simply standards of good practice, and 63% guard against toxic effects." This is not to say that 37% of the substances listed are only irritants or housekeeping problems, but rather these are the effects at TLV concentrations. Other, more serious effects occur at higher concentrations in almost all cases.

The Department of Labor, in developing OSHA Program Directives for the target health hazard program, considered the basis of each limit and the effect of exposure at that level and at higher levels in determining categories of violations as shown in Table 1. This classification is in line with the toxicologists point of view as expressed by Smyth that "De Minimus should apply to concentrations which may have an objectionable odor, a trivial irritation of eye, nose or throat, or which may simply represent poor housekeeping."

Table 1. CATEGORIES OF VIOLATION

	De Minimus	Non-serious	Serious	Imminent Danger
Carbon Monoxide	NA	50-150 ppm for 8 hrs	$>$150 ppm for 1 hr	$>$500 ppm for any time
Asbestos	NA	NA	5-6 for 8 hrs	NA
Quartz	NA	.1 - .4 mg/m^3 for 8 hrs	$>$.4 mg/m^3 for 8 hrs	NA
Lead	NA	.2 - .6 mg/m^3 for 8 hrs	$>$.6 mg/m^3 for 8 hrs	NA
Cotton	NA	1-3 mg/m^3 for 8 hrs	3 mg/m^3 for 8 hrs	NA
Coal Tar Pitch Volatiles	NA	NA	0.2 mg/m^3 for 8 hrs	NA

It is true that the TLV's are not fine lines and in fact that fine lines do not exist. It isn't even correct to talk about a safety factor because of the response of a population of individuals to an air contaminant looks more like either of the following illustrations. In the first case (Figure 1), we can say that there is a level at which no significant effect occurs and then beyond that there is a range over which a greater and greater proportion of people become affected until a level is reached at which virtually everyone is adversely affected. This is the traditional concept of the threshold. However, as is shown in Figure 2, a continuous range of doses from those at which very few people are affected to doses at which a great number of people are affected, is more likely. In this situation, the limit is set at a point where some acceptable percentage of individuals is affected. I use that word acceptable reluctantly since I feel, as probably you all do, that no occupational disease is acceptable. For example, 90 dbA does not prevent all acoustic trauma. The same is true with the limit for cotton and probably also with beryllium. It is evident, therefore, that any limit is arbitrary to a degree. The real question then is what dose levels can be permitted with an acceptable risk and are the present TLV's based on these dose levels. The answer is that certainly not all of them are. Some may be too low as in the case of nuisance or irritant materials. Some are too high as for example the asbestos TLV of two years ago. I think that it is probable that future evidence will show most of them to be too high. I base this supposition on the very limited and preliminary information that we have on the nonspecific diseases often referred to by Professor Hatch, the very limited data on long-term effects, and the very limited data on the combined effects of several hazards which coexist.

In NIOSH, as authorized under the Occupational Safety and Health Act, we are proceeding via the criteria document mechanism to propose to the Department of Labor new standards which will eliminate some of the objections I have described. These new standards should insure that no employee will suffer diminished health, functional capacity, or life expectancy when standards are enforced in conjunction with a program of medical surveillance to detect the hyper suspectible. Such standards, which are based on health effects rather than discomfort, may properly be considered fixed enforceable requirements rather than discretionary guides.

My own operating conclusions with regard to the question of the accuracy of standards as estimates of biological risk are as follows:

1 Limits must be set for hazardous air contaminants using the best information available.

2 The TLV's and ANSI limits are, on the whole, derived from the best estimates of acceptable dose levels.

3 These estimates are being continuously refined by epidemiological and toxicological research which will lead to periodic revision of the limits.

4 For practical control purposes the accuracy of the limits is adequate.

In the practice of industrial hygiene, although we may be unable to consider in the decision making process, the accuracy of the limit, especially when the limit has been adopted into a legally enforceable standard, we can and must consider a number of factors having to do with the accuracy of the measurement. It is in this respect that the dictum that we should not consider the standards to be fine lines has the greatest meaning.

The difficulty in measuring the biologically significant dose to the worker based on some number of measurements made with instrumentation of limited accuracy over a period of time whose extent is not identical with the period of exposure involves four basic problems.

1 The TLV and the standard derived from it are based on a dose-response relationship. From that dose-response relationship we establish a standard for exposure and then we go into the workplace and make a measurement of concentration. The bridges or connections between dose and exposure and concentration each involve

a potential error. It has long been recognized that there is considerable variability among individuals in terms of their response to a dose that was assumed to be the same. What may be happening in this case is an actual difference in dose even during the same exposure. For example, the dose will vary for the same exposure if the breathing rate varies. It will also vary with the effectiveness of the lung clearance mechanisms, which in turn are affected by such things as cigarette smoking. This problem partly relates to the earlier discussion on the validity of the limit since the limit is in terms of exposure. However, our estimate of exposure based on measurement of concentration is also subject to errors. When respirators are provided, it is necessary to consider whether they are really being used. Are they being used continuously when an exposure situation exists or are they only being used at the time that the inspector or industrial hygienist is present. Even when they are being used, how much protection is being provided? Has the proper type been selected and does it fit the worker? When a respirator is used and if it fits, then it is appropriate to divide the concentration by the respirator protection factor, if it is known, to determine the exposure. (You may be interested to know that among the goals of NIOSH is the assignment of protection factors to the various classes of respirators.)

The basic factor in the relationship between concentration and exposure doses is where the sample is taken. If a fixed, general air sample is collected, it will of course measure the concentration where the sampler is located, but that may not be where the worker is located. The obvious solution is to hang the sampler on the worker so that it travels around with him. It has become easier to do this with the advent of long-period personal samplers, charcoal tubes, and other solid sorbent methods for such things as solvent vapors, and the development of new low flow rate (50-200 cc/min) and intermediate flow rate (20-25 lpm) personal samplers that will accommodate a variety of sampling situations. Even when the sampler is hung on the worker, there is the possibility that the concentration at the location of the sampler inlet on the lapel is somewhat different from that in the inhaled air of the worker.

2 The second source of error in our estimate of exposure based on some set of measurements is caused by what the AIHA Committee referred to as "the temporal variability in the working environment air concentration." There are two aspects to this problem.

The first is that the dose of importance may be that received over some long period of perhaps years, whereas the standard is for an 8-hour average. In employer monitoring, some consideration should be given to whether the day on which the sample was selected was representative of all other days. Thus, for the purpose of monitoring worker exposure to determine the real risk to health, it is necessary to devise a sampling scheme where measurements are made on different days throughout the year to insure that an accurate estimate is made in view of this environmental variability. However, the inspector is in the position that if he finds that the concentration truly exceeded the standard for the appropriate period of time, it does not matter what concentrations existed at other times.

The second aspect of the effect of temporal variability on measurement accuracy is the relation of the sampling period to the period of exposure to which the standard applies. Before considering this source of error, it is first necessary to discuss the various limit internal concepts which are being used.

a Ceiling Limit - This is the simplest type limit in that there is only one time interval, 15 minutes, in the case of a TLV. For example, if a 17-minute sample for TDI yields a concentration of 0.03 ppm, the limit of 0.02 ppm is exceeded. (Figure 3)

b Eight-hour Average with Excursion - Most TLV's are for eight-hour average exposures except that an excursion factor is also given. This means that the TLV times the excursion factor should not be exceeded for a short period, usually considered 15 minutes. Thus, a 25-minute sample of acetone yielding a result of 1,500 ppm would exceed the excursion limit of 1,250 ppm obtained by multiplying the eight-hour limit of 1,000 ppm by the excursion factor of 1.25 (Figure 4).

c Eight-hour Average with Short-term Limit - Several recent criteria documents, such as those for beryllium and asbestos, have included limits for short periods in addition to the eight-hour average. For example, the eight-hour average for beryllium shall not exceed 2 μgm/m^3 and peak exposure based on a 30-minute or longer sample shall not exceed 25 μgm/m^3 (Figure 5).

d Eight-hour Average with Ceiling and Peak Limits - The ANSI Z37 standards frequently provide for a peak limit not to be exceeded for any time, over a ceiling which may be exceeded up to the peak, once a day, for a short period, in addition to the eight-hour average. A 15-minute sample of toluene at 400 ppm would exceed the ceiling limit of 300 ppm for 10 minutes (Figure 6).

The reasoning behind these various concepts is beyond the scope of this discussion. The important point, with respect to measurement accuracy is that, with the exception of the ANSI peak, which I do not understand, there is a time period appropriate to every limit.

The ideal sampling period would be equal to the period which applies to the limit. Even in the case of the 5-, 15-, and 30-minute limit periods this may be difficult and given the constraints imposed by our limited sampling methods, we are frequently unable to sample for a full eight hours. While much work is being done on the development of samplers that will permit full shift sampling, in many cases at the present time it is necessary to use grab samples and to statistically infer what conditions would have existed and what results would have been been found had we sampled for the full eight hours. Such statistical inference has a well defined and calculable error. We must insure then that when inferential measurements are made, this error is considered whether in the compliance decision or in the decision of the employer as to whether or not control is warranted. Appropriate methods are described in Appendix A.

To digress for a moment, the concept of the time weighted average should be considered. When an industrial process has a cyclical nature and when it is known that the concentration varies with these cycles and exhibits only random variation within cycles and when only short period sampling methods are available, then it may be appropriate to use the time-weighted method of calculation to determine the eight-hour average. If we are not able to sample for the full duration of each cycle, then a number of samples should be collected in each cycle and the cycle average inferred statistically. Given these cycle averages, and assuming the assumptions mentioned above are valid, the eight-hour average may be calculated from the formula:

$$\frac{C_1 T_1 + C_2 T_2 + \text{---} \; C_n T_n}{8 \text{ hrs}}$$

Figure 7 shows an example of this procedure.

Considering the assumptions which need to be made and the number of samples that need to be collected, both within and between cycles, in most cases the statistical method of random sampling over the eight-hour period will be more convenient and accurate. Of course, a single sample or a combination of samples covering the full eight hours is to be preferred over either the time weighted average calculation or the random inference method.

The third and most obvious source of error results from sampling and analytical inaccuracies. Due to rotameter reading errors and errors in calibration the flow rate of the sampling device could be off by as much as 5 to 10 percent. The analytical method error, when all things are considered including interlaboratory variations, could be up as high as 60 percent as was reported by Bumsted in the case of quartz analysis. Fortunately, analytical errors are frequently lower and the range of combined errors in sampling and analysis generally do not exceed 25 percent.

All I have been talking about up to now have been problems. It's about time I came up with some solutions. In other words, what can we do about all of this. There are two things we should not do, but which have been done all too frequently in the past. The first is to ignore all of this, to not consider any of the sources of errors that I have discussed, to take a grab sample with a detector tube, eyeball a reading of 51 when the limit is 50 and lower the boom. This is certainly not the way to go. Our credibility as professionals in the field of occupational safety and health cannot withstand behavior of this sort. The second is to recognize all these problems, throw up our hands and say it's all too complicated and that, therefore, we cannot enforce standards which will protect the health of the worker. This argument in all of its various forms has been at the root of the reason why air contaminant standards in industry have not generally been enforced in the past and is therefore one of the reasons for the passage of the Occupational Safety and Health Act. This alternative also fails for the obvious reason that if the standards are not enforced the worker is not protected.

There is a more constructive approach. Some suggestions may be offered to those who have the responsibility for determining compliance and for those who would critically evaluate the working environment in their own establishment.

1 Accept the standards as being based on the best estimate of the dose-response relationships available. And remember, the Act provides for setting standards "dealing with toxic materials or harmful physical agents ... on the basis of the best available evidence." There are many who argue that standards are too high and many who say they are too low, frequently talking about the same standard. It is clear also that this situation will improve as research develops better and better data. If we wait for the certainty that the standard is perfect and will never again need to be changed and will never be challenged, it goes without saying we will never have a standard and the worker will go unprotected.

2 Measure exposure wherever possible. Personal sampling is the preferred method with breathing zone sampling as a somewhat less satisfactory alternative. General air sampling for the measurement of exposure should only be used when the relationship between the general air concentrations and the worker exposure are known as a result of some specific studies.

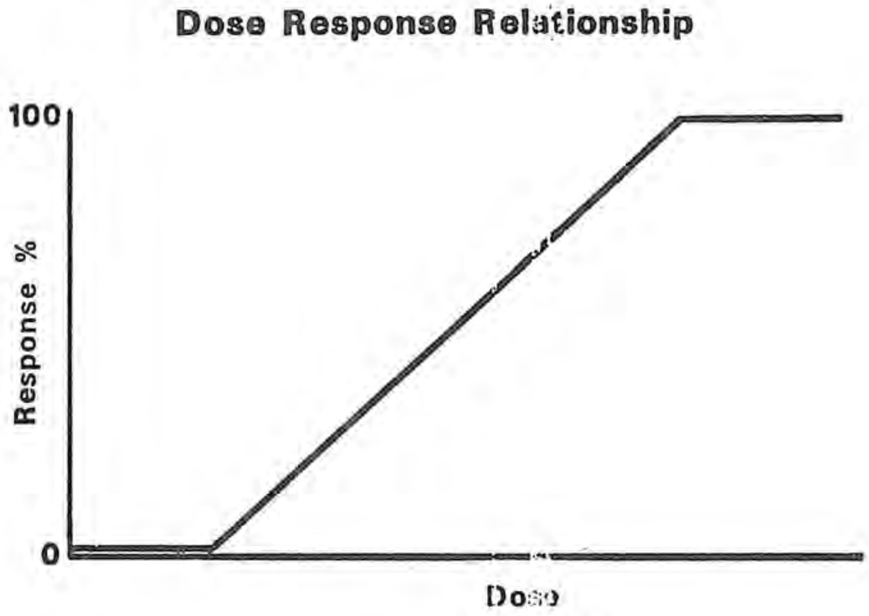
3 Sample over the full period appropriate to the standard whether it be 15 minutes in the case of the ceiling or eight hours in the case of a full shift standard. If this is not possible, then grab samples may be used to estimate the most likely measurement that would have been made if an eight-hour sample had been collected. Appropriate statistical techniques should be used to define the confidence limits of this estimate. As a last alternative, the time-weighted average method of estimating an eight-hour average based on a series of grab samples should only be used when sufficient hard data on the cycles and their effect on the concentration in the environment are known and enough samples are collected within each cycle.

4 When the limit is for an eight-hour average, samples should also be

collected during periods of peak exposures to evaluate the excursion or short term limit.

5 Consider both the environmental variability and the sampling and analytical error in making the decision. These errors should be considered both in the case of an inspector determining that the environment is certainly unsafe and therefore a citation is appropriate, and in the case of the employer's determination that the environment is certainly safe and that no control action need to be taken.

In conclusion, it has been my intent in these preceding remarks to take a positive view of what can be done in the application of the air contaminant standards adopted under the Occupational Safety and Health Act. Although these standards have been characterized as <u>not</u> fine lines between safe and unsafe conditions, they are the best available at this time and do constitute standards which should be enforced because not to enforce them would leave the worker unprotected. We should try to enforce them with logic and reason considering the principles that I have discussed and thereby arrive at conclusions that are fair to all concerned.



Dose Response Relationship

FIGURE 1

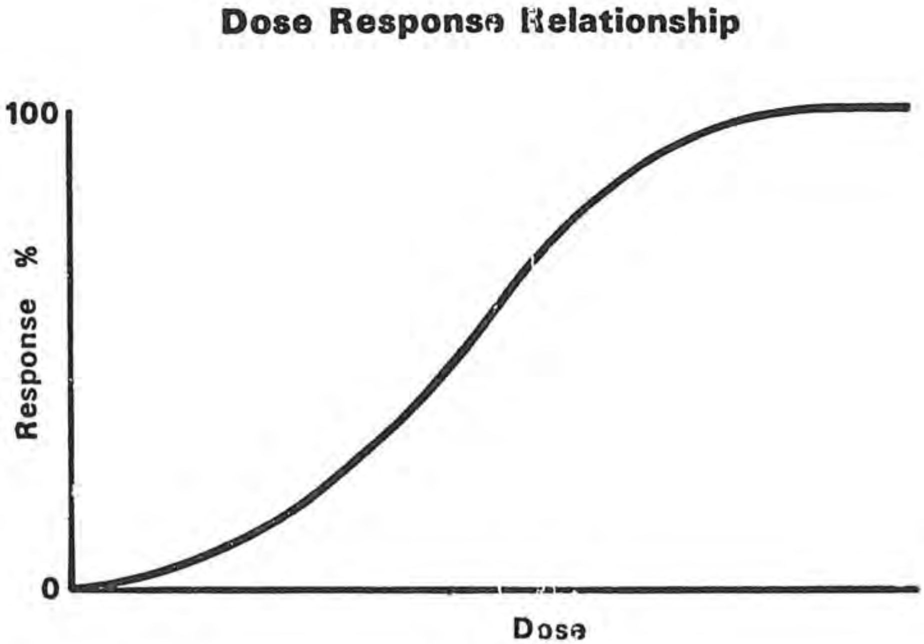


FIGURE 2

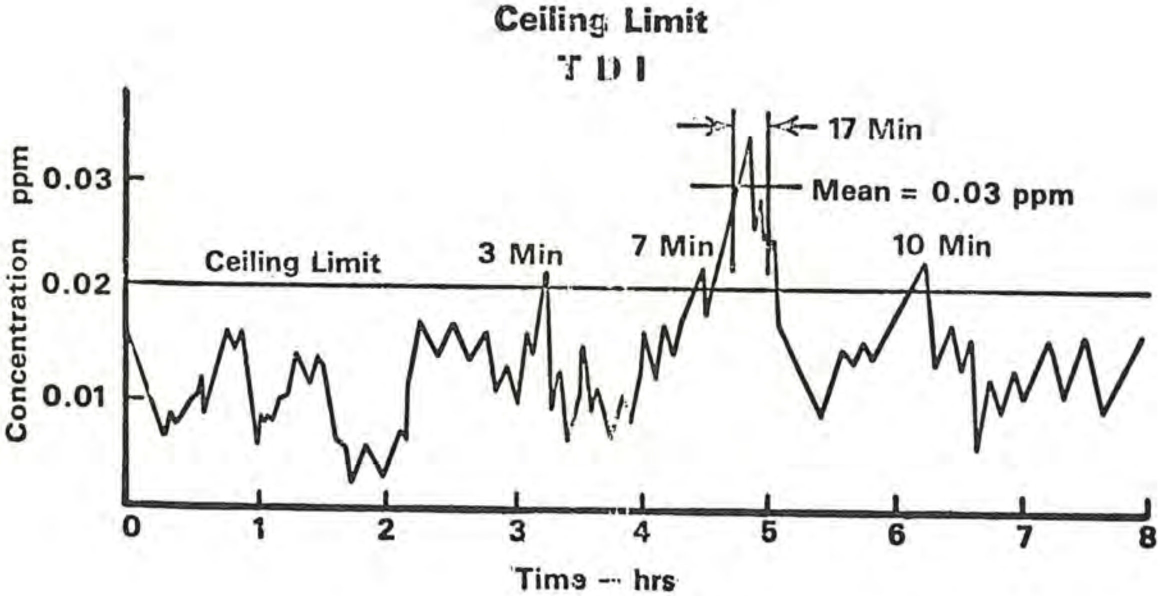


FIGURE 3

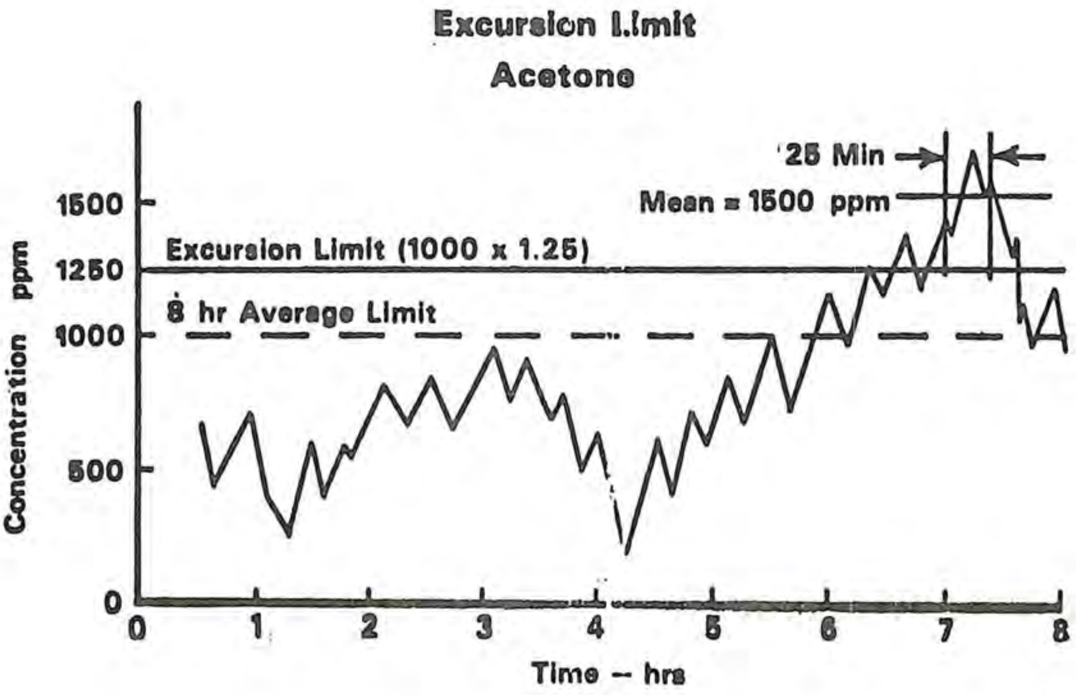


FIGURE 4

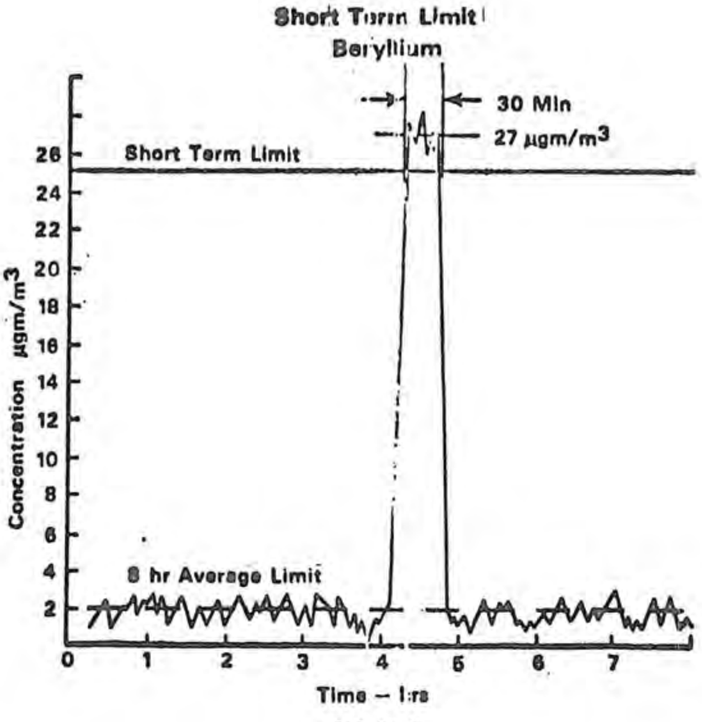


FIGURE 5

Ceiling and Peak Limits
Toluene

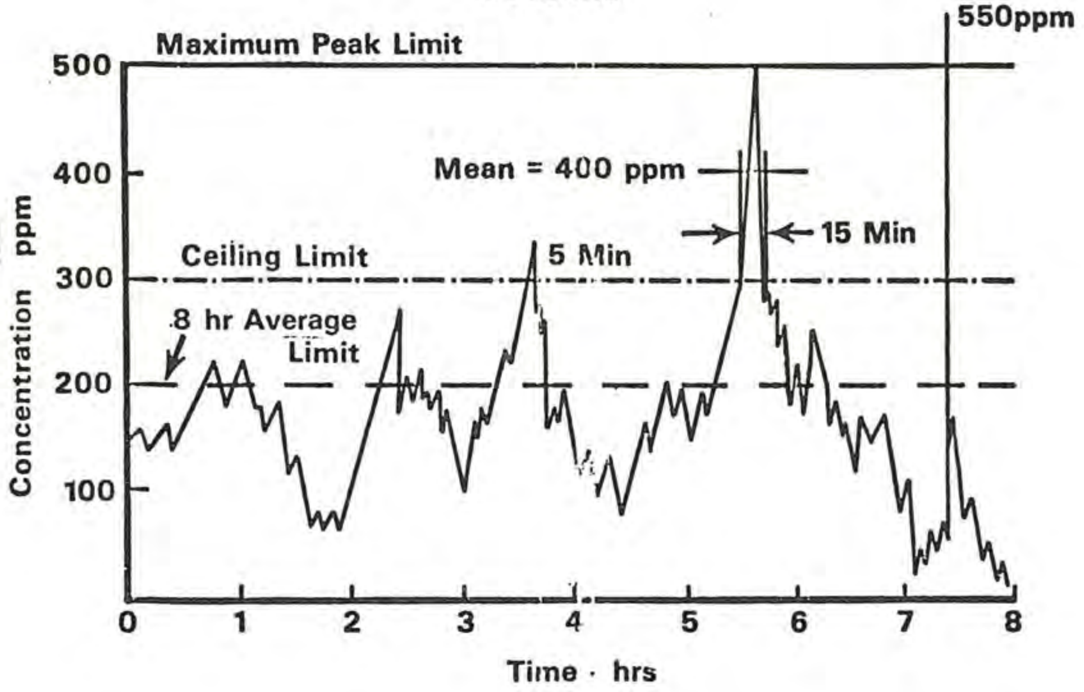


FIGURE 6

Time-Weighted Average

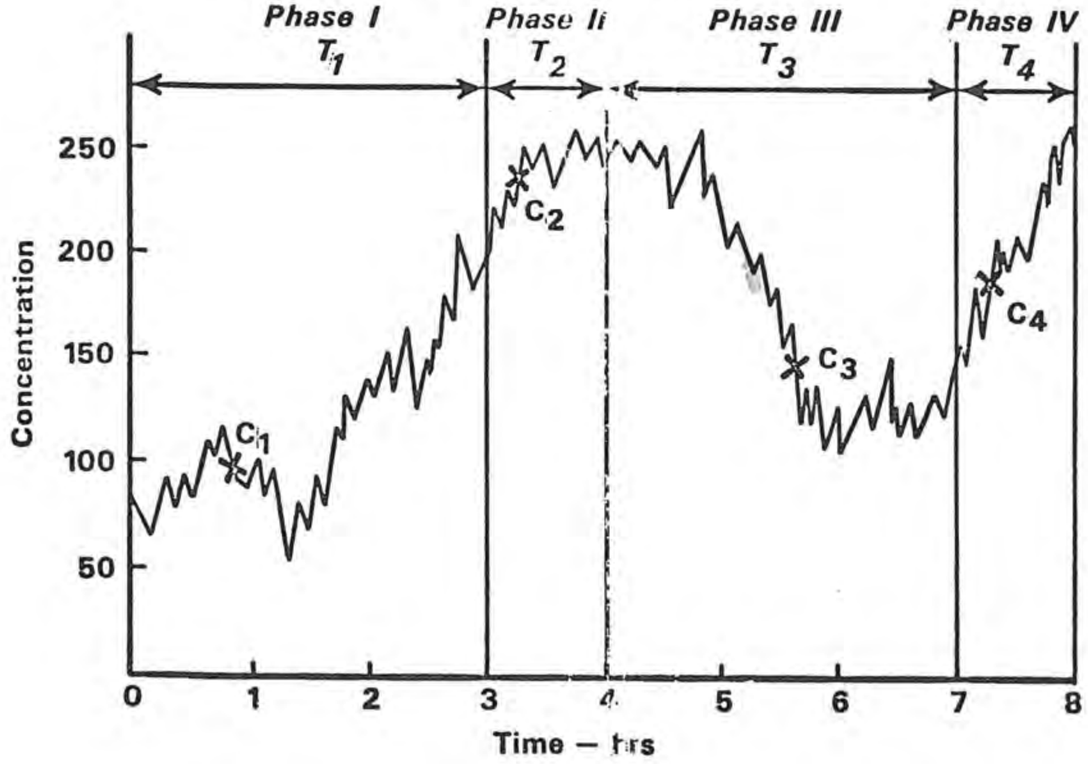


FIGURE 7

EVALUATION OF SHORT TERM EXPOSURES

I EMERGENCY EXPOSURE LIMITS, EEL's

A Tentative EEL's Developed by R. L. Zielhuis

1 Sulfur dioxide

2 Sulfuric acid

3 Chlorine

4 Phosgene

B Exposure Criteria for Fluorine Rocket Propellants Developed by P. M. Ricca

1 Hydrogen fluoride

2 Elemental fluorine

C EEL's Presented by the Toxicology Committee of the American Industrial Hygiene Association

1 Nitrogen dioxide

2 1,1-dimethylhydrazine (UDMH)

3 1,1,1-trichloroethane (methyl chloroform)

II NIOSH CRITERIA DOCUMENTS

A Asbestos

10 fibers > 5 μm/cc - minimum sampling time of 15 min.

B Beryllium

25 μg Be/m^3 - minimum sampling time of 30 min.

C Carbon Monoxide

No level to exceed 200 ppm ceiling

D Hot Environments

Wet Bulb Globe Temperature and Exposure Time Relationships

E Noise

No exposures to exceed 115 dBA-Slow

III SOURCES OF INFORMATION ABOUT SHORT TERM OR ACUTE EXPOSURE

A Governmental Agencies

1 OSHA 2 NIOSH

B Professional Societies

C ACGIH (TLV's)

D AIHA (Hygienic Guide Series)

E American National Standards Institute ANSI)

F National Safety Council (Industrial Data Sheets)

G Trade Associations (MCA Data Sheets)

H Books

I Journals

J Manufacturers Literature

REFERENCES

1 Ricca, P. M.: Exposure Criteria for Fluorine Rocket Propellants. Arch. Environ. Health 12:399-407 (March 1966).

2 Zielhuis, R. L.: Tentative Emergency Exposure Limits for Sulfur Dioxide, Sulfuric Acid, Chlorine, and Phosgene. Ann. Occup. Hyg. 13:171-6 (1970).

3 American Industrial Hygiene Association, Toxicology Committee: Emergency Exposure Limits. Am. Ind. Hyg. Assoc. J. 25:578-86 (Nov.-Dec. 1964).

Prepared by William H. Perry, Chemist, Division of Training, NIOSH, 9/72.

4 "Hygiene Guide Series", American Industrial Hygiene Association, 210 Haddon Avenue, Westmont, New Jersey 08108.

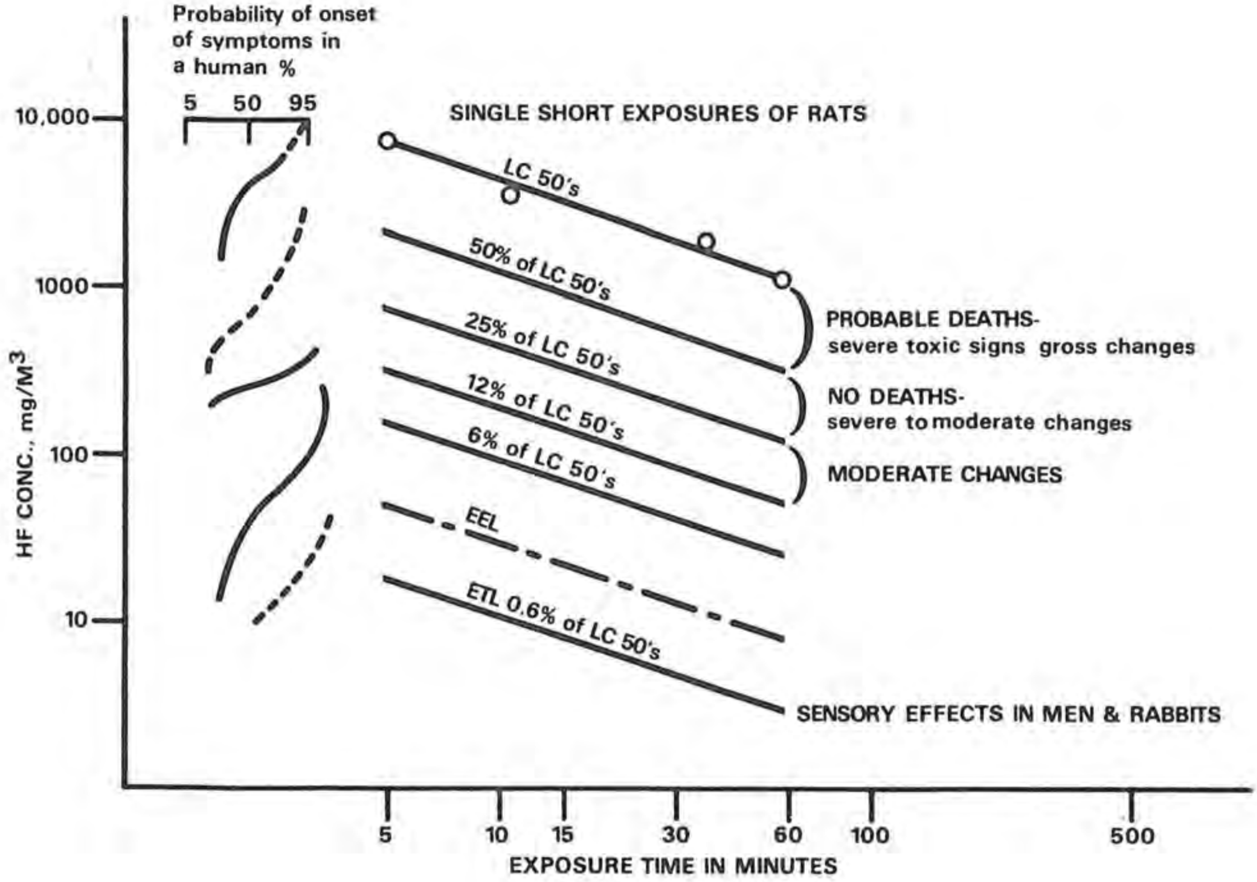
5 "Industrial Data Sheets" National Safety Council, 425 N. Michigan Avenue, Chicago, Ill. 60611.

6 "Data Sheets" Manufacturing Chemists' Association, 1825 Connecticut Avenue, N.W., Washington, D.C. 20009

7 Criteria for a recommended standard .... Occupational Exposure to:

Asbestos (HSM 72-10267)

Beryllium HSM 72-10268)
Hot Environments (HSM 72-10269)
Carbon Monoxide (HSM 73-11000)
Noise (HSM 73-11001)
USDHEW, PHS, HSMHA, NIOSH; 1972.



EMERGENCY EXPOSURE LIMITS - CHEMICAL

I. DEFINITIONS

A. Threshold Limit Values (TLV's) - OSHA (1968) and ACGIH

Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit, a smaller percentage may be affected more seriously by aggravation or a pre-existing condition or by development of an occupational illness.

Threshold limit values refer to time-weighed concentrations for a 7 or 8 hour workday and 40 hour workweek. They should be used as guides in the control of health hazards and should not be used as fine lines between safe and dangerous concentrations (Exceptions are the substances listed in Appendices E and F and those substances designated with a "C" or Ceiling value, Appendix D)

1. Ceiling Values

Although the time-weighed average concentration provides the most satisfactory, practical way of monitoring airborne agents for compliance with the limits, there are certain substances for which it is inappropriate. In the latter group are substances which are predominantly fast acting and whose threshold limit is more appropriately based on this particular response. Substances with this type of response are best controlled by a ceiling "C" limit that should not be exceeded. It is implicit in these definitions that the manner of sampling to determine compliance with the limits for each group must differ; a single brief sample, that is applicable to a "C" limit, is not appropriate to the time-weighed limit; here, a sufficient number of samples are needed to permit a time-weighed average concentration throughout a complete cycle of operations or throughout the work shift.

BASIS FOR ASSIGNING LIMITING "C" VALUES

By definition in the Preface, a listed value bearing a "C" designation refers to a "ceiling" value that should not be exceeded; all values should fluctuate below the listed value. This, in effect, makes the "C" designation a maximal allowable concentration (MAC). In general, the bases for assigning or not assigning a "C" value rest on whether excursions of concentration above a proposed limit for periods up to 15 minutes may result in a) intolerable irritation, b) chronic, or irreversible tissue change, or c) narcosis of sufficient degree to increase accident proveness, impair self-rescue or materially reduce work efficiency.

2. Excursions

Whereas the ceiling limit places a definite boundary which concentrations should not be permitted to exceed, the time-weighted average limit requires an explicit limit to the excursions that are permissible above the listed values. The magnitude of these excursions may be pegged to the magnitude of the threshold limit by an appropriate factor.

EXCURSION FACTORS

For all substances not bearing C notation

TLV (ppm or mg/m^3)	Excursion Factor
0-1	3
1-10	2
10-100	1.5
100-1000	1.25

The number of times the excursion above the TLV is permitted is governed by conformity with the Time-Weighted Average TLV.

Prepared by Adrian L. Linch, Consultant, Environmental Health, 6/76.

EXAMPLES

Substance	TLV	Excursion Factor	Max. Conc. Permitted for Short Time
	ppm		ppm
Nitrobenzene	1	3	3
Carbon Tetrachloride	10	2	20
o-Dichlorobenzene	50	1.5	75
Acetone	1000	1.25	1250
Boron trifluoride	C1	—	1
Butylamine	C5	—	5

3. Skin Absorption Factor (S)

"Skin" Notation. Listed substances followed by the designation "Skin" refer to the potential contribution to the overall exposure by the cutaneous route including mucuous membranes and eye, either by airborne, or more particularly, by direct contact with the substance. Vehicles can alter skin absorption. This attention-calling designation is intended to suggest appropriate measures for the prevention of cutaneous absorption so that the threshold limit is not invalidated.

4. Short Term Limits (STL's)

Short-Term Limits (STL's). Because many industrial exposures are not continuous, 8-hour daily exposures, but are short-term, or intermittent, to which the TLV's do not necessarily apply, STL's for 5, 15, or 30 minutes for 142 substances have been put into the regulations of the Pennsylvania Department of Health (Chapter 4, Art. 432, Revised Jan. 25, 1968). These STL's represent the maximal average atmosphere concentration of a contaminant to which a worker may be exposed for the stipulated time. The concentration represents an upper limit of exposure and assumes that there is sufficient recovery between exposures before another is initiated. The daily average exposure including that provided by the STL shall be such that the TLV shall not be exceeded.

Similar STL's for a more restricted number of substances have been recommended by the American National Standards Institute. This standard-setting body refers to these short-term limits as "peaks."

5. Physical Factors

Physical Factors. It is recognized that such physical factors as heat, ultraviolet and ionizing radiation, humidity, abnormal pressure (altitude) and the like may place added stress on the body so that the effects from exposure as a threshold limit may be altered. Most of these stresses act adversely to increase the toxic response of a substance. Although most threshold limits have built-in safety factors to guard against adverse effects to moderate deviations from normal environments, the safety factors of most substances are not of such a magnitude as to take care of gross deviations. For example, continuous work at temperatures above 90°F or overtime extending the workweek more than 25%, might be considered gross deviations. In such instances judgment must be exercised in the proper adjustments of the Threshold Limit Values.

Reference: The foregoing paragraphs were taken from "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1974. ACGIH, P.O. Box 1937, Cincinnati, Ohio 45201.

B. Emergency Exposure Limits (EEL) and Short Term Tolerance (STT) Limits (Ref. Amer. Ind. Hyg. Association J., Nov-Dec. 1964, 572)

Emergency Exposure Limits are concentrations of contaminants that can be tolerated without adversely affecting health but not necessarily without acute discomfort or other evidence of irritation or intoxication. They are intended to give guidance in the management of single, brief exposures to airborne contaminants in the working environment.

In recommending these Limits, the Committee makes several assumptions: (1) Exposures at these levels will be accidental, not the result of engineering controls designed to hold exposures at these levels. (2) Normally prevailing values of airborne contamination will be below Threshold Limit Values or Maximal Acceptable Concentrations. (3) These accidental exposures will be single events, i.e., if a man is exposed at these levels, further exposure will be prevented (e.g., by removing the man from the work area) until he regains his normal resistance. (4) Men who could be exposed under these conditions are not idiosyncratic, hypersensitive, or otherwise predisposed to disease from the specific contaminant. (5) Men who would be exposed under such conditions are under medical surveillance. (6) The probable severity of injury due to secondary accidents, including those resulting from impairment of vision, judgement and coordination, must be considered by those applying these values. In connection with this last point, a degree of intoxication, even though reversible, that prevents self-rescue is not considered acceptable; these Limits are believed sufficiently low so that exposure at these levels will not prevent such self-rescue operations as walking out of the area or shutting off valves.

In contrast to Threshold Limit Values recommended by the American Conference of Governmental Industrial Hygienists, Maximal Acceptable Concentrations recommended by the American Standards Association, or Hygienic Guides of the American Industrial Hygiene Association, these Emergency Exposure Limits are not intended to be used as guides in the maintenance of hygienic work environments, but rather as guidance in advanced planning for the management of emergencies. They are peak values which should not be exceeded except in circumstances where impairment to health is justifiable in order to prevent a still more serious event. The "safety factor," often used in deriving air-quality guides, is not applied in these Limits except in cases of low confidence in the extrapolation to man of data derived from animals.

Mixtures of contaminants involve additional factors that have not been taken into account in recommending these values. Industrial Hygienists should consider possible interactions such as potentiation or antagonism in making recommendations for specific situations where two or more contaminants may co-exist.

Like other guides in industrial hygiene practice, these Emergency Exposure Limits are intended for use by specialists in industrial hygiene. Their use as indices of comparative toxicity and as fine lines dividing dangerous from tolerable levels of contamination can lead to false conclusions, and such uses should be avoided. Further, extrapolation of these Limits to other exposure periods, by use of the CT product, dosage rate, or other relationships, is not necessarily valid; it is especially dangerous to extrapolate these Limits to time periods of less than 5 minutes.

C. Immediately Hazardous to Life (IHL) and Immediately Dangerous to Life and Health (IDLH)

Limits of concentration and time beyond which death probably would occur. Below these limits recovery would be expected for most people, but permanent physiological damage could be expected. These values are extreme emergency conditions which must be limited to a once in a lifetime event. The limits can be used in the calculation of disaster conditions which might arise in the failure of storage tanks, runaway chemical reactions, transportation accidents, explosions, etc.

II. TABULATION OF LIMITS - Table 1

A. Explanation of Terms - Notes for Table 1

B. Inter-relationships between Limits

Fine lines of distinction cannot be drawn between TLV, tolerance levels and emergency limits due to uncertainty of the data, variations in human response to any given stress, chemical or physical. Also, ambient conditions such as temperature, humidity, combustion products, physical exertion, excitement and panic may potentiate the effects of the exposure. In some cases narcotic or anesthesia effects may incapacitate the person to a point which prevents self-rescue or other life preserving activity without causing death or permanent injury (ethyl ether). Others are simple asphyxiants which reduce oxygen concentration below viable levels (acetylene) or concentrations reach explosive limits.

C. Animal versus Human Experience

In many cases only experimental animal data is available (asterisk* notations). Judgment must be exercised in the application of these limits as animal physiological response cannot be directly extrapolated to human reactions. In many cases the animal is more susceptible, but this factor cannot be applied without direct observation. Therefore, these data are only indicative of the degree of hazard and a generous safety factor must be used in direct applications.

D. Questionable Data

In some cases, for example ethyl acetate, the time limit is not reported in minutes, but subjectively as "short" which leaves interpretation up to the user, and therefore, incorporates chance for error. In other cases very wide ranges of both time and concentration have been recommended - for example, 2-hexanonl, 10,000 to 20,000 PPM for 30 to 60 minutes. In other cases no time limit is stated - example, ethyl bromide. This type of data relies too heavily on human judgment.

III. NUISANCE VERSUS HAZARDOUS SUBSTANCES

Even a cursory examination of Table 1 will disclose large discrepancies in the concentrations of various substances at the hazard level. Example:

Substance	TLV	STT	IHL
	ppm	ppm	ppm
Propylene Dichloride	75	400-500	above saturation
Acrolein	0.1	1	133-178

However, the numbers in themselves cannot be used to compare toxicities as the tissue system attacked, or the physiological effects may be entirely different as phosgene versus aniline.

IV. SUSCEPTIBILITY FACTORS

A. Between individuals - See Part I-A - TLV's

"Because of wide variation in individual susceptibility, however, a small percentage of workers may experience discomfort from some substances at concentrations at or below the threshold limit; a smaller percentage may be affected more seriously by aggravation of a pre-existing condition or by development of an occupational illness."

The same conditions will be encountered in the EEL and STT limits. Some few individuals may succumb to ranges of concentration which can be tolerated by 95% of the work force. In some cases such as the diisocyanate respiratory sensitization syndrome these individuals can be identified and placed in work areas

Table 1. THRESHOLD LIMIT VALUES FOR HAZARDOUS SUBSTANCES IN THE WORK ENVIRONMENT
PERMISSIBLE, SHORT TERM TOLERANCE (STT) AND IMMEDIATELY HAZARDOUS TO LIFE (IHL)

Hazardous Substance	TLV	(Permissible)		AIHA Hygienic Guides				IDLH		Others		
	OSHA	ACGIH-1975		STT		IHL					Time	Ref.
	PPM	PPM	Exc.	PPM	Min	PPM	Min	PPM	Min.	PPM	Min.	
1. Acetic Acid	10	10	20	50	-	5620	60	-	-			
2. Acetone	1000	1000	1250	10000	30-60	-	-	-	-			
3. Acetonitrile	40	40	60	500+	-	4000*	240	-	-			
4. Acetylene	-	F	-	200000	-	35000	5	-	-			
5. Acetylene tetrabromide	1	1	2	-	-	-	-	10				
6. Acrolein	0.1	0.1	0.3	1	5	133-178	10	-	-			
7. Acrylonitrile-S	20	20	30	-	-	-	-	110				
8. Allyl alcohol-S	2	2	4	100*	60	22000*	10	-	-			
9. Allyl chloride	1	1	2	2900*	60	25000*	10	300				
10. Allyl glycidyl ether-S	10	5	10	-	-	6200	60	-	-			
11. 2-Aminopyridine	0.5	0.5	1.5	-	-	-	-	5				
12. Ammonia ref. 8	50	25	38	400-700	-	2500- 6500	30	-	-	10000 0.5-1%	- 30	2 8
13. n-Amyl acetate	100	100	125	1000	60	-	-	-	-			
14. Aniline-S	5	5	10	50-100	60	-	-	100				
15. Arsenic trichloride	-	-	-	-	-	337*	10	-	-			
16. Arsine	0.05	0.05	0.15	-	-	-	-	6				
17. Benzene-C	10	10	50	3000	30-60	20000	5-10	-	-			
18. Beryllium mg/M^3	0.002	0.002	0.006	0.025	30	-	-	-	-			
18a. Bromotrifluro Methane	-	-	-	-	-	-	-	-	-	832000	15	8
19. Bromine	0.1	0.1	0.3	0.6	-	1000	"rapid"	-	-			
19a. Bromochlorodifluoromethane	-	-	-	-	-	-	-	-	-	324000	15	8
20. Butadiene	1000	1000	1250	20-25*	10	25%*	23	-	-			
20a. Bromochloromethane (CH_2BrCl)	-	-	-	-	-	-	-	-	-	65000	15	8

Table 1. THRESHOLD LIMIT VALUES FOR HAZARDOUS SUBSTANCES IN THE WORK ENVIRONMENT PERMISSIBLE, SHORT TERM TOLERANCE (STT) AND IMMEDIATELY HAZARDOUS TO LIFE (IHL) (Cont'd)

Hazardous Substances	TLV OSHA PPM	(Permissible) ACGIH-1975 PPM	ACGIH-1975 Exc.	AIHA Hygienic Guides STT PPM	STT Min.	IHL PPM	IHL Min.	IDLH PPM	IDLH Min.	Others PPM	Others Time Min.	Others Ref.
21. Butyl Acetate-n	150	150	225	3300	-	10000*	120+	-	-			
22. Butylamine-C-S	5	5	10	10-15	"short"	2000-3000	50	2000				
23. Cadmium oxide (as Cd) - C-mg/M^3	0.1	0.05	0.15	2900	CT	-	-	-	-			
24. Carbon dioxide	5000	5000	7500	50000	-	100000	-	-	-	658000	15	8
25. Carbon disulfide-S	20	20	30	1100	30	4815	30	-	-			
25a. Carbon Monoxide	50	50	75	-	-	-	-	-	-	1500-6400	CT 10-15	1 6
26. Carbon tetrachloride-S ref. 8	10	10	20	300*	60	1000-2000	60	300		28000	15	8
27. Chlorinated diphenyl oxide-mg/M^3	0.5	0.5	1.5	-	-	-	-	5				
27a. Chlorine - ref. 10	1	1	2	7	5	30	30	-	-			
28. Chlorine dioxide	0.1	0.1	0.3	20*	120	150-200	60-	-	-			
29. Chlorobenzene	75	75	113	6500*	30	8000*	30	2400				
30. o-Chlorobenzylidene malononitrile	0.05	0.05	0.15	-	-	-	-	0.6				
31. Chlorodiphenyl (42% Cl)-S-mg/M^3	1	1	2	10	-	-	-	10				
32. Chlorodiphenyl (54% Cl)-S-mg/M^3	0.5	0.5	1.5	10	-	-	-	5				
33. Chromic Acid - mg/M^3	-	0.1	0.3	-	-	-	-	-				
34. Chloroform	50	25	50	-	-	-	-	100		2-2.5%	60	8
35. Cresol (all isomers)-S	5	5	10	saturated vapor+			8	-	-			
36. Cumene	50	50	75	saturated vapor*			4	-	-			
37. Cyclohexane	300	300	375	9300*	30	14600-122000*	-	-	-			
38. Diazomethane	0.2	0.2	0.6	-	-	-	-	10				

Table 1. THRESHOLD LIMIT VALUES FOR HAZARDOUS SUBSTANCES IN THE WORK ENVIRONMENT
PERMISSIBLE, SHORT TERM TOLERANCE (STT) AND IMMEDIATELY HAZARDOUS TO LIFE (IHL) (Cont'd)

Hazardous Substance	TLV	(Permissible)		AIHA Hygienic Guides						Others		
	OSHA	ACGIH-1975		STT		IHL		IDLH				
	PPM	PPM	Exc.	PPM	Min.	PPM	Min.	PPM	Min.	PPM	Time Min.	Ref.
39. Diborane	0.1	0.1	0.3	6-14	45*	300+	-	-	-			
39a. Dibromodifluoromethane	-	-	-	-	-	-	-	-	-	54000	15	8
40. O-Dichlorobenzene-C	50	50	75	900-1000*	120	1700+	60	1700				
40a. Dibromotetrafluoro ethane	-	-	-	-	-	-	-	-	-	126000	15	8
41. p-Dichlorobenzene	75	75	113	-	-	sat.+	-	-	-			
42. 1,3 dichloro 5,5 dimethyl hydantoin	0.2	0.2	0.6	-	-	-	-	2				
43. 1,1 dichloroethane	100	200	250	-	-	-	-	4000				
44. 1,2 dichloroethylene	200	50	75	-	-	-	-	1000				
45. Dichlorodifluoromethane	1000	1000	1250	50000	-	100000+	F	-	-			
46. Diethylamine	25	25	38	-	-	sat.*	5	4000				
47. Diethylene-triamine	-	1	2	-	-	sat.+	480	-	-			
48. Diethylamino ethanol-S	10	10	15	-	-	-	-	500				
49. Diisobutyl ketone	50	25	38	500	"few"	2000*	480	-	-			
50. Di-isopropylamine-S	5	5	10	-	-	-	-	1000				
51. Dimethylamine	25	10	15	-	-	-	-	200				
52. Dimethyl formamide-S	10	10	15	-	-	sat.*+	240	-	-			
53. 1,1 Dimethyl Hydrazine-S ref. 7	0.5	0.5	1.5	50 600	5 5	22000- 24460	5	50		1000	5	7
54. Dioxane-S	100	50	75	1000*	30	30000	180	-	-			
55. Epichlorhydrin-S	5	5	10	40	-	23000*	10	250				
56. Ethanolamine	3	3	6	-	-	sat.+	-	230				
57. Ethylacetate	400	400	500	400-600	180	8600- 20000	"short"	-	-			
58. Ethylacrylate-S	25	25	38	25	"few"	50000*	15	-	-			

Table 1. THRESHOLD LIMIT VALUES FOR HAZARDOUS SUBSTANCES IN THE WORK ENVIRONMENT PERMISSIBLE, SHORT TERM TOLERANCE (STT) AND IMMEDIATELY HAZARDOUS TO LIFE (IHL) (Cont'd)

Hazardous Substance	TLV	(Permissible)		AIHA Hygienic Guides				IDLH		Others		
	OSHA	ACGIH-1975		STT		IHL					Time	Ref.
	PPM	PPM	Exc.	PPM	Min.	PPM	Min.	PPM	Min.	PPM	Min.	
59. Ethylamine	10	10	15	-	-	-	-	4000				
60. Ethyl benzene	100	100	125	3000*	60	"sat."+ 10000	-					
61. Ethyl bromide	200	200	250	6500	3	100000	-	-	-	2-2.5%	120	8
62. Ethyl chloride	1000	1000	1250	19000	22	33600	8.5	-	-			
63. Ethyl ether	400	400	500	2000- 7000	-	10%		-	-			
64. Ethylenediamine	10	10	15	-	-	-	2000					
65. Ethylenimine-S	0.5	0.5	1.5	-	-	500*	10	-	-			
66. Ethylene chlorohydrin-S	5	1	2	125*	240	305	135	-	-			
67. Ethylene dibromide	20	20	30	800*	6	5000	-	-	-			
68. Ethylene glycol dinitrate	0.2	0.2	0.6	3	-	-	-	-	-			
69. Ethylene oxide	50	50	75	-	-	800*- 1500	-	-	-			
70. N-ethylmorpholine-S	20	20	30	-	-	-	-	2000				
70a. Fluorine	0.1	1	2	15	10	3500- 5850	CT	-	-	3500- 5850	CT	5
71. Formaldehyde-C	3	2	C	13.8	30	815*	30	-	-			
72. Furfural-S	5	5	10	20-50	-	2800*	30					
73. Heptane	500	400	500	5000	15	15900*	30	-	-			
74. Hexane	500	100	125	5000	10	34000*- 42600	120	-	-			
75. 2-Hexanone-S	100	25	38	1000	"several"	10000*	30-60	-	-			
76. Hydrazine-S	1	0.1	0.3	-	-	100*	30	-	-			
77. Hydrogen chloride-C	5	5	C	50	-	1000- 2000	-	-	-			
78. Hydrogen bromide	3	3	6	-	-	-	-	40				
78a. Hydrogen cyanide-C	10	10	15	-	-	-	-	-	-	100-200 300	30-60 few	6 6

Table 1. THRESHOLD LIMIT VALUES FOR HAZARDOUS SUBSTANCES IN THE WORK ENVIRONMENT
PERMISSIBLE, SHORT TERM TOLERANCE (STT) AND IMMEDIATELY HAZARDOUS TO LIFE (IHL) (Cont'd)

Hazardous Substance	TLV	(Permissible)		AIHA Hygienic Guides						Others		
	OSHA	ACGIH-1975		STT		IHL		IDLH			Time	Ref.
	PPM	PPM	Exc.	PPM	Min.	PPM	Min.	PPM	Min.	PPM	Min.	
79. Hydrogen fluoride	3	3	6	67	1	670-1000*	5	30				
ref. 9	-	-	-	67	5	1000*	5	-	-			
80. Hydrogen peroxide	1	1	2	75	-	1000	"few"	-	-			
81. Hydrogen selenide	0.05	0.05	0.15	0.2	-	0.3	240	-	-			
82. Hydrogen sulfide	20-C	10	15	170-300	60	400-700	30-60	-	-	1000	"rapid"	6
83. Hydroquinone-mg/M^3	2	2	4	20-35	-	-	-	-	-			
83a. Lindane(Hexachlorocyclohexane) mg/M^3-S	0.5	0.5	1.5	1	30	-	-	-	-			
84. Lithium hydride-mg/M^3	0.025	0.025	0.075	0.5	"brief"	-	-	-	-			
85. Mercury - mg/M^3	1-C	0.05	0.15	28.8*	240	-	-	-	-	0.8	-	3
86. Mesityl Oxide	25	25	38	100	5	5000	30-60	-	-			
87. Dinitrobenzene-S	1	0.15	0.45	-	-	-	-	-	-			
88. Methyl Acetate	200	200	250	16000*	240	20000	"short"	-	-			
89. Methanol - Methyl alcohol-S	200	200	250	1000-2000	30	40000	-	-	-			
90. Methyl amine	10	10	15	-	-	-	-	4000				
91. Methyl bromide-S	200	15	23	500*	120	29000*	5	450		5900	15	8
92. Methyl chloride	-	100	125	500	-	95000*	2	-	-	2-2.5%	120	8
93. Methyl ethyl ketone (2-butanone)	200	200	250	3000	"short"	10000	-	-	-			
94. Methyl-isobutyl ketone (Hexone)-S	100	100	125	200	15	"sat"*	30	-	-			
95. Methylene chloride	100	200	250	-	-	-	-	2300				
96. Methyl chloroform	350	350	438	-	-	-	-	900				
97. Mono Methyl Aniline-S	2	2	4	-	-	-	-	85				
98. Mono Methyl hydrazine-S	0.2	0.2	0.6	-	-	-	-	20				
99. Morpholine	20	20	30	-	-	-	-	8000				

Table 1. THRESHOLD LIMIT VALUES FOR HAZARDOUS SUBSTANCES IN THE WORK ENVIRONMENT
PERMISSIBLE, SHORT TERM TOLERANCE (STT) AND IMMEDIATELY HAZARDOUS TO LIFE (IHL) (Cont'd)

Hazardous Substance	TLV	(Permissible)		AIHA Hygienic Guides						Others		
	OSHA PPM	ACGIH-1975		STT		IHL		IDLH			Time	Ref.
		PPM	Exc.	PPM	Min.	PPM	Min.	PPM	Min.	PPM	Min.	
100. Naphthalene	10	10	15	25	"short"	-	-	-	-			
101. Nickel Carbonyl	0.001		0.05	- 3	- 30	7-178* 30	30 30	-	-			
102. Nitrobenzene-S	1	1	2	200	60	-	-	-	-			
103. Nitro ethane	100	100	125	2500*	180	30000*	30	-	-			
104. Nitrogen dioxide-C ref. 7	5 -	5 -	C -	25 35	"few" 5	200-700 250	"rapid" -	- -	- -	200-700	short	6
105. Nitro methane	100	100	125	500*	60	30000*	15	-	-			
106. Nitrogen tetroxide (N_2O_4) ref. 7	-	-	-	17	5	125	-	-	-			
107. Nitropropane (1 and 2 isomers)	25	25	38	500-1000*	60	3000-9000	"brief"	-	-			
108. Osmium - mg/M^3	0.002	0.002	0.006	1	30	400*	30	-	-			
109. Ozone	0.1	0.1	0.3	1.5-2	120	50	60	-	-			
110. Oxygen difluoride	0.05	0.05	0.15	0.5	10	10*	10	-	-			
111. Pentaborane	0.005	0.005	0.015	25	5	1000 250*	1 15	- -	- -			
112. Pentane	1000	600	750	5000	10	128200*	37	-	-			
113. Petroleum naphtha	500	calc.	calc.	4000-7000	60	10000-20000	-	-	-			
114. Phenol-S	5	5	10	S	-	S	-	-	-			
115. Phosgene-C ref. 10	0.1	0.05	C	10 2	1 5	50	-	12		50	rapid	6
116. Phosphine	0.3	0.3	0.9	50-100	60	400	1-	-	-	400	rapid	6
117. Phthalic anhydride - mg/M^3	12	6	12	30	-	-	-	-	-			
118. Propyl alcohol-S	200	200	250	4000+*	60	sat.+	480	-	-			
119. Propylene dichloride	75	75	113	400-500	"short"	sat.+	480	-	-			
120. Propylene oxide	100	100	125	4000*	30	-	-	-	-			

Table 1. THRESHOLD LIMIT VALUES FOR HAZARDOUS SUBSTANCES IN THE WORK ENVIRONMENT PERMISSIBLE, SHORT TERM TOLERANCE (STT) AND IMMEDIATELY HAZARDOUS TO LIFE (IHL) (Cont'd)

Hazardous Substance	TLV	(Permissible)		AIHA Hygienic Guides						Others		
	OSHA	ACGIH-1975		STT		IHL		IDLH			Time	Ref
	PPM	PPM	Exc.	PPM	Min.	PPM	Min.	PPM	Min.	PPM	Min.	
121. Pyridine	5	5	10	125	240	23000*	90	-	-			
122. Propylene imine-S	2	2	4	-	-	-	-	500	-			
123. Quinone	0.1	0.1	0.3	1-2	-	-	-	-	-			
124. Selenium and Compounds mg/M^3	0.2	0.2	0.6	-	-	1*	240	-	-			
125. Stibine	0.1	0.1	0.3	-	-	40-45*	60	-	-			
126. Stoddard Solvent	500	100	125	470	15	5000	-	-	-			
127. Styrene Monomer (phenylethylene)	100	100	125	800	240	10000*	120	-	-			
128. Sulfur dioxide	5	5	10	50-100	30-60	400-500	"short"	-	-	400-500	Immed	6
129. Sulfur trioxide - mg/M^3	1	1	2	5	5	200*	60	-	-	1/2-1%	5	8
130. Sulfuric acid mg/M^3 ref. 10	1	1	2	5 8	5 5	-	-	-	-			
131. Tetrachloroethylene (Perclene)-S	100	100	125	600	45	6000*	"few"	200				
132. 1,1,1,2 Tetrachloro-2,2 difluoroethane	500	500	625	-	-	-	-	10000				
133. Tetra-ethyl lead mg/M^3-S	0.075	0.100	0.300	0.15	C	100	60	-	-			
134. Tetra-hydrofuran	200	200	250	17000	180	-	-	-	-			
135. Tetra-nitromethane	1	1	2	1*	-	5*	-	-	-			
136. Toluene-S	200	100	125	600	180	8000*- 12000	-	-	-			
137. Toluene 2,4 diisocyanate-C (TDI)	0.02	0.02	0.06	0.5	-	600*	360	-	-			
138. 1,1,2 Trichloroethane-S		10	15	-	-	-		500				
139. 1,1.1 Trichloroethane (methyl chloroform)	-	-	-	2500	5	20000	60	-	-			7
140. Trichloroethylene (Triclene)	100	100	125	400	"few"	20000	24	400		8000	-	4
141. Trichloronaphthalene mg/M^3-S	10	5	10	-	-	-	-	50				
142. 1,2,3 Trichloropropane	50	50	75	-	-	-	-	1000				

Table 1. THRESHOLD LIMIT VALUES FOR HAZARDOUS SUBSTANCES IN THE WORK ENVIRONMENT
PERMISSIBLE, SHORT TERM TOLERANCE (STT) AND IMMEDIATELY HAZARDOUS TO LIFE (IHL) (Cont'd)

Hazardous Substance	TLV	(Permissible)		AIHA Hygienic Guides						Others		
	OSHA	ACGIH-1975		STT		IHL		IDLH			Time	Ref
	PPM	PPM	Exc.	PPM	Min.	PPM	Min.	PPM	Min.	PPM	Min.	
143. 1,1,2 Trichloro 1,2,2-trifluoroethane (F-113)	1000	1000	1250	2500	165	100000*	3-15	4500				
144. Triethylamine	25	25	38	-	-	-	-	1000				
145. Tetramethyl succinonitrile-S	0.5	0.5	1.5	-	-	-	-	30				
146. Trinitrotoluene-S mg/M^3	1.5	1.5	3.0	-	-	-	-	-				
147. Turpentine	100	100	125	750-1000	"several hours"	2880*	45-60	-	-			
148. Trifluoromonobromomethane	1000	1000	1250	-	-	-	-	50000				
149. Vanadium pentoxide-mg/M^3	0.5	0.5	1.5	-	-	200*	420	-	-			
150. Vinyl Chloride - (C)	500	10	15	6000	5	150000*	120	-	-			
151. Xylene-S (all isomers)	100	100	125	2300-* 3500	-	-	-	-	-			
152. Zinc oxide (fume) mg/M^3	5	5	10	56	20	-	-	-	-			

NOTES FOR TABLE 1

TLV = Threshold Limit Value
ACGIH = American Conference of Governmental Industrial Hygienists
OSHA = Occupational Safety and Health Administration
Exc = Excursion Calculated from ACGIH-TLV's Threshold Limit Values for Chemical Substances and Physical Agents In the Work Environment with Intended Changes for 1975.
AIHA = American Industrial Hygiene Association
STT = Short Term Tolerance
IHL = Immediately Hazardous to Life
PPM = Parts per million v/v
Min = Time in minutes
NIOSH = National Institute for Occupational Safety and Health
IDLH = The definition of IDLH provided in 30 CFR 11.3(T) is as follows:

"Immediately Dangerous to Life or Health" means conditions that pose an immediate threat to life or health or conditions that pose an immediate threat of severe exposure to contaminants, such as radioactive materials, which are likely to have adverse cumulative or delayed effects on health.

The purpose of establishing an IDLH exposure concentration is to insure that the worker can escape without injury or irreversible health effects from an IDLH concentration. The IDLH is considered a maximum concentration above which only highly reliable breathing apparatus providing maximum worker protection is permitted. Since IDLH values are conservatively set, any approved respirator may be used up to its maximum use concentration below the IDLH.

S = Skin - potential contribution to the overall exposure by the cutaneous route including mucuous membranes and eye, either by airborne or more particularly by direct contact with the substance.
C = Limit that should not be exceeded
Mg/M^3 = Milligrams per cubic meter
* = Animal test data
\+ = Following a number means greater than
F = Asphyxiant
CT = Concentration multiplied by time
sat = Saturated vapor at 20°C

where exposure risk is minimal. In cyanogenic risk areas (aniline, nitrobenzene, etc.) those individuals who exhibit cyanosis susceptibility or anemia can be restricted to areas where these substances are not present.

B. With the Same Individual

Exposure tolerance will be mediated by bacterial or viral infections, aging, diet, fatigue, physical stress such as heat, humidity and medication. For example a person suffering from a respiratory infection will be considerably more susceptible to severe lung damage from a massive exposure to phosgene or chlorine. Similarly a worker on sulfa drug therapy will be predisposed to cyanosis from aniline or nitrobenzene exposure.

C. Route of Entry to the Body

In many cases the hazard will to a great extent be determined by skin absorption (cyanogenic chemicals) as well as inhalation. These materials are identified by "S" notation. This factor must be considered carefully in the event of a chemical disaster where direct contact with a hazardous material such as clothes saturated with aniline has occurred. In other cases skin contact may produce severe burns as would occur in contact with liquid phosgene or hydrogen fluoride.

V. SOURCES OF INFORMATION

1. Ricca, P. M., Exposure Criteria for Fluorine Rocket Propellants. Arch. Environ. Health 12:399 (1966).

2. Zielhuis, R. L.: Tentative Emergency Exposure Limits for Sulfur Dioxide, Sulfuric Acid, Chlorine and Phosgene. Ann. Occup. Hyg. 13:171 (1970).

3. Amer. Ind. Hyg. Assoc, Toxicology Committee: Emergency Exposure Limits. Am. Ind. Hyg. Assoc. J. 25:578 (1964).

4. Hygienic Guide Series, Amer. Ind. Hyg. Assoc., 665 Miller Road, Akron, Ohio 44313.

5. Industrial Data Sheets, National Safety Council, 425 N. Michigan Ave., Chicago, Ill. 60611.

6. Data Sheets, Manufacturing Chemists Association, 1825 Conn. Ave., N.W., Washington, D.C. 20009.

7. Criteria for Recommended Standard - Occupational Exposure to - DHEW, PHS, HSMHA, NIOSH — Robert A. Taft Laboratory, Cincinnati, Ohio.

8. Pennsylvania Dept. of Health, Chapter 4, Article 432, Revised Jan. 25, 1968 - Short Term Limits for 142 Substances. Harrisburg, Pa.

9. American National Standards Institute (ANSI) - Short Term Limits (Peaks) 1430 Broadway, New York, N.Y. 10018.

REFERENCES (for Table 1)

1. Henderson, Y. and H. W. Haggard. Noxious Gases and Principles of Respiration Influencing Their Action. Reinhold Publishing Company, New York, 2nd Edition (1943).

2. Criteria for a Recommended Occupational Exposure to Ammonia - (NIOSH) HEW Publication No. 74-136 (1974).

3. Criteria for a Recommended Standard - Occupational Exposure to Inorganic Mercury - HEW Publication HSM-73-11024 (1973) NIOSH.

4. Criteria for a Recommended Standard - Occupational Exposure to Trichloroethylene — HEW Publication HSM-73-11025 (1973).

5. Ricca, P. M. A Survey of the Acute Toxicity of Elemental Fluorine - Amer. Ind. Hyg. Assoc. J. 30:22 (1970).

6. Meidl, J. H., Explosives and Toxic Hazardous Materials, Glencoe Press (1970).

7. Frawley, J. P., Emergency Exposure Limits. Amer. Ind. Hyg. J. (Nov.-Dec., 1964) 578.

8. NFPA - Fire Protection Handbook - 13th Edition (1969).

9. Ricca, P. M. Exposure Criteria for Fluorine Rocket Propellants. Arch. Environ. Health 12:399 (1966).

10. Ziehluis, R. L. Tentative Emergency Exposure Limits for Sulfur Dioxide, Sulfuric Acid, Chlorine and Phosgene. Amer. Occup. Health 13:171 (1970).

OTHER REFERENCES (for Table 1)

1. NIOSH - The Industrial Environment - Its Evaluation and Control - U.S. Department of Health, Education and Welfare - Public Health Service (1973).

2. ACGIH - Documentation of the Threshold Limit Values for Substances in Workroom Air - 3rd Edition (1971) P.O. Box 1937, Cincinnati, Ohio 45201.

3. OSHA - Occupational Safety and Health Standards - Code of Federal Regulations, Title 29, Chapter XVII, Part 191037 FR 22102 (Oct. 18, 1972) Subpart G - 1910.93 Air Contaminants Federal Register 31:5303.

Table 2. TOXICITY CLASSES

Toxicity Rating	Descriptive Term	LD_{50}-Wt/kg Single Oral Dose Rats	4 hr Inhalation LC_{50} - PPM Rats
1	Extremely toxic	1 mg or less	< 10
2	Highly toxic	1-50 mg	10-100
3	Moderately toxic	50-500 mg	100-1,000
4	Slightly toxic	0.5-5 g	1,000-10,000
5	Practically non toxic	5-15 g	10,000-100,000
6	Relatively harmless	15 g or more	> 100,000

1

MEASUREMENT OF GASES

Matter, depending on temperature and pressure, may exist as a gas, liquid or solid. A liquid or solid occupies a definite volume while a gas, on the other hand, occupies all space made available to it.

The molecules of a gas are always in constant motion. The motion of gas molecules without pressure being applied to them is called diffusion. A gas diffuses completely to fill all space made available to it even if the space is already occupied by another gas. Gases readily form homogenous mixtures. The volume occupied by a given mass of gas is many times larger than the volume occupied by the same mass of substance in the liquid or solid state. Gases are highly compressible while liquids and solids are not. The volume occupied by a gas depends on temperature and pressure. The volume of a liquid or solid is only slightly affected by changes in temperature and pressure.

Since the volume of a liquid or solid changes very little with changes in temperature and pressure knowing the volume sufficiently describes the quantity of a solid or liquid present. This is not so with gases. Two equal volumes of a gas at different conditions of temperature and pressure will not contain equal masses of the gas. To characterize the amount of gaseous matter in a volume of a gas temperature and pressure must be known.

The behavior of gases is explained by the gas laws. The ideal or general gas law correlates four properties of a gas – volume, temperature, pressure, and number of molecules.

In order to compare gas data, the data must be reduced to standard reference conditions. The gas laws are applied in determining gas volume and pressure, in determining the quantity of a gas in a gas sample, in determining gas diffusion rates, in calculating gas flow rates, in calibrating gas measuring devices, in determining gas solubilities, in calculating gas density, in collecting air samples, in coverting gas data from one measuring system to another system, in preparing known concentrations of gas mixtures and in correcting errors due to deviations in gas behavior.

The behavior of gases has been studied by many scientists. The earliest of these investigations was carried out by Robert Boyle.

Robert Boyle, in 1660, postulated that at constant temperature, the volume of a given mass of gas is inversely proportional to the pressure exerted on the gas. This is represented as:

$$V \alpha \frac{1}{P}$$

Approximately 120 years later when temperature could be measured, Jacques Charles observed that at constant pressure, the volume of a given amount of gas changes 1/273 of its volume at $0^{O}C$ for each degree Centigrade change in temperature. This observation lead to the establishment of the absolute temperature scale where the degrees are called absolute of Kelvin degrees. The degree is the same size as the Centigrade degree, but zero is 273 degrees below on the Centigrade scale, e.g., zero on the absolute scale is $-273^{O}C$. The Kelvin temperature scale shows a direct relationship between temperature and volume of a gas. The volume of a given mass of gas doubles when the Kelvin temperature is doubled.

Charles' law states that at constant pressure the volume of a given mass of a gas is directly proportional to the absolute temperature. This is expressed as:

$$V \alpha T$$

Prepared by Steven N. Dereniuk, Analytical Chemist, Division of Training, NIOSH, 7/75.

From this temperature -- volume relationship it was deduced that if the volume of a gas is kept constant, the pressure exerted by a given mass of gas is also directly proportional to absolute temperature.

Avogadro in 1811, established that equal volumes of gases at the same temperature and pressure contain an equal number of molecules.

Combining the two equations, $V_{\alpha}\frac{1}{P}$ and $V\alpha T$, and inserting a proportionality constant gives the equation PV = RT. For n moles of a gas, the equation is:

$$PV = nRT$$

This is the ideal gas law and it holds strictly only for ideal gases. With real gases, deviations occur especially at high pressures and low temperatures.

In the equation PV = nRT

P is pressure of gas

V is volume of gas

T is absolute temperature of gas

n is number of moles of a gas

R is the gas constant

The value of R depends on the units used in the equation. For one mole (n = 1) of gas at standard conditions where temperature is $0^{o}C$ or $273^{o}K$, pressure is 1 atmosphere, and volume is 22.41 liters, R has a value of 0.082.

From the equation, it is apparent that volume of a gas is determined by temperature, pressure and n, the number of moles of a gas.

The behavior of many real gases has been studied experimentally, and it has been found that 1 gram molecular weight of any gas occupies approximately 22.41 liters at $0^{o}C$ and 1 atmosphere pressure.

In industrial hygiene work, it has become standard practice to use $25^{o}C$ and 1 atmosphere pressure as a reference condition for expressing gas volume. Under these conditions, the volume of one gram molecular weight of gas is approximately 24.45 liters.

Since the volume of a gas changes with changes in temperature and pressure, it follows that the density of the gas also changes. Density is inversely proportional to temperature and directly proportional to pressure. This may be expressed as $d\alpha\frac{1}{T}$ and $d\alpha P$. For a given mass of gas:

$$\frac{d_1 T_1}{P_1} = \frac{d_2 T_2}{P_2} \quad \text{or} \quad d_2 = \frac{d_1 T_1 P_2}{T_2 P_1}$$

where:

d_1 and d_2 is the original and final density

T_1 and T_2 is the original and final absolute temperature

P_1 and P_2 is the original and final pressure.

The kinetic energy of gas molecules is directly proportional to the temperature of the gas molecules. Ideal gas molecules possess the same average kinetic energy at the given temperature. This means that the lighter the molecule, the higher is its velocity. This principle lead to the development of the formula:

$$\frac{R_1}{R_2} = \sqrt{\frac{m_2}{m_1}} = \sqrt{\frac{d_2}{d_1}}$$

which states that the ratio of the rates of diffusion of two gases at the same temperature and pressure is inversely proportional to the square root of their molecular weights or densities.

Discussions dealing with the ideal gas law are usually restricted to a one component gas system. The ideal gas law also applies to gas mixtures.

The pressure exerted by a gas depends on the number of molecular collisions with the walls of the container. In a gas mixture, each gas contributes to the total pressure. The pressure produced by each gas is called the partial pressure of that gas. The total pressure of a gas mixture is the sum of the partial or individual gas pressures. This is expressed as:

$$P = P_1 + P_2 + P_3 \ldots$$

where P is total pressure and P_1, P_2, P_3... are the partial pressures of the individual gases in a gas mixture.

Molecules in the gaseous state move about freely. They are restricted in their movement only by the walls of the vessel containing them. In the liquid state, because the molecules are very close together, the attractive forces between molecules are appreciable. This restricts their movement. However, in spite of these attractive forces, some molecules possess sufficient kinetic energy to escape from the surface of the liquid. The molecules which escape into the gaseous phase are called vapor.

The molecules which are in the vapor state exert pressure, and the liquid is said to possess vapor pressure. Since the average kinetic energy of molecules is directly proportional to temperature, it follows that a liquid has a specific vapor pressure for a given temperature. Vapor pressure always increases with temperature. When the air above the liquid is saturated with vapor molecules, the number of molecules leaving the liquid is equal to the number of vapor molecules returning to the liqud . The system is said to be at equilibrium. In a system at equilibrium, the number of molecules in the vapor state is at its maximum and is a function of temperature. This is readily attained in a closed system.

In calculating the amount of vapor present in air saturated with the vapor, one need know only the temperature of the liquid, the vapor pressure of the liquid at this temperature, and the barometric pressure. Vapor pressure data is available in chemistry handbooks, chemistry textbooks, and manufacturers' literature. Similarly, the amount present can be calculated if the partial pressure of the vapor is known.

In making gas measurements and calculations, one must understand the fundamental gas laws which relate the volume, temperature, pressure and the number of molecules or moles of a gas. In gas calculations, temperature is always expressed in the absolute or Kelvin temperature scale.

In engineering work, temperature is expressed in Fahrenheit degrees (conversion to absolute is 460 + $^{\circ}$F), gas volume in cubic feet, gas weight in pounds, and pressure in pounds per square foot. Whatever the units, the ideal gas law holds. In gas calculations, units must not be mixed.

GAS MEASUREMENT PROBLEMS

1. A liter of air is collected at -23°C. and 600 mm pressure. Calculate the volume at 27°C. and 760 mm pressure.

2. A gas mixture at 760 mm pressure and 25°C contains by volume 28.0% nitrogen, 28.0% carbon monoxide and 44.0% carbon dioxide. What is the partial pressure of each gas in mm Hg?

3. A gaseous mixture at 760 mm pressure and 25°C contains by weight 28.0% nitrogen, 28.0% carbon monoxide and 44.0% carbon dioxide. What is the partial pressure of each gas in mm Hg?

4. A liter sample of air at 23°C is saturated with water vapor. The total pressure is 760 mm. What is the volume of the dry air sample at 0°C and 760 mm pressure? The water vapor pressure at 23°C is 21.0 mm.

5. The molecular weights of methane and xylene are 16 and 106 respectively. Calculate the ratio of their rates of diffusion.

6. In a gaseous mixture at 20°C, the partial pressures of the component gases are: hydrogen 200 mm, carbon dioxide 135 mm, nitrogen 320 mm, and argon 105 mm. What is the total pressure? What is volume percent of hydrogen?

7. The partial pressure of water vapor in an atmosphere at 35°C is 37 mm. Hg. What is the relative humidity? What is the absolute humidity? The vapor pressure of water at 35°C is 42 mm Hg. Total pressure is 740 mm Hg.

8. A work room at 25°C and 760 mm pressure because of careless work practice contains mercury on the floor and work benches. No ventilation is provided. The vapor pressure of mercury at 25°C is 0.0018 mm. What is the highest possible mercury vapor concentration in the work air? Is there a health hazard? The TLV for mercury is 0.05 mg/M^3.

Prepared by Steven N. Dereniuk, Analytical Chemist, DTMD, NIOSH, 8/77.

9. A 10 liter sample of air collected at 25°C and 1 atmosphere pressure was found to contain 1 mg of carbon tetrachloride. Calculate the parts per million (ppm) of carbon tetrachloride in the air. Is the TLV exceeded? The molecular weight of carbon tetrachloride is 154 g and the molar volume at 25°C is 24.45 liter.

10. A reaction vessel contains a gas at 20°C and 10 atmospheres pressure. The vessel was designed to withstand a pressure of 55 atmospheres. A change in operations requires that the gas be heated to 1652°F. Will the vessel rupture before their temperature is reached?

11. A liter of oxygen weighs 1.43 g at 0°C and 1 atmosphere pressure. Calculate the density at 27°C and 0.6 atmospheres pressure. Use the formula:

$$d_2 = d_1 \times \frac{T_1}{T_2} \times \frac{P_2}{P_1}$$

12. An air sampling pump with rotameter to indicate flow rate is calibrated at Cincinnati in an air-conditioned room at 77°F and 740 mm Hg pressure. It will be used at Denver at 95°F and 610 mm pressure. What must the flow be set at to deliver 1 liter of air per minute? Use the formula:

$$Q_{T_2P_2} = Q_{T_1P_1}\left(\frac{P_2T_1}{P_1T_2}\right)^{1/2}$$

or:

$$Q_{T_1P_1} = Q_{T_2P_2}\left(\frac{1}{\frac{P_2T_1}{P_1T_2}}\right)^{1/2}$$

where:

T_1P_1 is calibration temperature and pressure

T_2P_2 is temperature and pressure at Denver

$Q_{T_1P_1}$ is air flow at Cincinnati temperature and pressure

$Q_{T_2P_2}$ is air flow at Denver temperature and pressure

13. A rotameter calibrated for air flow at 25°C and 1 atmosphere pressure will be used to measure methane gas at the same temperature and pressure. Methane is lighter than air. What must the flow rate be set at to deliver 5 liters per minute of methane? Use the formula:

$$Q_2 = Q_1 \left(\frac{\rho_1}{\rho_2}\right)^{1/2}$$

where:

Q_1 is air flow rate

Q_2 is methane flow rate

ρ_1 is the experimental density of air (1.29)

ρ_2 is the experimental density of methane (0.71)

14. Air contains, by volume, 21% oxygen and 78% nitrogen at a barometric pressure of 760 mm Hg. What are the partial pressures of oxygen and nitrogen? What are the partial pressures of oxygen and nitrogen at an altitude of 10,000 feet where the pressure is 525 mm?

15. Health standards for gases and vapors can be expressed in ppm or mg/M^3. The TLV for acetone is 1000 ppm. Express this in mg/M^3.

16. The health standard for vapor X is 100 ppm. A whole shift monitoring of a work area established concentrations of 85 ppm for 2 hrs., 125 ppm for 4 hrs. and 95 ppm for 2 hrs. Calculate the TWA. Was the standard for compound X exceeded?

17. One ppm by volume is 1 volume in 1 million volumes. One ml of a gas or vapor in 1 million ml of air is also 0.001 ml or 1 μl in 1 liter. What volume of CO gas must be injected into 100 liters of air to give 50 ppm?

18. Methane is present in air at a 10% concentration by volume. Calculate the oxygen content of this mixture.

19. The carbon monoxide content by volume in a work area is 0.05%. Calculate the concentration in ppm. Is the health standard for CO exceeded?

20. Air expands with increase in altitude. Toluene concentration at 760 mm pressure and 25°C is 200 ppm. Assume that the air is taken to an altitude where pressure is 608 mm and temperature is 25°C and is allowed to expand freely. Does the ppm of benzene change? Calculate the weight per cubic meter of benzene at the two locations.

Problem Set: GAS AND VAPOR CALCULATIONS

1. A liter of air is collected at 23°C and 600 mm pressure. Calculate the volume at 27°C and 760 mm pressure.

2. A mixture of gases at 760 mm pressure contains 66.0 percent nitrogen, 14.0 percent oxygen and 20.0 percent carbon dioxide by volume. What is the partial pressure of each gas in mm Hg?

3. In a gaseous mixture at 20°C, the partial pressures of the component gases are: hydrogen, 200 mm, carbon dioxide, 135 mm, nitrogen, 320 mm, and argon, 105 mm.

   What is the volume percent of hydrogen?

4. One liter of oxygen is collected over water at 23°C and 800 mm pressure. The oxygen is saturated with water vapor. The vapor pressure of water at 23°C is 21.0 mm.

   What is the volume of the dry oxygen at standard conditions (0°C and 760 mm pressure)?

Prepared by Steven N. Dereniuk, Analytical Chemist, Division of Training, NIOSH, 2/73.

5. The molecular weights of hydrogen and carbon dioxide are 2 and 44 respectively. Calculate the ratio of their rates of diffusion.

6. A steel tank contains oxygen at 20°C and 10 atmospheres pressures. Calculate the pressure if the tank is heated to 150°C.

7. A gas mixture at 1 atmosphere pressure contains 28% nitrogen, 44% carbon dioxide and 28% carbon monoxide by weight.

   What is the partial pressure of each gas?

8. The vapor pressure of water at 25°C is 24 mm of Hg. What is the partial pressure of the water vapor if the atmospheric pressure is 750 mm of Hg and the air contains 1.6% vapor by volume?

Problem Set: GAS MEASUREMENT

1. A liter of air is collected at −23°C and 600 mm pressure. Calculate the volume at 27°C and 760 mm pressure.

2. A gas mixture at 760 mm pressure contains by volume 28.0% nitrogen, 28.0% carbon monoxide and 44.0% carbon dioxide. What is the partial pressure of each gas in mm Hg?

3. A gaseous mixture at 760 mm pressure contains by weight 28.0% nitrogen, 28.0% carbon monoxide and 44.0% carbon dioxide. What is the partial of each gas in mm Hg?

4. A liter sample of air at 23°C is saturated with water vapor. The total pressure is 760 mm. What is the volume of the dry air sample at 0°C and 760 mm pressure? The water vapor pressure at 23°C is 21.0 mm.

5. The molecular weights of hydrogen and carbon dioxide are 2 and 44 respectively. Calculate the ratio of their rates of diffusion.

6. In a gaseous mixture at 20°C, the partial pressures of the component gas are: hydrogen 200 mm, carbon dioxide 135 mm, nitrogen 320 mm, and argon 105 mm. What is the total pressure? What is volume percent of hydrogen?

7. The partial pressure of water vapor in an atmosphere at 35°C is 37 mm. Hg. What is the relative humidity? What is the absolute humidity? The vapor pressure of water at 35°C is 42 mm Hg. Total pressure is 740 mm Hg.

8. A work room at 25°C and 760 mm pressure because of careless work practice contains mercury on the floor and work benches. No ventilation is provided. The vapor pressure of mercury at 25°C is 0.0018 mm. What is the highest possible mercury vapor concentration in the work air? Is there a health hazard? The TLV for mercury is 0.05 mg/M^3.

9. A 10 liter sample of air collected at 25°C and 1 atmosphere pressure was found to contain 1 mg of carbon tetrachloride. Calculate the parts per million (ppm) of carbon tetrachloride in the air. Is the TLV exceeded? The molecular weight of carbon tetrachloride is 154 g and the molar volume is 24.45 liter.

10. A reaction vessel contains a gas at 20°C and 10 atmospheres pressure. The vessel was designed to withstand a pressure of 55 atmospheres. A change in operations requires that the gas be heated to 1652°F. Will the vessel rupture before their temperature is reached?

11. A liter of oxygen weighs 1.43 g at 0°C and 1 atmosphere pressure. Calculate the density at 27°C and 0.6 atmospheres pressure. Use the formula:

$$d_2 = d_1 \times \frac{T_1}{T_2} \times \frac{P_2}{P_1}$$

12. A rotameter is calibrated at Cincinnati in an air-conditioned room at 77°F and 740 mm Hg pressure. It will be used at Denver at 95°F and 620 mm pressure. What must the flow be set at to deliver 1 liter of air per minute? Use the formula:

$$Q_{T_2P_2} = Q_{T_1P_1}\left(\frac{P_2T_1}{P_1T_2}\right)^{\frac{1}{2}}$$

or

$$Q_{T_1P_1} = Q_{T_2P_2}\left(\frac{1}{\frac{P_2T_1}{P_1T_2}}\right)^{\frac{1}{2}}$$

Prepared by Steven N. Dereniuk, Chemist, Division of Training, NIOSH, 4/75.

where:

T_1P_1	is calibration temperature and pressure
T_2P_2	is temperature and pressure at Denver
$Q_{T_1P_1}$	is air flow at Cincinnati temperature and pressure
$Q_{T_2P_2}$	is air flow at Denver temperature and pressure

13. A rotameter calibrated for air flow at 25°C and 1 atmosphere pressure will be used to measure argon gas at the same temperature, pressure and setting. Argon is heavier than air. What must the flow rate be set at to deliver 5 liters per minute of argon? Use the formula:

$$Q_2 = Q_1\left(\frac{\rho_1}{\rho_2}\right)^{\frac{1}{2}}$$

where:

Q_1 is air flow rate

Q_2 is argon flow rate

ρ_1 is the experimental density of air (1.29)

ρ_2 is the experimental density of argon (1.78)

14. Air contains by volume 21% oxygen and 78% nitrogen at a barometric pressure of 760 mm Hg. What are the partial pressures of oxygen and nitrogen?

What are the partial pressures of oxygen and nitrogen at an altitude of 10,000 feet where the pressure is 525 mm?

SAMPLING AND ANALYSIS OF GASES AND VAPORS

Introduction

This lecture deals principally with the methods and instrumentation used for the sampling and analysis of gases and vapors present as atmospheric contaminants in the industrial environment. In the sections dealing with sampling procedures, direct reading instruments are not discussed as there is a separate lecture on this topic. In both the sampling and analysis sections, the emphasis is placed on fundamental techniques rather than on specific methods for individual substances. This approach eliminates unnecessary repetition.

Properties of Gases and Vapors

The distinction between gases and vapors is somewhat vague. An "elastic fluid" is generally called a gas if its temperature is very far removed from that required for liquefaction; conversely, it is termed a vapor if it is near its temperature of liquefaction. In the field of industrial hygiene, a substance is considered as a gas if this is its normal physical state at room temperature and atmospheric pressure. It is called a vapor if, under the environmental conditions, conversion of the liquid or solid form to the gaseous state results from its vapor pressure effecting its volatilization or sublimation into the atmosphere of the container, the process equipment, or the workroom. Our chief interest in distinguishing between gases and vapors lies in our need to assess the potential occupational hazards associated with the use of specific chemical agents, an assessment which requires a knowledge of the physical and chemical properties of these agents.

Prepared by: Robert G. Keenan

Sampling Methods

The primary objective of this phase of an environmental survey is to obtain representative samples of the atmospheric contaminant in forms suitable for subsequent analysis. A general discussion of the fundamental aspects of plant surveys to provide adequate evaluations of the environment is given in Section B-1.

Basic Techniques

Two basic methods for the collection of gaseous samples are employed. The first involves the use of a gas collector, such as an evacuated flask or bottle, to obtain a definite volume of air at a known temperature and pressure. The collector is re-sealed immediately to prevent any loss before the sample can be analyzed. The second method involves the passage of a known volume of air through an absorbing or adsorbing medium to remove the desired contaminants from the sampled atmosphere. The absorbing medium, which may be a solvent such as ethyl alcohol or amyl acetate, can be transferred with the collected sample to a reagent type, glass stoppered bottle for transfer to the laboratory.

The selection of one or the other of these techniques depends upon the type and purpose of a particular sample. When the major components of a gas or of air are to be determined, a gas collector is used. When a minute quantity (parts per million level) of a contaminant must be estimated, the method of concentrating the substance in an absorber or on an adsorbent must be employed. The collection of instantaneous samples, those taken within a time period extending from a few seconds to one or two minutes, is made to determine the composition of an atmosphere at a specific time and location. Such samples may best be taken with evacuated flasks or with gas or liquid displacement collectors. However, an absorption or adsorption device must usually be employed for collecting continuous samples of a non-uniform atmosphere, for the estimation of the average composition during a given time period.

Method Requirements

Sampling methods for gases or vapors should meet the following requirements:

1. Provide an acceptable efficiency of collection for the substance or substances involved.
2. Maintain this efficiency at a rate of air flow which can provide sufficient sample for the analytical procedure in a reasonable period of time.
3. Retain the collected gas or vapor in a form which is transportable to the analytical site.
4. Yield the sample in a form suitable for the analytical method.
5. Require minimal manipulation in the field.
6. Avoid use of corrosive or otherwise hazardous sampling media whenever possible.

These requirements are considered as practical guides in planning a plant survey and, by their wording, indicate the need of consultation between the engineer and the chemist for optimal results from each survey.

Sampling Instruments

In the application of the two basic sampling methods, numerous sampling devices have been employed. For more complete information on the construction, recommended uses, and efficiencies of specific instruments, the appropriate reference works should be consulted.(1,2) For outline purposes, the following tables contain a limited listing of the devices commonly used for gas and vapor sampling, along with selected typical applications of each.

The sampling instruments given in Tables 1 and 2 include those most commonly used in gas and vapor sampling. Other devices, such as glass-bead packed columns containing absorbing solutions, freeze-out traps, the Harrold mist and gas collector, are invaluable in certain situations. The collection efficiencies reported in Table 2 are absolute values based upon sampling of known atmospheric concentrations of the indicated gas or vapor at the specified rate of air flow.

In planning an environmental survey it must be remembered that gases and vapors, unlike dusts, fumes or mists, form a true solution with air and, hence, drastic physical or chemical action is required to collect these substances efficiently from the atmosphere. The industrial hygienist must be familiar with the advantages, limitations, and performance characteristics of each type of sampling device to provide samples of utmost value to the laboratory for chemical analysis.

In addition to the sampling instruments, a suction device, such as an electrically operated pump, which will provide a reasonably constant rate of air flow through the sampler and an air flow measuring instrument, such as an orifice flowmeter, are required to collect the sample. The flowmeter, attached to the assembled equipment, must be calibrated in the laboratory with a wet or dry gas meter or with a mercury manometer. A separate lecture entitled "Air-flow Calibrations" is presented in Section B-3 and, therefore, the details of this calibration will not be discussed in the present lecture.

Instructions on the preparation of known concentrations of gases and vapors are given in Section B-8. The industrial hygienist should be familiar with this technique so as to establish the collection efficiency of his sampling apparatus.

Table 1. - Gas and vapor collectors with typical applications

Collector	Size in ml	Gas or Vapor
Evacuated flask	250 - 300 ml	Gross components of air or of sewer or mine gases
Evacuated flask	1000	Carbon monoxide in air
Vacuum bottle	500 - 2500	Substances not easily trapped by absorbents or adsorbents: total oxides of nitrogen; benzene
Gas or liquid displacement collector, glass	250 - 4000	Gross components of air or gas mixture
Metallic collectors	Ditto, or larger	Non-corrosive gases

Table 2. - Gas and vapor samplers, with partial listing of applications, sorption media and collection efficiencies

Sampler	Sorption Medium	Air Flow l/m	Gas or Vapor	Efficiency %
U-tube	Silica gel or activated carbon	5	Organic solvent vapors	[*]
Fritted glass bubbler	Sodium hydroxide	5	Hydrochloric Acid	95
	Sodium bisulfite	1-3	Formaldehyde	ca 100
	Barium hydroxide	1	Carbon dioxide	60-80
	Iodine	5	Hydrogen sulfide	95
Midget fritted glass bubbler (60-70 micron max. pore diam.)	Saltzman reagent[‡]	0.4	Nitrogen dioxide	94-99
Petri bubbler	Nitrating acid	0.25	Benzene	95
Impinger	Sulfuric acid	28.3	Ammonia	95
	2% Glycerol in 0.05 N sodium hydroxide	28.3	Sulfur dioxide	95
Midget impinger	1% KI, 0.1 M KH_2PO_4, and 0.1 M Na_2HPO_4	1-3	Ozone	95+

[*] Dependent upon nature of vapor, adsorbent, and number of tubes

[‡] Dissolve 5 grams sulfanilic acid in almost a liter of nitrite free water containing 140 ml of glacial acetic acid; add 20 ml of 0.1% aqueous solution of N-(1-naphthyl)-ethylenediamine dihydrochloride and dilute to 1 liter.

Fundamental Gas Laws

The actual measurements of the volumes of gases or gas-air mixtures must be corrected to standard conditions of temperature and pressure in order for the measurements to have meaning. The conversion of actually measured volumes to the standard conditions of 0°C (273°K) and 760 mm of mercury pressure requires a knowledge of the fundamental gas laws, given in any text on general or physical chemistry.

The combined laws of Boyle and Charles state that the volume of a gas is inversely proportional to its pressure and directly proportional to its absolute temperature (°C + 273):

$$(1)\ v \propto \frac{T}{p}$$

By introducing a proportionality factor, "k", expression (1) becomes

$$(2)\ pv = kT$$

If this equation of state is applied to 1 mole of gas, "R", the molar gas constant, may be substituted for "k", and "V", the molar gas volume, may be used in place of "v". The equation can be made more general by introducing "n", which represents the number of moles in any given system. Equation (2) then is converted to the familiar ideal gas equation

$$(3)\ pV = nRT$$

where "R" must be expressed in the same terms as those used for the pressure-volume relationship. For example, if the gas volume is expressed in liters and the pressure in atmospheres, "R" has a value of 0.08206 liter-atmospheres per degree. If the volume is expressed in cubic centimeters and the pressure in terms of millimeters of mercury, the value of "R" is 62,370 cc-mm per degree Kelvin.

In dealing with the gas mixtures encountered in industrial hygiene, Dalton's law must be applied first to correct the pressure of the total mixture by that portion of the pressure due to water vapor in the atmosphere. Dalton's law states that the total pressure of a mixture of gases is the sum of the pressures of the individual gaseous components. Therefore, the barometric pressure at the time the gas is collected minus the pressure of the water vapor (often termed the aqueous tension) is the actual pressure of the gas or gas-air mixture. The pressure due to water vapor at the temperature of gas collection, assuming gas saturation with water vapor, can be found in any handbook of physical constants.

With these laws the following equation can be used to convert the measured gas volume to standard conditions of temperature and pressure:

$$(4)\ V_{S.T.P.} = V_{\text{meas.}} \times \frac{P_{\text{bar.}} - p_w}{760} \times \frac{273}{273 + t^{\circ}\,C}$$

where the volume is expressed in any convenient unit, such as liters, and the pressure is expressed in terms of millimeters of mercury.

Special Calculations and Conversion Formulas

The equation for the calculation of the actual volume of a gas collected in a partially evacuated flask is

$$(5)\ V_s = V_F \left(1 - \frac{T_s P_1}{T_1 P_s}\right)$$

where V_s = volume of gas collected at absolute (°K) temperature T_s and pressure p_s

V_F = volume of the flask

p_1 = residual pressure of flask after partial evacuation for sampling

and T_1 = temperature of flask (°K) when p_1 was measured.

In applying a gas displacement method, the volume of the atmosphere being sampled or flushed through the flask should be 8 to 10 times that of the flask.(3) The time required to raise the concentration of the contaminant in the flask to 99 percent of its concentration in the entering air stream is given in the following equation:

(6) $t_{99\%} = 4.605\ a/b$

where t = time in minutes
a = volume of flask in liters
and b = air flow in liters per minute

The following conversion formulas are useful for gas or vapor calculations:

(7) mg per liter x 1000
= mg per cubic meter

(8) mg per liter x 28.32
= mg per cubic foot

(9) mg per cubic foot x 35.314
= mg per cubic meter

(10) mg per cubic meter x 0.02832
= mg per cubic foot

(11) parts per million =

$$\frac{24{,}450 \times \text{mg per liter}}{\text{molecular weight}}$$

One gram molecular weight of a gas occupies 24.45 liters at 25°C and 760 mm of mercury pressure.

Analysis

A complete review of the analytical methods which have been used successfully for the analysis of gas and vapor samples is beyond the scope of this lecture. These methods are given in detail in the reference texts(1,2,4) as well as an appended summary of satisfactory chemical methods for specific applications.(4) In addition to the methods suggested in these works, new techniques aimed at greater sensitivity and specificity are being developed which will be extremely helpful to the chemist. Of particular assistance will be the applications of vapor phase chromatography(5,6) and infrared spectrophotometry. These techniques provide powerful tools to assist the chemist faced with the problems of identifying and determining part per million concentrations of mixtures of substances which may interfere with each other in the application of certain conventional chemical methods. Such substances as the halogenated hydrocarbons have generally had no specific analytical methods and their estimation on an individual basis has been difficult. With vapor phase chromatography, the physical separation and determination of such mixtures is now becoming possible. Infrared spectroscopy is an important technique in the analysis of such materials and, along with vapor phase chromatography which effects the separations and provides increased sensitivity, can be expected to play an important role in this field.

References

1. Jacobs, Morris B.: The Analytical Chemistry of Industrial Poisons, Hazards and Solvents. Interscience Publishers, Inc., 2nd Ed., New York, N.Y., 1949.
2. Elkins, Hervey B.: The Chemistry of Industrial Toxicology. John Wiley and Sons, Inc., New York, N.Y., 1950.
3. Silver, S. D.: Constant flow gassing chambers: Principles influencing design and operation. J. Lab. & Clin. Med. 31:1153, (1946).
4. Goldman, Frederick H., and Jacobs, Morris B.: Chemical Methods in Industrial Hygiene. Interscience Publishers, Inc., New York, N.Y., 1953.
5. Scott, R.P.W., Editor,: Gas Chromatography 1960. Butterworth Inc., Washington, D.C., 1960.
6. Szymanski, H. A.: Progress in Industrial Gas Chromatography. Plenum Press, New York, N.Y., 1961.

DETECTOR TUBES

The detector tube system is one of several direct reading devices available to the industrial hygienist for monitoring toxic gases and vapors. A detector tube consists of a hand pump, a detector tube and a calibrated scale or color standard.

The pump may be a bellows or piston type. Most pumps are made to deliver 100 ml of air sample per stroke. With some piston type pumps the plunger can be set to deliver less than 100 ml.

The detector tube is a sealed glass tube containing a solid support impregnated with a reactive chemical reagent. The most common solid support is silica gel of a selected particle size range and processed to some specified purity, activity and moisture content. A definite particle size range is important in maintaining a uniform density pack and pressure drop, in avoiding particle separation and in eliminating channeling. Moisture content is important as it can affect the activity of the silica gel, the color forming reaction and the stability of the chemical reagent.

An air sample is drawn through the tube with a hand pump and if a contaminant is present it reacts with the reagent in the tube producing a color. The color is evaluated to represent a level of concentration of the contaminant in the air.

Some tubes contain ahead of the silica layer one of several "clean-up" sections. This may be a drying agent to remove moisture if high humidity is a problem, a special layer to remove gases and vapors which interfere with a test, or an oxidizing layer. The oxidizing reagent may also be in a thin vial incorporated into the tube and which is broken just prior to test. Some contaminants are not reactive and do not easily form colored derivatives. Chlorinated hydrocarbons are an example. The oxidizing chemical oxidizes or "cleaves" the chlorinated hydrocarbon molecule releasing chlorine which then reacts with the color forming reagent. These tubes are very useful but care must be exercised in using them. The air sample must first be drawn through the forward layer and then the silica gel layer, otherwise the test is missed. Direction of flow through the tube is usually indicated by an arrow or dot.

The presence of a contaminant is indicated by a color change in the tube. No color means no contaminant or the contaminant concentration is below the sensitivity of the tube. One could be tempted to save the tube and use it again. This is not recommended as other contaminants and moisture introduced into the tube may affect the color forming reagent and the silica gel activity and subsequently the test. Where tubes can be reused, they should be reused as specified in the instruction sheet.

Just prior to the test, the ends of the sealed tube are broken off and the tube is inserted into the tube holder of the pump. Where direction of flow must be in one direction, the tube must be held in the pump as indicated by direction marking on the tube. A volume of air is drawn through the tube and if a contaminant is present a color is produced. This may be measured as stain length in millimeters and then converted to concentration or with many tubes concentration is read directly from an imprinted scale on the tube. With some tubes, the density of the color produced is compared with a standard color chart. Length of stain tubes are preferred to color density tubes as the evaluation of the latter is difficult with the naked eye and depends on the color acuity of the testor and prevailing lighting conditions.

Certified detector tubes are accurate to ± 35% at 1/2 the TLV. This could make one think that detector tubes are of little values as test devices. This certainly is not the case, but they must be used within their limitations. They are very good for "yes", there is a problem the contaminant concentration is high; "no", there is no problem, the concentration is definitely below the health standard. In the

---

Prepared by Steven N. Dereniuk, Analytical Chemist, DTMD, NIOSH, 8/77.

area 25% or slightly larger variation above and below the health standard, the detector tubes lack the accuracy required in making a decision. In this "grey-area" samples should be taken with a charcoal tube, a midget impinger or by some other method and analyzed in the laboratory.

Detector tubes are calibrated, depending on the manufacturer, at temperature of 20 or 25°C, normal atmospheric pressure, about 50% humidity and at a specific flow rate. In some systems, flow rate is controlled by an orifice in the pump, in others, it is controlled by the density of the tube pack. In the field, detector tubes should be used close to calibration conditions, especially flow rate. If flow rate is faster then the calibration flow rate, stain length will be longer than it should and if it is slower, stain length will be shorter than it should because contact time between contaminant and color forming reagent is different from calibration contact time. Different manufacturers pumps and tubes should never be interchanged; volumes delivered may be the same, but flow characteristics are not. Although tubes are calibrated at a specific temperature, a certain temperature latitude is allowed and they can be used over a specified temperature range. Some typical temperature ranges are 0-40°C, 0-50°C, 10-30°C, etc. The calibration temperatures given are the temperatures of the tube and unless a relatively large sample volume is drawn, or the air temperature is high, tube temperature will not be appreciably affected. Temperature correction factors are given with some tubes. One SO_2 tube with a test temperature range of 0-40°C is supplied with corrections for 0, 10, 30 and 40°. Hot gases can be tested but they first must be cooled by drawing the sample through a special probe.

Remote test places can be reached with a sampling line, but the order must always be: tube – sampling line – pump. The air sample should not be first drawn through the sampling line because an appreciable amount of a gas vapor can be lost on the walls of the sampling line.

Detector tubes should be stored cool, preferably in a refrigerator. The shelf-life of tubes is increased if they are refrigerated and are kept out of the light. Tubes are dated and should not be used beyond the expiration date. Just enough tubes should be removed from storage to complete a test. They should not be carried in car, truck, or on the dash board where they may be exposed to a high temperature.

The detector tube system must always be checked for proper operation and response. Pumps are checked for leaks, flow rate and volume delivery. Pumps wear, corrode, clog, and are damaged by use. Detector tubes are affected by heat, light and age and reach expiration dates. Procedures for this test are outlined in the laboratory section under "Detector Tubes" – "Calibration and Tests."

Pumps should first be checked for proper operation as outlined in the laboratory section. Screens and orifices should be removed, examined and cleaned. Care must be exercised in cleaning orifices. Corroded and damaged orifices must be replaced. Bellows pumps should open freely, arrestor chains should not be loose, stretched or kinked, sealing screws should be tight. Pumps requiring periodic greasing should be greased with silicon grease rather than petroleum grease which can attach the teflon "0" rings. In a piston pump, the plunger and cylinder should line up properly for test as indicated by index marks on the pump. The plunger should lock easily in a 100 ml position. Pumps must not leak.

Detector tubes should be checked for tube uniformity, uniform particle distribution and pack and any discoloration. Tubes with indications of color change should not be used. Tube reaction and color formation in tubes can easily be studied by preparing gas or vapor mixture as outlined in the laboratory section. Tube ends when broken off should have relatively large openings. Very small openings will restrict flow rate. Tubes should be used within the specified temperature range and recommended detection level, i.e., a tube made to measure in the 100 – 1000 ppm range would not be suitable to measure at a 1 ppm level.

In making tests, the tester should be aware of humidity, temperature, pressure and interference problems. Knowledge of operations, materials used and products, by-products and wastes produced are extremely helpful in performing and interpreting tests.

Detector tubes are inexpensive, easily portable and easy to use. Evaluation of color obtained however, can be difficult and requires experience. They are a very short term test, producing quick results, often in 60 seconds. In the hands of an experienced industrial hygienist, they are a valuable tool in mnoitoring work places.

A recent development in detector tubes is the long term tube which can be used over an eight-hour period for a time weighted average. The tube is carried in a special tube holder clamped to the worker near his breathing zone. Air is drawn through the tube with a low volume pump; one manufacturer's pump samples at 10 to 20 milliliters per minute.

OXYGEN DEFICIENCY AND COMBUSTIBLE GAS METERS

Combustible Gases and Vapors

Many gases and vapors form flammable mixtures with air. For combustion to occur we need a fuel, air and an ignition source. If any one of these three is eliminated combustion cannot occur. Fire with a combustible material can be prevented by reducing the oxygen content of the atmosphere. The degree to which the oxygen content has to be reduced varies with the combustible material under consideration.

Liquids and many solids give off vapor. Vapor pressure is a function of temperature. The higher the temperature the greater the vapor pressure. A flammable liquid has to be heated to a specific temperature to give off enough vapor to form a flammable mixture with air. This temperature is the flash point of the liquid. Gases do not have flash points.

Flammable gases and vapors are rated as possessing a certain <u>lower explosive limit</u> and an <u>upper explosive limit</u> in normal air. The upper explosive limit is the "rich" mixmixture or the point beyond which combustion will not occur as the oxygen has been diluted too much. In an oxygen rich atmosphere the range of the upper explosive limit is extended.

Most combustible gas-air mixtures in explosive proportions are only slightly affected as to the explosive hazards by moderate changes in temperature. Combustible liquids on the other hand can be markedly affected by even small changes in temperature. In many cases a few degrees increase in temperature will raise the vapor pressure high enough to form a flammable mixture.

Fires and explosions resulting from combustible gases and vapors are among the major hazards in industrial operations. Flammable gases as a group are more dangerous than liquids. Pressurized gases present other hazards. Cylinders can explode and a ruptured valve assembly can cause "rocketing" which can propel a gas cylinder with tremendous force.

The terms "explosive limits," flammable limits" and "limits of flammability" are often used. These terms are really different expressions for the same thing. Flammable limit values found in the literature may vary depending on the procedures used to make the tests. Flammable limit values obtained may be affected by the geometry of the test apparatus, temperature and pressure of the mixture at ignition, humidity and source of ignition.

Limits of flammability can be calculated according to Burgess and Wheeler. They stated that there is a definite relationship between the colorific value of a combustible and its lower limit of flammability. The colorific values of pure hydrocarbons multiplied by the lower limits of flammability give a constant; e. g. , a lower-limit mixture of any paraffin hydrocarbon on combustion with air liberates the same amount of heat.

Thornton postulated that the upper limit bears a direct relation to the amount of oxygen needed for complete combustion. For paraffin hydrocarbons the upper-limit mixture contains twice the volume of gas as the mixture for complete combustion and acetylene and carbon disulfide, three times the volume. Lower-limit mixtures that just failed to propogate a flame contained twice the volume of oxygen for complete combustion of paraffin and three times the volume for mixture of acetylene and carbon disulfide. Thornton's predication holds for some mixtures and varies widely for other mixtures.

Calculations for limits of flammability of combustible mixtures have been worked out from limits of each combustible and the percentage of each in the mixture. The "mixture law" of Le Chatelier states that if we separate limit combustible-air-mixtures and mix them, then this mixture will be a limit mixture. This can be expressed by the equation:

$$L = \frac{100}{\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \frac{P_4}{N_4}}$$

Prepared by Steven Dereniuk, Analytical Chemist, Division of Training, NIOSH, 6/72.

When P_1, P_2, P_3 and P_4 are proportions of the combustible gases in mixture free of air and inerts, N_1, N_2, N_3 and N_4 are the respective lower and upper limits of flammability in air. L is the lower or upper limit of flammability of the mixture. This postulate holds accurately for a number of mixtures.

It is possible to calculate limits of flammability for flammable mixtures of gases and vapors containing inert gases and air, but the calculations are complicated.

Combustion and explosions can be minimized by reducing oxygen content and other means.

Combustible gases, vapors or mists will not burn or explode when the oxygen content of the air is below a certain level. This level varies with the combustible substance in question.

The oxygen content can be reduced by absorption on special reagents, by dilution with inert gases such as nitrogen, carbon dioxide, freons and other gases. Toxic and corrosive gases should not be used.

Combustible liquids can be controlled by low temperature because vapor pressure is reduced by lowering the temperature.

Flammability and explosion can be minimized by proper storage and handling, by eliminating open flames, by installing explosion proof electrical equipment, by eliminating static electricity; boilers, hot water heaters and other equipment with open flames should be isolated.

Adequate ventilation should be provided to prevent high concentrations of gases and vapors through dilution with air.

The atmosphere should be continuously monitored. Combustible gas indicators are available for monitoring combustible materials.

PREPARATION OF CONTROLLED GAS AND VAPOR CONCENTRATIONS

I Test atmospheres may be prepared by quantitative dilution of pollutants of interest with pure air. The concentration of pollutant can be calculated from dilution data and this value will be accurate provided none of the pollutant is lost, gained, or chemically altered during the dilution and storage of the test atmosphere. These atmospheres are often used to establish cause and effect relationships. Test atmospheres are very useful for development and evaluation of analytical methodology.

A Suggested Topics

1 Static procedures
2 Dynamic procedures
3 Dilution air
4 Pollutant transfer or generation
5 Materials of construction
6 System design

REFERENCES

1 Lodge, J. P., Jr. Production of Controlled Test Atmospheres in "Air Pollution," edited by A. C. Stern, Academic Press, New York. 1962.

2 Altshuller, A. P., Wartburg, A. F., Cohen, I. R., Sleva, S. F. Storage of Vapors and Gases in Plastic Bags. Int. Journal of Air Water Poll., 6:75-81. 1962.

3 Nelson, G. O. Controlled Test Atmospheres - Principles and Techniques. Ann Arbor Science Publishers. 1971.

SUPPLIERS OF PLASTIC BAGS

1 The Anspec Co. — Saran
P.O. Box 44
Ann Arbor, Michigan 48107
(313) 971-1911

2 R. E. Allen Inc. — Saran
233 W. Ohio Street
Kenton, Ohio

3 Fluorodynamics, Inc. — CHEMTON, Teflon FEP, Tedlar, Kynar, Aclar
Diamond State Industrial Park
Newark, Delaware 19711
(302) 368-2511

4 Norwood Scientific Associates — Mylar
P.O. Box 396
Norwood, New Jersey 07648
(201) 767-0294

PLASTIC FILM SUPPLIERS

ABS	Acrylonitrile-butadiene-styrene
Mylar	(Dupont) polyester
Polyethylene	
Saran	(Dow) PVC, polyvinyl chloride
Scotchpak	(3M) polyester
Scotchpar	(3M) polyester
Tedlar	(Dupont) PVF, polyvinyl fluoride

"1968 Modern Plastics Encyclopedia," McGraw-Hill, Vol. 45, No. 1A, September 1967, New York, pp. 528-577, Film, Sheeting and Shapes.

Plastic bags used in Training Institute Courses are heat sealed Tedlar.

E. I. DuPont De Nemours & Co., Inc.
1007 Market Street
Wilmington, Delaware 19898
774-2421

A 100 lb. (minimum order) roll of Tedlar film was obtained directly from Dupont in September 1969. This film has the designation:

Dupont PVF (TEDLAR) film
200 SG 40 TR
38" width

The 200 indicates a 2 mil. thickness, the S sealable, the G glossy, the 40 refers to certain physical properties, and the TR transparent.

Prepared by William H. Perry, Chemist, Division of Training, NIOSH, 1/73.

The cost per pound was $4.75 and the actual weight of the roll was 114 pounds.

A heat sealer was ordered from:

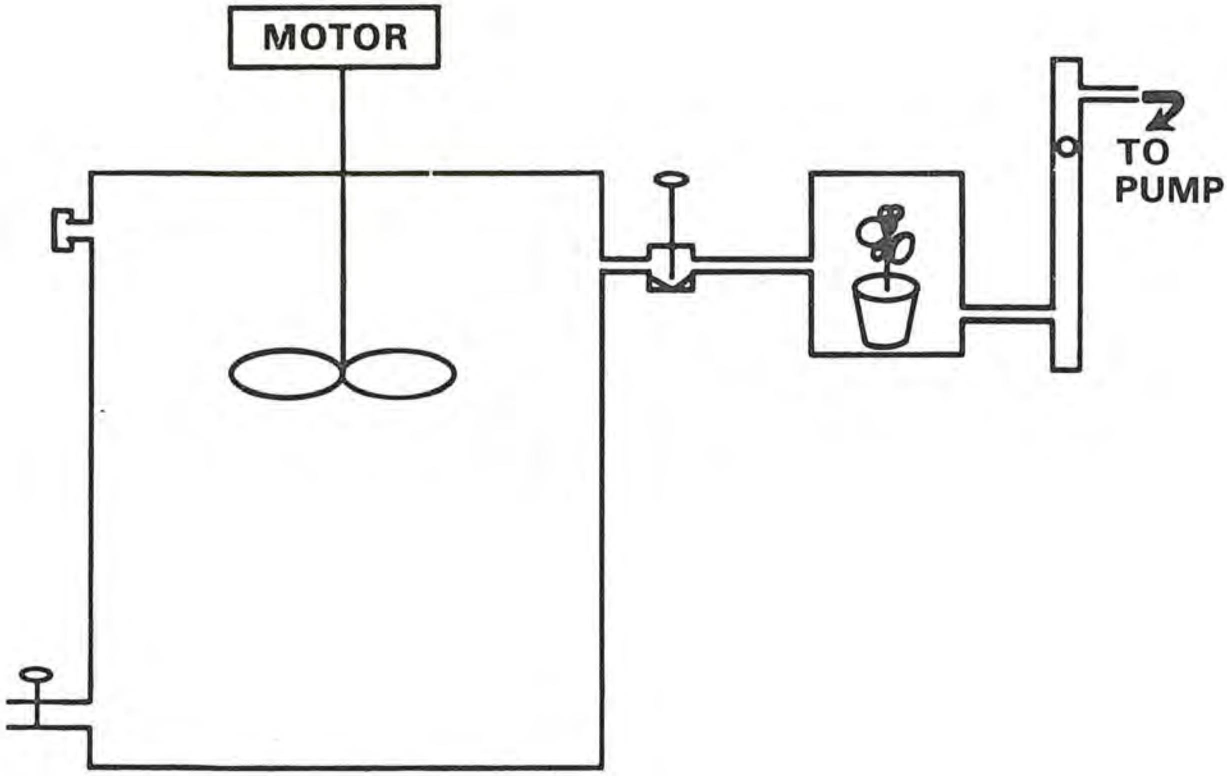
Packaging Industries, Inc.
Airport Road
Hyannis, Massachusetts 02601

It has the designation:

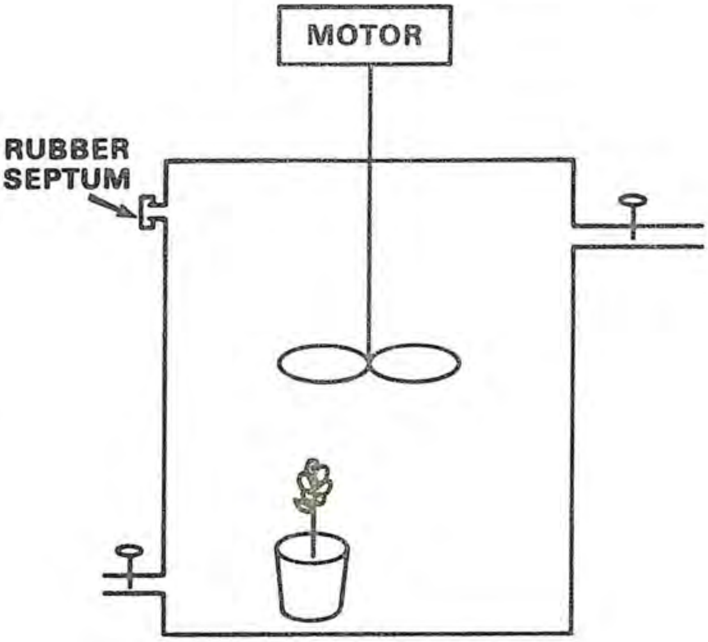
Sentinel Model 16T Pacemaker
Thermal Impulse Sealer

It costs $425. including a $25. crating charge.

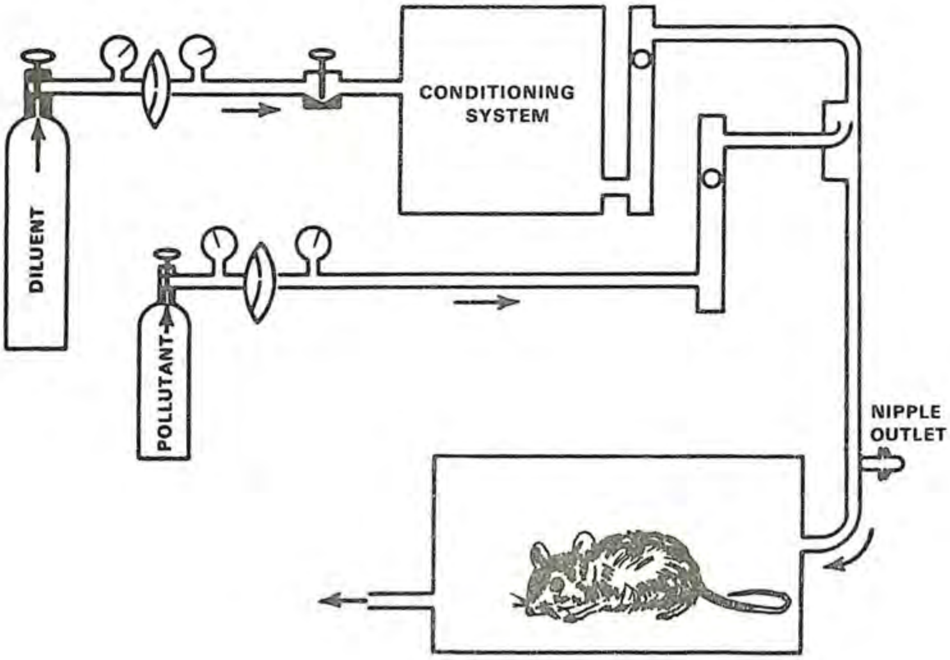
QUASI-STATIC SYSTEM



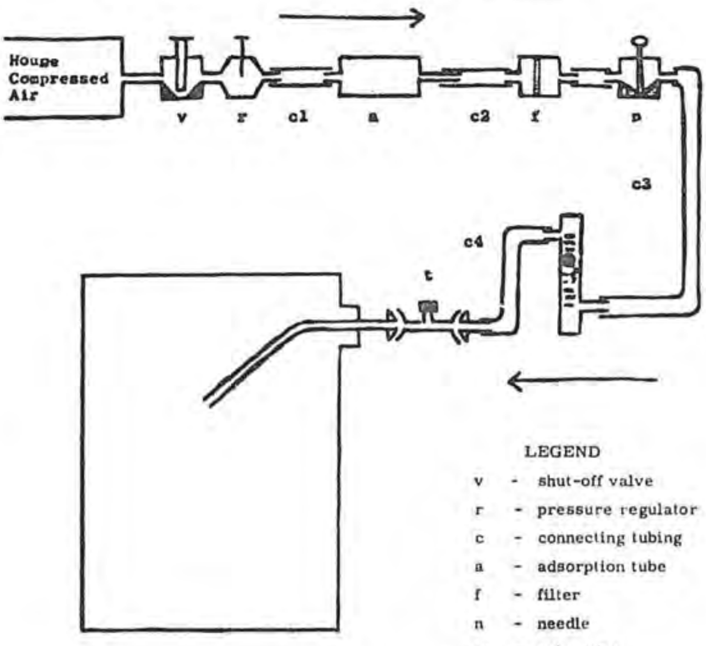
STATIC SYSTEM



QUASI-DYNAMIC SYSTEM



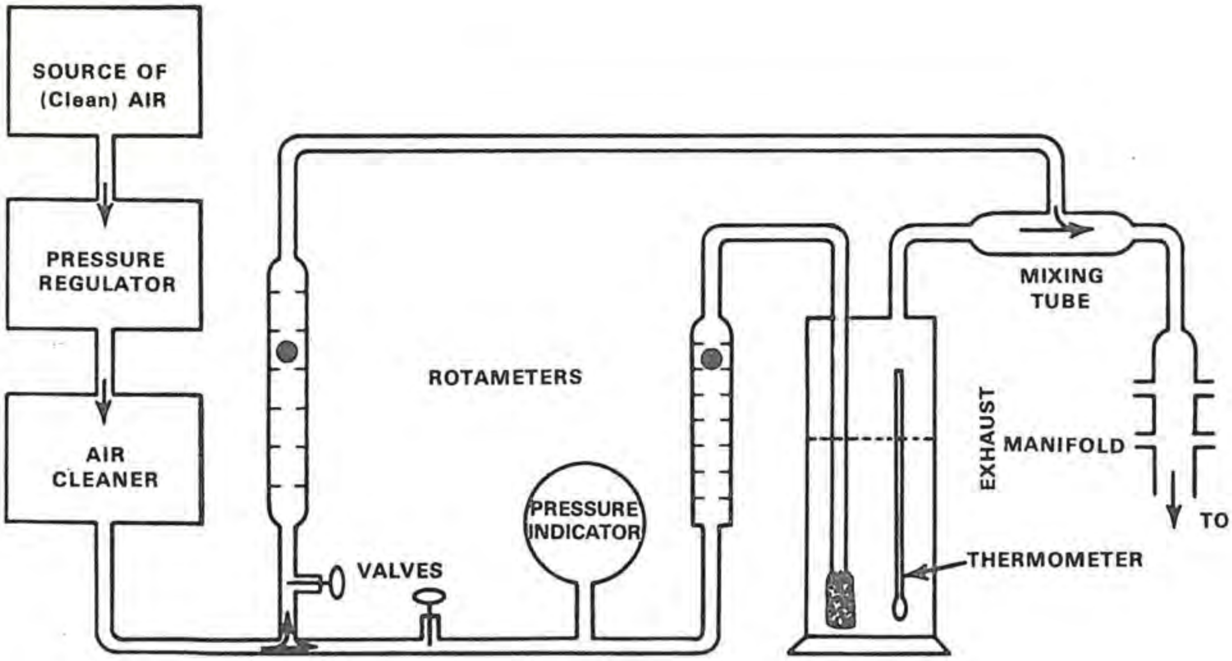
SYSTEM FOR FILLING OF PLASTIC



LEGEND

v - shut-off valve
r - pressure regulator
c - connecting tubing
a - adsorption tube
f - filter
n - needle
m - rotameter
b - bag
t - injection T

PREPARATION OF CONTROLLED CONCENTRATIONS OF VAPOR IN AIR BY THE VAPOR PRESSURE METHOD (WHP 8/5/70)



Problem Set

CALCULATION OF NOMINAL CONCENTRATIONS OF CONTROLLED TEST ATMOSPHERES

INSTRUCTIONS:

In these problems assume that all measurements of liquid and gaseous volumes are made at 25°C and 760 mm Hg unless otherwise indicated. Also assume that all gases and vapors behave ideally and have a molar volume of 24.45 liters at 25°C and 760 mm Hg.

Indicate the choice which best completes the statement by encircling the appropriate letter.

1 A test atmosphere is prepared by introducing 1 microliter of sulfur dioxide into 1 liter of clean air. The concentration of sulfur dioxide in the resulting mixture is:

a 0.10 ppm
b 1.00 ppm
c 10 ppm
d 100 ppm
e 1000 ppm

2 A mixture is prepared by diluting 1.00 ml of sulfur dioxide with clean air so that a final volume of one cubic meter is obtained. The concentration of sulfur dioxide in the resulting mixture is:

a 0.10 ppm
b 1.00 ppm
c 10 ppm
d 100 ppm
e 1000 ppm

3 A mixture is prepared by diluting 1 ml of sulfur dioxide with clean air so that a final volume of 100 liters is obtained. The concentration of sulfur dioxide in the resulting mixture is:

a 0.10 ppm
b 1.00 ppm
c 10 ppm
d 100 ppm
e 1000 ppm

4 A mixture is prepared by diluting 10 microliters of sulfur dioxide with clean air so that the total volume is 10 liters. The concentration of sulfur dioxide in the resulting mixture is:

a 0.10 ppm
b 1.00 ppm
c 10 ppm
d 100 ppm
e 1000 ppm

5 A mixture of carbon monoxide in nitrogen contained in a cylinder is known to contain 0.10% carbon monoxide. This concentration can also be expressed as:

a 0.10 ppm
b 1.00 ppm
c 10 ppm
d 100 ppm
e 1000 ppm

6 One volume of a mixture containing 0.1% carbon monoxide in nitrogen is diluted with 49 volumes of clean air. The concentration of carbon monoxide in the resulting mixture is:

a 10 ppm
b 20 ppm
c 100 ppm
d 200 ppm
e 500 ppm

7 A stream of air containing 1000 ppm carbon monoxide in nitrogen is metered at 50 cc/min and is mixed with a stream of clean air metered at 4950 cc/min. The concentration of carbon monoxide in the resulting mixture is:

a 10 ppm
b 20 ppm
c 25 ppm
d 100 ppm
e 200 ppm

8 The brownish orange gas obtained from a cylinder is known to be an equilibrium mixture of nitrogen dioxide and its dimer nitrogen tetroxide. If the dimer were to be able to dissociate and the mixture then followed the behavior of an ideal gas, each volume of the monomer-dimer mixture would produce 1.74 volumes of nitrogen dioxide monomer. The nitrogen dioxide concentration obtained by dilution of 10 microliters of the equilibrium mixture with 10 liters of clean air would be:

a 1.00 ppm
b 1.74 ppm
c 10.0 ppm
d 17.4 ppm
e 100 ppm

9 It is intended to prepare 15 liters of a mixture containing 5 ppm sulfur dioxide in air. What volume of gaseous sulfur

Prepared by William H. Perry, Chief, Program Assistance Branch, Division of Training. 4/74

dioxide should be added to the 15 liters of clean air to produce the intended concentration?

a 15 microliters
b 30 microliters
c 50 microliters
d 60 microliters
e 75 microliters

10 What rate of flow of 0.1% carbon monoxide in nitrogen should be metered into a flow of clean air to produce a total flow of 4000 cc/min at a concentration of 50 ppm:

a 100 cc/min
b 200 cc/min
c 400 cc/min
d 1000 cc/min
e 2000 cc/min

11 The vapor pressure of toluene at 25°C is 28 mm Hg. What is the maximum concentration of toluene vapor in air that can be obtained at 25°C at a total pressure of 760 mm Hg?

a 280 ppm
b 352 ppm
c 368 ppm
d 3.52%
e 3.68%

12 The vapor pressure of benzene at 25°C is 97 mm Hg. What is the maximum concentration of benzene vapor in air that can be obtained at 25°C at a total pressure of 760 mm Hg?

a 97 ppm
b 760 ppm
c 1270 ppm
d 12.7%
e 22.7%

13 An air stream that has been saturated with mercury vapor at 25°C (vapor pressure 0.002 mm Hg) is diluted with clean air in the ratio of nine parts of clean air to one part of air saturated with vapor. The dilution system is at atmospheric pressure (760 mm) and 25°C. The concentration of mercury in air resulting from the dilution is:

a 0.26 ppm
b 2.6 ppm
c 26 ppm
d 0.26%
e 2.60 ppm

14 An air stream that had been saturated with isobutanol vapor at 25°C (vapor pressure, 13 mm Hg) is diluted with clean air in the ratio of nine parts of clean air to one part of air saturated with isobutanol. The dilution system is at atmospheric pressure (760 mm) and 25°C. The concentration of isobutanol vapor in air resulting from the dilution is:

a 0.17 ppm
b 1.7 ppm
c 17 ppm
d 0.17%
e 1.7%

15 Ethyl alcohol has a molecular weight of 46.07 and a density of 0.785 g/ml at 25°C. The volume occupied by one gram molecular weight of liquid ethanol at 25°C is:

a 11.7 microliters
b 58.8 microliters
c 11.7 ml
d 117 ml
e 58.8 ml

16 At 25°C the weight of 1 ml of liquid ethanol is:

a 588 mg
b 785 mg
c 1.00 g
d 5.88 g
e 7.85 g

17 At 25°C the weight of one microliter of liquid ethanol is:

a 0.558 mg
b 0.785 mg
c 1.00 mg
d 5.58 mg
e 7.85 mg

18 A purge tube gas collector (250 ml) fitted with an injection port is partially evacuated after it has been purged with clean air. A 10 microliter quantity of liquid ethyl alcohol is injected through a rubber serum stopper attached at the injection port. The liquid is allowed to completely vaporize. The stopcock at one end is opened for an instant to allow clean air to enter and for the mixture to attain the pressure of the ambient atmosphere. The concentration of ethyl alcohol vapor in air in the collector is:

a 16.7 ppm
b 167 ppm
c 1670 ppm
d 1.67%
e 16.7%

19 A 10 microliter portion of liquid ethyl alcohol is injected into a stream of metered clean air. A flow of 5 liters/min into a plastic bag is maintained for 5 minutes. The alcohol is introduced early in the

bag-filling procedure so that all of it is evaporated and is carried into the bag. The concentration of alcohol in air produced in the bag by this procedure is:

a 16.6 ppm
b 166 ppm
c 1660 ppm
d 1.66%
e 16.6%

20 Toluene has a molecular weight of 92 and its density at 25°C is 0.86 g/ml. The concentration of toluene in air produced by vaporizing 1 ml of liquid toluene into clean air to produce a total volume of 100 liters is:

a 860 ppm
b 920 ppm
c 0.23%
d 2.30%
e 8.60%

PROBLEM SET

PREPARATION OF CONTROLLED CONCENTRATIONS OF VAPORS AND GASES IN AIR

1 A chemist desires to prepare an air sample containing 0.20 ppm butene-1. He finds it convenient to meter 100 liters of clean air into a Mylar bag. What volume of gaseous butene-1 should he introduce into this volume of air to obtain the desired concentration?

Answer: ______________________________ µl butene-1

2 A system is designed so that phosgene can be diluted with clean air in three stages. In the first stage, the phosgene is metered at 10 cc/min and mixed with a variable amount of clean air. This flow rate can be adjusted over the range 0.1-10 liters/min. Most of the mixture produced in the first stage is vented to the hood. A 10 cc/min flow of mixture 1 is diluted with a 10 liter/min flow of clean air to produce mixture 2. The dilution is completed in a third stage where 10 cc/min of mixture 2 is diluted with a 10 liter/min flow of clean air.

What is the range of concentrations of phosgene in air which can be prepared at this third stage of dilution?

Answer: ________________________ to ________________ ppm phosgene in air.

3 A chemist injects 5 µl of liquid benzene into a 250 ml glass dilution-purging tube. He warms the walls of the tube to ensure complete vaporization of the liquid. After the tube has returned to room temperature, he transfers 1 ml of the vapor-air mixture to a Mylar bag containing 100 liters of clean air. What is the concentration of benzene in the Mylar bag which results from this two-stage dilution?

Answer: ______________________________ µg benzene/M^3

______________________________ ppm benzene

Note: The molecular weight of benzene is 78.11, the density of liquid benzene at 20° is 0.88, and it can be assumed that the molar volume of the vapor at 25° is 24.4 liters.

4 The permeation rate of butane through a particular size and type of teflon tubing is 6.4 ng/cm/min at 15.5°C. A tube containing butane and having an effective length of 10 cm is placed in a metered and thermostatted (15.5°C) stream of clean air. The flow rate of air is 10 liters/min. What is the concentration of butane in the air sample which is produced by this system?

Answer: ______________________________ ng/liter

______________________________ µg/M^3

______________________________ ppb

______________________________ ppm

Note: The molar volume of an ideal gas at 25°C is 24.4 liters and the molecular weight of butane is 58.1.

1ng = 1 nanogram = 10^{-9} gram

5 A chemist desires to prepare an air sample containing 0.05 ppm acrolein. He finds it convenient to prepare 160 liters of this sample in a Mylar bag. He prepares a solution of acrolein in ethanol by diluting 1 ml of acrolein with ethanol to give a total volume of 200 ml. What volume of this ethanolic solution should he introduce into the Mylar bag to obtain the desired concentration in the 160 liter sample?

Note: Molar volume of ideal gas at 25°C = 24.4 liters
Density of acrolein at 25°C = 0.81 g /ml
Molecular weight of acrolein = 56

6 A chemist desires to prepare an air sample containing 0.1 ppm formaldehyde. He finds it convenient to prepare 100 liters of this sample in a Mylar bag. He prepares a solution by diluting 1 ml of formalin with water to give a total volume of 100 ml. What volume of this solution should he introduce into the Mylar bag to obtain the desired concentration in the 100 liter sample?

Note: The formalin which is available meets the following specifications: assay, 37% formaldehyde; Methanol preservative, 12%; specific gravity at 25°C, 1.08

Assume: Molar volume of ideal gas at 25°C = 24.4 liters
Molecular weight of formaldehyde = 30.0

Laboratory: Gas and Vapor Sampling
DETECTOR TUBES AND PUMPS
CALIBRATION AND TESTS

I. The direct reading gas detector tube system consisting of assembled pump and tube, like any measuring device, periodically must be checked for proper performance. The purpose of this laboratory exercise is to acquaint the trainee with the calibrations and tests involved.

Pumps wear, corrode and can be damaged by hard use. Sealing screws loosen, screens and orifices become clogged with pieces of glass and dirt. The arrestor chain on the bellows-type pump can loosen or be damaged. The pump inlet tube holder is easily cut by the sharp edges of the detector tube; it can become brittle and crack.

Before beginning tests, examine the pumps and tubes for any obvious flaws. Correct pump flaws if possible. Discard obviously bad tubes.

II. EQUIPMENT AND SUPPLIES NEEDED ARE:

Detector tube pumps

Detector tubes

Test solvents

Test gases

Burettes, 100 and 250 ml.

Burette supports

Clamps

Rubber tubing

Teflon tubing

Glass tubing

Stopwatch

Beakers, 250 ml.

Rotameter, 2 lpm capacity

Air pump

Hot plate, small

Gas mixing vessel with side inlet with rubber septum

Soap solution (1% synthetic detergent in water)

Syringe, microliter, 10 μl and 25 μl size

Syringe, gas tight, about a 0.5 ml size

Tedlar, Mylar, or Teflon bag, 30 liter size, at least 2

III. PUMP TESTS

A. Leak Tests

Insert an unbroken detector tube into the pump inlet tube holder. Match tube and pump. Pull out plungers and lock in 100 ml position. Compress bellows-type pump. Time test as follows:

Kitagawa	2 minutes
Gastec	1 minute
MSA	2 minutes at setting #4
Drager	10 minutes

Repeat MSA pump leak test with rotating head set approximately midway between two orifice numbers. Leaks can develop in rotating head.

At the end of the indicated time, release the plunger. It is good practice to restrain the plunger because with some pumps, it can retract with enough force to damage the pump. In most cases, the plunger will return to zero position. If it remains out approximately 5 ml a leak is indicated.

Drager pump is considered satisfactory if bellows does not open completely in 10 minutes.

If pumps leak, check tube holder, valves, gaskets, seals and for wear. If fault cannot be corrected, pump should be discarded or returned to supplier for servicing.

Prepared by Steven N. Dereniuk, Analytical Chemist, DTMD, NIOSH, 8/77.

B. Flow Rate Tests

Assemble test equipment as shown in Figure 1. Pour a small amount of soap solution into burette and hold it in an almost horizontal position and rotate to completely wet the inside wall. Pour out excess solution and clamp burette to support. Touch lower end of burette with soap solution to form film and with suction, draw it, preferably to the zero position, but initial position can be any point not greater than 20 ml on a 100 ml burette. Connect MSA pump to burette with rubber tubing. Have a trap in the line to avoid drawing soap film into pump. Pull out plunger and lock in 100 ml position and simultaneously have fellow trainee start stopwatch to time flow rate through 80 ml. Test orifices 1, 2 and 3 at least twice. Flow rates should be as follows:

#1 setting	44-48 seconds
#2 setting	24-26 seconds
#3 setting	12-14 seconds
#4 setting	1-2 seconds

Kitagawa pump – withdraw plunger quickly and lock at 100 ml position. Time 30 seconds and release plunger. Note where plunger stops. Not more than 35-40 ml of air will enter if pump is operating properly.

Drager pump – this pump does not have a flow restricting orifice. Flow rate is controlled by tube density rack. Break off ends of any Drager tube and insert into tube holder. Compress bellows and start stopwatch. Observe number of seconds it takes bellows to fully open and note if time is within time range given in the instruction sheet. Note: Always break off tube ends with care. Pieces of flying glass can strike user's eye. Eye protection is recommended.

Gastec pump – this piston-type pump does not have a flow rate orifice. Flow rate in this system is controlled by the indicator tube.

If flow rate is faulty, check screens, orifices, valves, seals, arrestor chain, tubes, etc. and correct fault if possible.

If orifices are removed to be cleaned, clean them carefully as they are easily damaged.

C. Volume Delivery

Wet inside of 250 ml with soap solution and connect to support. Touch lower end with soap solution and draw film to just within the burette scale and note reading. Connect pump to burette using rubber tubing. Have a trap in the line. Withdraw plunger and lock at 100 ml position or compress bellows. Note where film stops. Note volume delivered. Take several readings. Pump is considered satisfactory if volume delivered by a 100 ml capacity pump is within 5 ml of 100 ml.

IV. DETECTOR TUBES

Assemble test equipment as shown in Figure 2 and prepare vapor-air mixture at or near the health standard concentration as follows:

First fill and empty bag several times to remove previous test mixture. Roll up bag to completely expel air from it. Start ambient air pump and set rotameter to deliver 2 liters per minute. Simultaneously connect bag and start stopwatch and time for a total of 5 minutes. After about 2 minutes, carefully measure 10 microliters of toluene with a microliter syringe (eliminate bubbles from syringe) and inject through septum into slightly heated gas mixing chamber. Toluene is very volatile and with slight heat, is completely swept into bag before pump is stopped. At the end of 5 minutes, stop pump, disconnect bag, cap it and knead to give a uniform mixture. Remove cap and apply very slight pressure to expel "dead" air from connecting tube. Connecting tubes between bag and mixing chember should be glass or teflon.

Determine toluene concentration using different manufacturer's tubes. Depending on manufacturer, detector tube may be listed as toluene or aromatic hydrocarbon tube. Never interchange different manufacturer's pumps and tubes.

Select tube, break off ends (protect eyes from possible flying pieces of glass) insert into

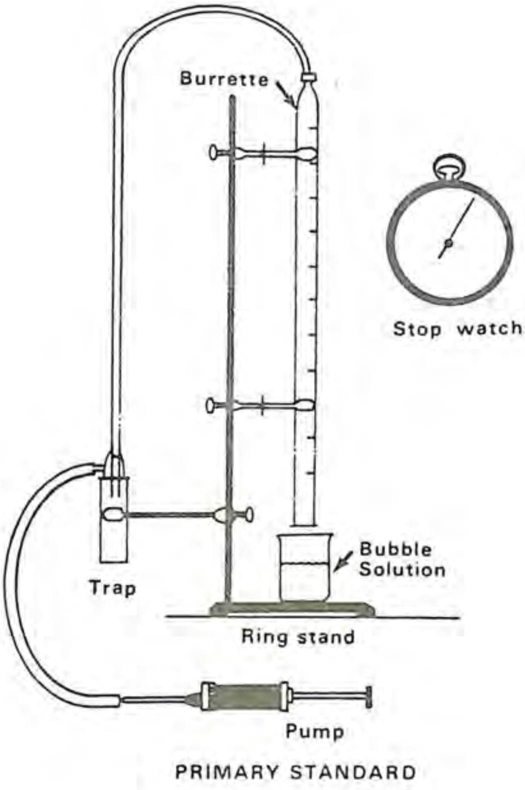


Figure 1

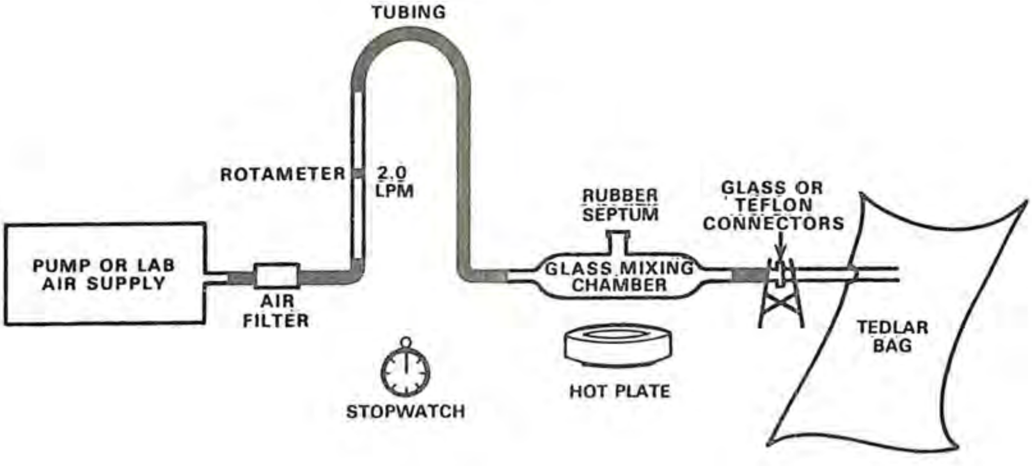


Figure 2

pump tube holder and determine toluene concentration by sampling from bag outlet. Draw number of strokes indicated in tube instruction sheet. With piston pump, wait indicated time between strokes because if plunger is unlocked too soon, full sample volume will not be drawn.

Read respective tubes in accordance with instructions to determine concentration and note accuracy and precision. Record readings. Some gases and vapors may be rapidly and appreciably absorbed on the bag surface resulting in low readings. If this occurs the mixture should be expelled from the bag and the preparation repeated. Usually the second or third preparation will contain the calculated concentration.

Repeat tests with toluene mixture concentrations at 1/2 and 2 times the health standard if time permits.

Compare accuracy of tubes at different concentrations.

The calculations involved in preparing vapor test mixtures in air are:

> Remember: 1 microliter (1 l) of a gas or vapor (not 1 μl of liquid) in 1 liter of air is 1 ppm. One μl is 0.001 ml.
>
> One gram mole (gram molecular weight) of a chemical in the gaseous state at 25°C and 1 atmosphere pressure occupies 24.45 liters.
>
> The molecular weight of toluene is 92.1 gm and its density is 0.866 gm per ml.
>
> One gram mole of toluene in the liquid state occupies
>
> $$\frac{92.1}{0.866} = 106 \text{ ml}$$
>
> at room temperature and normal pressure.
>
> Again, 106 ml (1 gram mole) of liquid toluene in the gaseous state occupies 24.45 liters at 25°C and 1 atmosphere pressure.
>
> One ml occupies $\frac{1}{106} \times 24.45 = 0.231$ liters or 231 ml.
>
> 1 μl occupies 231 μl.
>
> 1 μl of liquid toluene injected into 1 liter of air and completely evaporated and evenly dispersed gives a concentration of 231 ppm of toluene.
>
> 10 μl of liquid toluene in 10 liters of air is 231 ppm. 5 μl of liquid toluene in 10 liters of air is 115 ppm, while 20 μl produces 462 ppm.
>
> Solvent vapor test concentrations can easily be prepared following the above example. Molecular weights and densities are found in chemical handbooks.
>
> Gas – air test mixtures can be prepared by carefully measuring a gas with a gas tight syringe and injecting it into a specified volume of air. Many gases are available as pure gases in laboratory size cylinders.
>
> Some gas and vapors test calibration mixtures can be prepared using permeation tubes.
>
> Perform all tests and prepare all calibration test mixtures in a hood because of the hazardous nature of many gases and vapors.
>
> Break off tube ends carefully. Eye protection is recommended. Hands can be cut with the sharp broken tube ends.
>
> Many indicator tubes contain hazardous reagents. Dispose of them properly.

REFERENCES

Linch, A. L., Evaluation of Ambient Air Quality by Personnel Monitoring, CRC Press, Inc., Cleveland, 1974.

Nelson, Gary, O., Controlled Test Atmospheres – Principles and Techniques, Ann Arbor Science Publishers, Inc., Ann Arbor, 1971.

GAS AND VAPOR SAMPLING DEMONSTRATION

CARBON MONOXIDE DETECTION

I. INSTRUMENTS AND EQUIPMENT

A. Fully Charged Operational Ecolyzer

B. Ecolyzer Components

  1. Electrochemical sensor from which the sulfuric acid electrolyte has been removed
  2. Disassembled electrochemical sensor
  3. Ecospan gas; nominal concentrations 50 ppm and 250 ppm each equipped with indicator valves
  4. Flexible bags with polyethylene connectors
  5. Screw driver for zero adjustment and calibration adjustment
  6. Rotameter in the range of 500 to 1000 cc/min of air

C. Detector Tube Systems for Carbon Monoxide

  1. MSA
  2. Dräger
  3. Bendix Gastec

II. SEQUENCE OF EVENTS

A. The operating principle of electro-oxidation is explained in simple terms using the disassembled sensor.

B. Flow rate at exit side of operational Ecolyzer is adjusted to 700 cc/min. Flow rate at inlet on face of meter is checked. Any leaks are eliminated.

C. Battery tests are made.

D. Meter is adjusted to zero.

E. The meter is adjusted to agree with Ecospan gas by using the gas whose nominal value is 50 ppm. The adjustment is made to agree with the value indicated on the particular cylinder used to fill the plastic bag.

F. A bag containing the higher concentration (250 ppm nominal) is connected to the Ecolyzer. The meter reading is compared with the value indicated on the particular cylinder used to fill the bag.

G. The higher concentration of Ecospan is used to check the performance of the various detector tube systems.

H. Values obtained by the Ecolyzer and the detector tubes are compared with one another and with the value indicated on the Ecospan gas cylinder.

COMPARISON OF OBSERVED VALUES FOR NOMINAL CONCENTRATION OF 250 PPM CO

Suppliers	Observed Values, ppm			
Analysis, ppm	Ecolyzer	Dräger	MSA	Bendix
______	______	______	_____	_____

Prepared by William H. Perry, Chemist, Division of Training, NIOSH, 11/75.

III. REFERENCES

1. Harrison, N.: A Review of Techniques for the Measurement of Carbon Monoxide in the Atmosphere. Ann. Occup. Hyg. 18:21-28 (Aug. 1975).

2. Bergman, I: Electrochemical Carbon Monoxide Sensors Based on the Metallized Membrane Electrode. Ann. Occup. Hyg., 18:53-62 (Aug. 1975).

3. Blurton, K. F., Bay, H. W.: Controlled-Potential Electrochemical Analysis of Carbon Monoxide. American Laboratory, pp. 50-55, (July 1974).

4. Suppliers manuals and promotional materials.

Laboratory I — Gas and Vapor Sampling

3. COMBUSTIBLE GAS METER — ETHANOL

In calibrating or checking combustible gas indicators known specific concentrations of a gas or vapor in air are needed.

There are several methods for preparing known concentrations of gas-air mixtures or vapor-air mixtures. In this exercise combustible gas indicators will be checked against specific concentrations of ethyl alcohol vapor in air. The dynamic gas-stream will be used to prepare the vapor-air mixtures.

The molecules in a liquid, because they are relatively close together are appreciably affected by intermolecular attractive forces. These forces limit their motion; they are not totally free to move about like molecules in the gaseous state. However, molecules with sufficient average kinetic energy to overcome these attractive forces escape from the liquid. The molecules that leave the liquid and pass into the gaseous state are called the vapor of the liquid. Vapor molecules exert pressure and the liquid is said to possess vapor pressure.

The molecules in a liquid have to possess a certain average kinetic energy in order to escape from the liquid. Since the average kinetic energy of a molecule is a function of temperature, it follows that the vapor pressure of a liquid is also a function of temperature. Each liquid has its own particular vapor pressure for a specific temperature.

The partial pressure of the vapor molecules cannot be greater than the vapor pressure of the liquid. When the partial pressure of the vapor in the air is equal to the vapor pressure of the liquid, the air is said to be saturated with vapor molecules. When this occurs, the number of vapor molecules is constant and remains constant as long as the temperature remains constant. This state is readily attained in a closed system.

In preparing known concentrations of a vapor in air, one has to know only the temperature of the liquid, the vapor pressure of the liquid at this temperature and the atmospheric pressure. If the air is saturated with vapor, the concentration of the vapor can be calculated using Dalton's law of partial pressures. If a system is available for metering the air and the vapor, the desired concentrations can be prepared.

In preparing a combustible vapor-in-air mixture by the dynamic gas-stream mixing method, a stream of air and a stream of air saturated with solvent vapor is metered and combined in a mixing chamber. The air flowing out of the mixing chamber is then examined with a combustible gas indicator.

The equipment required for this exercise is:

1 Calibrated rotameters - 2 (approximately 1500 cc/min and 7000 cc/min)

2 Small brass valves - 4

3 Y Tube - 1

4 Gas mixing chamber - 1 (about 100 cc capacity)

5 Gas bubbler bottles - 2 (250 ml capacity)

6 Erlenmeyer flask - 1 (1000 ml, ground glass connection, inlet and outlet tube; inlet tube reaching bottom of flask)

7 Thermometer - 1 (short enough to fit into Erlenmeyer flask)

8 Air pump or compressed air

9 Filter - 1 (for air-line to remove rust particles, oil and other particulate matter)

10 Organic solvents (combustible)

Prepared by Steven N. Dereniuk, Analytical Chemist, Division of Training, NIOSH, 2/73.

11 Gases (combustible)

12 Hood

13 Teflon Tubing

A sketch of the laboratory apparatus is shown in Figure 1.

In this exercise, known concentrations of ethyl alcohol vapor in air will be prepared. The lower explosive limit of ethyl alcohol vapor is 3.3 percent by volume. Concentrations of alcohol vapir in air containing less than 3.3 percent will be prepared.

At 25°C, the vapor pressure of ethyl alcohol is 57 mm mercury. Let's assume that today, in Cincinnati, the atmospheric pressure is 748 mm mercury. Under these conditions, the concentration of ethyl alcohol vapor in saturated air is:

$$\frac{57}{748} \times 100 = 7.6\%.$$

Knowing this any concentration below 7.6 percent can be prepared. However, since combustible gas indicators respond in the lower explosive limit range and since the lower explosive limit for ethyl alcohol is 3.3 percent, nothing would be gained by preparing concentrations greater than 3.3 percent. The volume of the air mixture supplied to the combustible gas indicator must be in excess of the volume drawn by the indicator pump. The J-W Model SS-P Indicator draws in air at approximately 1500 cc per minute, while the M-S-A Model 40 draws in air at approximately 50 cc with each operation of the hand pump.

The alcohol vapor-air mixture can be prepared in concentrations below the lower explosive limit as outlined in Table 1.

Table 1. PREPARATION OF ETHYL ALCOHOL VAPOR IN AIR BELOW THE L.E.L.

Air cc/Min	Air + Vapor[1] cc/Min	Dilution	Vapor[2] Concentration	Percent of L.E.L.	Indicator Readings
1000	1000	1-2	3.8	115	
2000	1000	1-3	2.5	76	
3000	1000	1-4	1.9	58	
4000	1000	1-5	1.5	45	
3600	600	1-7	1.1	33	
4500	500	1-10	0.7	21	
5500	500	1-12	0.6	13	

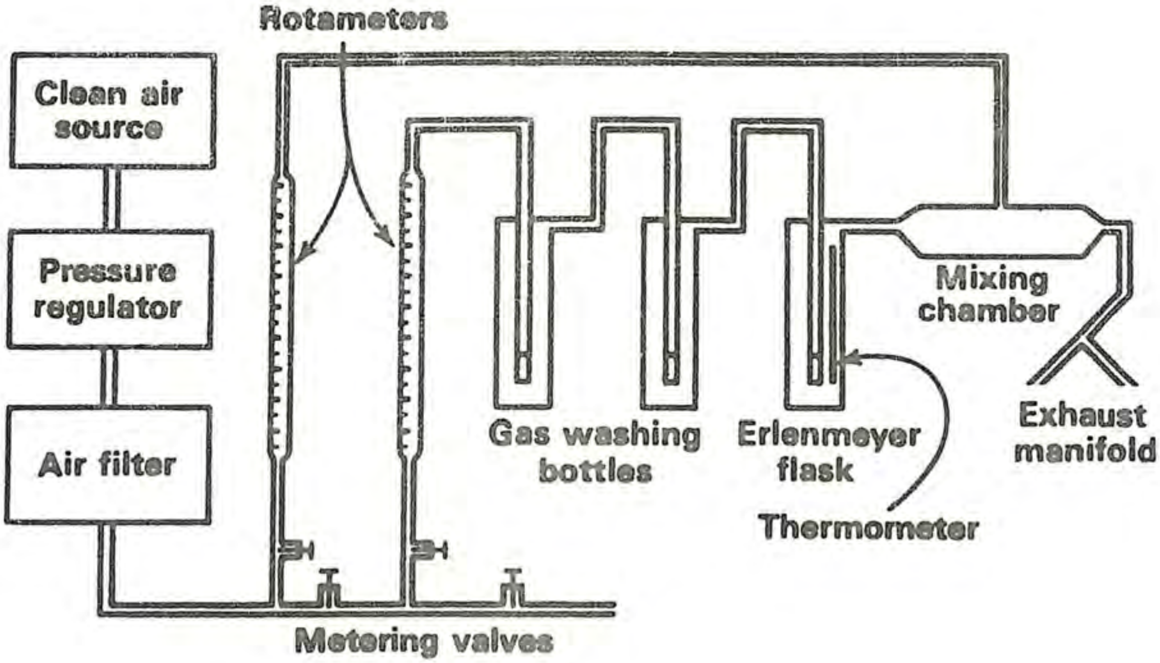
[1] Air containing 7.6 percent by volume of ethyl alcohol vapor.

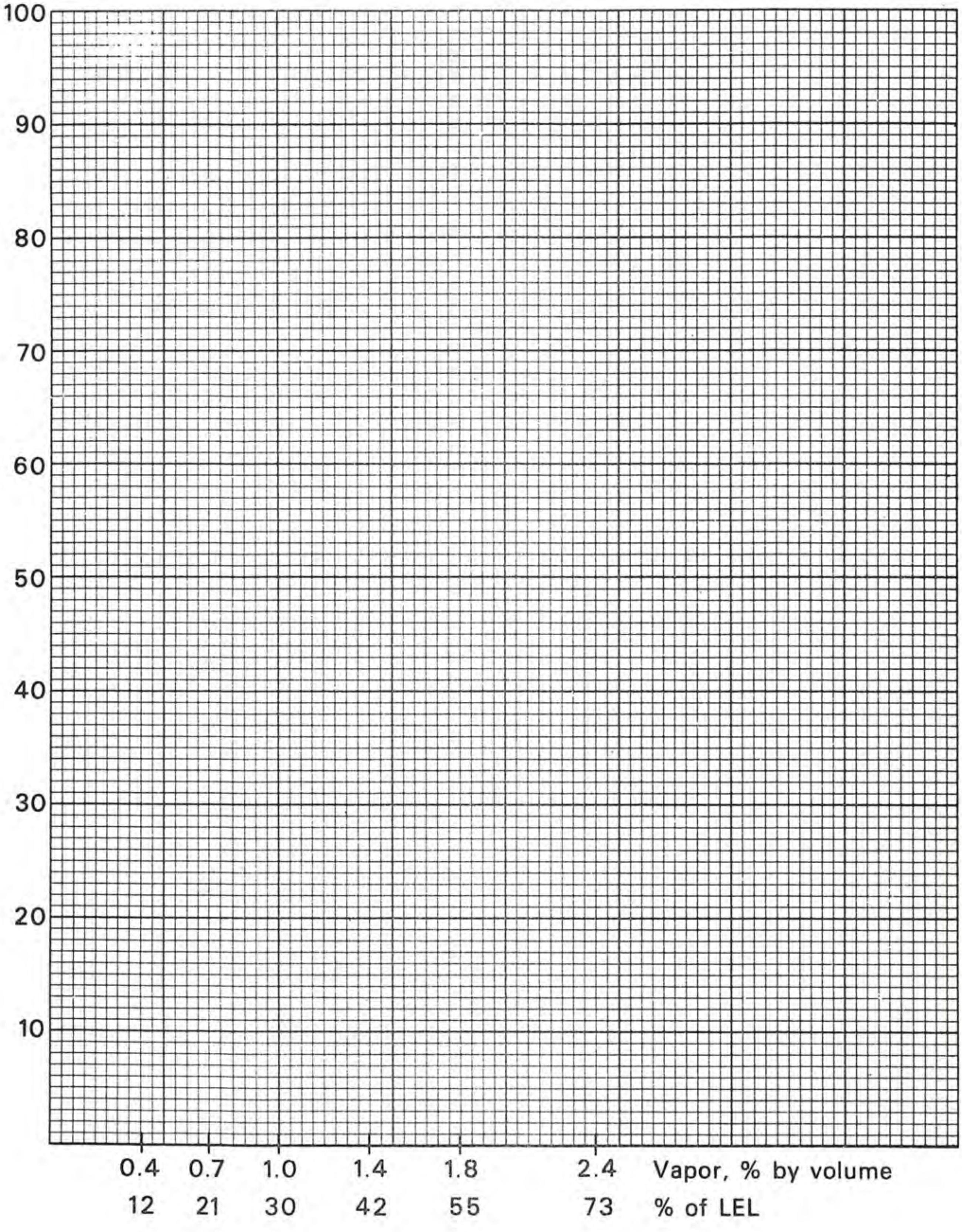
[2] Final air mixture containing ethyl alcohol vapor in percent by volume.

The above approach can be used to prepare many vapor-air mixtures. If a gas is used, a double dilution of the gas may be necessary. Maintaining the system in a controlled temperature chamber permits one to operate the system at other than room temperature.

REFERENCE

NELSON, G. O., Controlled Test Atmospheres, Principles and Techniques. Ann Arbon Science Publishers, Inc., Ann Arbor, Michigan (1971).




100
90
80
70
60
50
40
30
20
10
0.4
0.7
1.0
1.4
1.8
2.4
Vapor, % by volume
12
21
30
42
55
73
% of LEL

Laboratory IA -- Gas and Vapor Sampling Demonstration

4. METHANOMETER

Laboratory IA -- Gas and Vapor Sampling Demonstration

5. MERCURY VAPOR DETECTOR

Laboratory IA — Gas and Vapor Sampling

6. COMBUSTIBLE GAS METER — METHANE

2

AIR FLOW CALIBRATION

I. INTRODUCTION

"Air samples are collected in order to determine the concentrations of one or more airborne contaminants." The Industrial Environment – Its Evaluation and Control.

A. Contaminant Treatment

1. Do not extract contaminant
2. Recover or alter contaminant
   a. Collection efficiency
   b. Sample mass
   c. Sample volume
   d. Measurement error

B. Calibration Checks

1. When to calibrate
2. Why recalibrate

3. Frequency

C. Parameters to Determine and Control

1. Sampled volume
2. Sample mass
3. Flowrate

D. Flowrate Constant?

1. Flowrate
2. Sampling interval
3. Integrated volume

Prepared by John M. Yacher, Chemical Engineer, NIOSH, Cincinnati, Ohio.

E. Flowmeters – Type of Measurement Made

1. Integrated – volume meters
2. Flowrate meters
3. Velocity meters

F. To Analyze a Sampling Problem, Consider –

1. Flowrate and sample volume
2. Collection efficiency
3. Sample stability
4. Efficiency of recovery
5. Analytical background
6. Effect of co-contaminants

II. INSTRUMENT CALIBRATION AND OPERATION

A. Definition

B. Types of Calibration

1. Fixed volume samples
2. Integrated samples

C. Precalibration Considerations

1. Understand operation/use
2. Necessary accuracy
3. Calibration facilities available
4. Familiarity with gas laws and calculations

D. Primary Standards

1. Definition
2. Limitations
    a. Atmospheric pressure
    b. Volume

        - c. Flow rates
        - d. Usually requires some skill in operation
    - 3. Spirometer
    - 4. Marriotti bottle
    - 5. Bubble meter

E. Intermediate Standards

    1. Definition
    2. Wet test meter
    3. Dry gas meter
    4. Pitot tube
        - a. Standard
        - b. Modified
        - c. Manometers
    5. Thermoanemometer

F. Secondary Standards

    1. Definition
    2. Limitations (especially orifice meters)
        - a. Initial calibration often difficult
        - b. Must be used under same conditions - P, T, gas density
        - c. Calibration change due to dirt or damage
        - d. High pressure drop

3. Rotameter

4. Orifice meter

5. Venturi meter

6. Critical flow nozzle

7. Plug flow meter

III. PRINCIPLES OF OPERATION

A. Conservation of Mass

1. Volume meters
2. Primary and intermediate

B. Conservation of Energy

1. Flowrate meters
2. Calculate flowrate from
   a. Pressure drop
   b. Flow cross section
   c. Density
   d. Coefficient of discharge
3. Variable – head meter
4. Variable – area meter
5. Intermediate and secondary

IV. REFERENCES

1. The Industrial Environment – its Evaluation and Control (Syllabus), PHS No. 614, Sections B-3 and C-7, 1965 (Out of print).
2. The Industrial Environment – its Evaluation and Control, DHEW-PHS-CDC-NIOSH, Chapters 11 and 40, 1973 (Superintendent of Documents, U. S. Government Princing Office).

Note: Please read the Summary and Conclusions, p. 121–122, Chapter 11.

AIR FLOW CALIBRATION

Introduction

In sampling an atmosphere for contaminants the objective is to determine as accurately as possible the concentration of various substances. Usually this requires that the air containing the contaminants be captured and analyzed simultaneously, or that the contaminants be removed from the air and retained for subsequent analysis. The results of such determinations are usually expressed in terms of weight, number of particles, activity, or parts per unit volume of the atmosphere sampled. Therefore, the sample volume is equally as important as the quantitative determination. Since it is possible to determine gas volumes or flow rates to a high degree of accuracy, it is prudent to reduce to a minimum this potential source of error for any sampling system.

Air volume or flow calibration may be defined as the determination, within given limits, of the true value of the scale reading, volume or indications of an instrument. The calibration of air sampling instruments or systems can be divided into two basic groups:

Grab, instantaneous, fixed or captured volume samples. These usually are calibrated by direct volumetric means or by a technique such as the bubble meter. Primary standards usually are available for this type of instrument.

Continuous or integrated samples. These usually are calibrated against a secondary standard such as a gas meter, orifice meter, or in special cases the air-flow velocity through a fixed area or gas dilution technique may be employed.

The frequency of calibration is dependent on the use, care, and handling of the instrument and probably most important - to what purpose the data are to be applied. Ordinarily, air sampling devices are calibrated in the laboratory before they are used in the field. The instruments should be calibrated if they have been subjected to misuse, cannot be properly adjusted or zeroed, or if they have just been repaired or received from a manufacturer. It is also wise to check the calibration of flow measuring devices after they have been used in the field to collect a large number of samples.

Before initiating an air-flow calibration of a given instrument it is necessary to:

(1) Understand the operation of the instrument and how it is to be used,

(2) determine the degree of accuracy necessary,

(3) know what calibration facilities are available, and

(4) have a familiarity with the gas laws and calculations.

Calibration Equipment

Primary Standards

These are usually volume measuring devices. The volume under consideration is measured by some direct physical method independent of the air or gas involved, such as physical dimensions of the containing vessel.

Spirometer. The spirometer(1) (see Figure 1) is simply a bell or cylinder with one end closed floating in water or oil. The weight of the bell is counter-balanced by weights so there is negligible resistance to movement in and out of the fluid as air is removed or added to the cylinder cavity. The volume ($V = AxH$) of the cavity is determined by the cross sectional area (A) of the cylinder and

---

Prepared by: Julius H. Fanney, Jr.

the height (H) of the cylinder above the fluid. Spirometers are commercially available with capacities ranging from a few hundred centimeters to 10 or more cubic feet.

Other standards. An even simpler, and by far cheaper, apparatus which can be fabricated in most laboratories consists of a carboy of large volume fitted with a drain (Marriotti's bottle) or siphon carboy(2,3) from which water is displaced and measured volumetrically. For smaller volumes a burrette can be used to make a bubble meter(4) for the calibration purposes. (See Figure 2).

Limitations. All of the primary standards available are subject to the following limitations in their application:

(1) Limited to atmospheric pressure applications

(2) limited volume

(3) low flow rates

(4) usually requires some skill in operation.

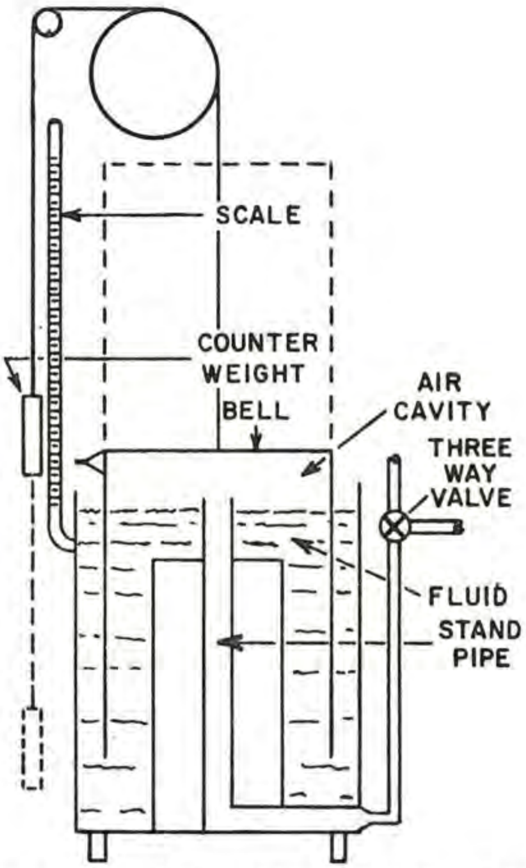


Figure 1. - Schematic drawing of a spirometer.

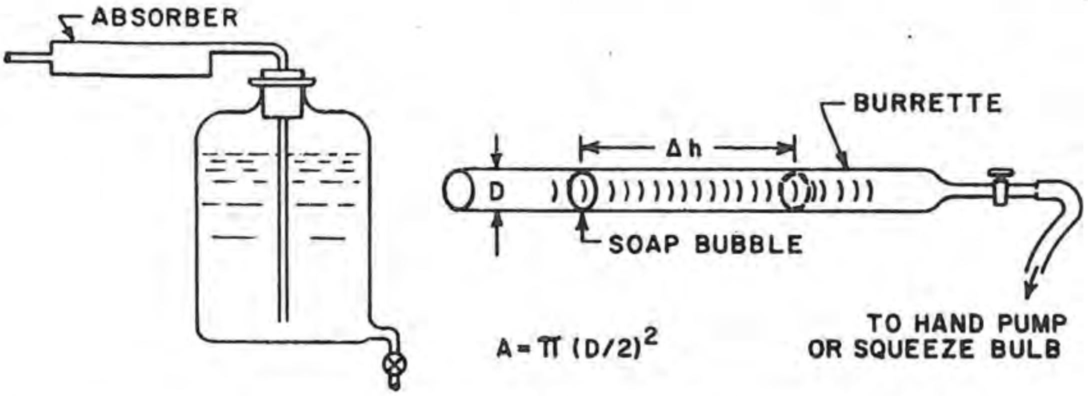


Figure 2. - Marriotti bottle (left) and bubble meter (right).

Manometer. In almost all instances of calibration, it is necessary to have some means of measuring pressure or vacuum in one or more branches of the system. The primary standard device for measuring this variable is the manometer. The simplest form is a glass tube bent in the form of the letter "U" and partially filled with a liquid. There are many special forms of manometers designed to meet the specific conditions or measurements required.

In use, if one leg of a manometer is connected to a calibration system in which the pressure is slightly greater than atmosphere, then the column of liquid will go down on the connected side and up on the open leg. The difference in the levels of the liquid in the two legs is a measure of the pressure difference. The amount that the levels will move, or the difference in level depends not only on the pressure differential, but also on the unit volume weight (density) of the liquid being used.

Care must be exercised in the use of these instruments to keep the fluid and tube clean. It is also important to use the correct specific gravity fluid and not to "blow" the meter by applying too much pressure or vacuum.

Intermediate Standards

There are several pieces of equipment which are not primary standards by the strict definition; however, they are accurate and maintain their accuracy if they are handled and used properly. Examples are: wet test meter, dry gas meter, Pitot tube(5), and orifice plates(6).

Wet test meter. A wet test meter consists of a partitioned drum half submerged in a liquid (usually water) with openings at the center and periphery of each radial chamber. Air or gas enters at the center and flows into an individual compartment causing it to rise thereby producing rotation. This rotation is indicated by a dial on the face of the instrument. The volume measured will be dependent on the fluid level in the meter since the liquid is displaced by air. A sight gauge for determining fluid height is provided and the meter may be leveled by screws and a sight bubble which are provided for this purpose.

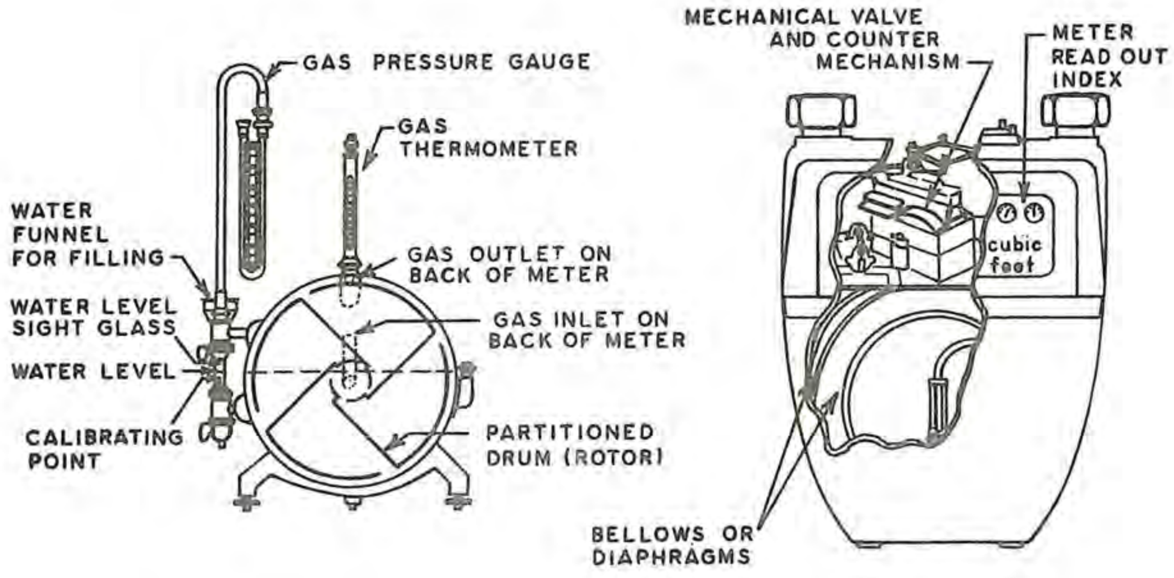


Figure 3. - Wet test meter (left) and dry gas meter (right).

There are several errors inherent in the use of a wet test meter. The drum and moving parts are subject to corrosion and damage from misuse, there is friction in the bearings and the mechanical counter, inertia must be overcome at low flow (1 RPM), and at high flow (3 RPM), the liquid might surge and break the water seal at the inlet or outlet. In spite of these factors, the accuracy of the meter usually is within one percent when used as directed by the manufacturer.

Dry gas meter. The dry gas meter, very similar to the domestic gas meter, consists of two bags interconnected by mechanical valves and a counting device. The air or gas as it fills one bag mechanically empties itself. Any such device has the disadvantage of mechanical drag, pressure drop, and leakage; however, the advantage of being able to use the meter under rather high pressures and volumes often outweighs these errors, which can be determined for a specific set of conditions.

Other meters. The orifice meter(6,7), Pitot tube(5,8) and thermal anemometer(9) also fall into the category of intermediate standards. If carefully designed and constructed these devices can be used as intermediate, secondary standards(10) without calibration against a primary standard. The use of the latter two as calibration instruments is secondary since they were originally designed and intended for air velocity measurements. A discussion of these instruments and their theoretical calculation are covered in Section C-7, Measurement of Air Flow.

The major difficulties with the above instruments are:

1. Setting up a calibration procedure which uses the instrument in the proper velocity range and application.
2. Determining if changes have occurred since they were last checked, or constructed.
3. In the case of the orifice meter there is a high pressure drop across it.

Secondary Standards

A secondary standard is any type of apparatus, either flow or volume meter, which has been accurately calibrated by comparison under a given set of conditions with a primary calibrating device. Secondary standards must be used in other systems under conditions similar to the original calibration for the results to be significant(11). This is particularly true if the conditions of use would affect the physical properties such as pressure, temperature, density, etc., of the gas passing through the unit.

Examples of flow mass or resistance meters of this type are: rotameters(12), venturi, critical(13) and variable orifice plates(7), and packed plug meters(14). These instruments are the most commonly used devices to measure air flow in sampling instruments.

Quantity meters. The general formula for volume rate of air flow in a quantity meter is given by the following relationship:

$$(1) \quad Q = 0.0997\left(\frac{CD^2}{\sqrt{1-\beta^4}}\right)\sqrt{\frac{h_w}{\rho}}$$

where Q = volume rate of air flow in cubic feet per second
C = coefficient of discharge
D = diameter of throat or orifice in inches
β = ratio of throat or orifice diameter to pipe or tube diameter
h_w = pressure differential in inches of water
ρ = density of fluid (air, gas or liquid) lb/cu. ft.

Variable orifice meter. Flow conditions through these metering devices are affected by a number of factors; however, for orifice meters two of these factors

(C and β) have been determined experimentally(15) for a selected set of conditions related to the Reynolds number. (See Section C-6, Principles of Ventilation, for discussion of Reynolds number.) By letting K represent the function $C/\sqrt{1 - \beta^4}$, inserting 0.0749 for ρ (the density of air at 70°F and 760 mm Hg) and converting to more convenient units, the generalized equation (1) becomes:

$$(2) \qquad Q = 21.8\ K\ d_m^2\ \sqrt{\Delta h_w}$$

where Q = volume rate of air flow in cu. ft/min.

K = factor representing coefficient of air flow conditions related to Reynolds number(15, 16).

d_m = orifice diameter in inches

Δh_w = pressure drop across orifice in inches of water

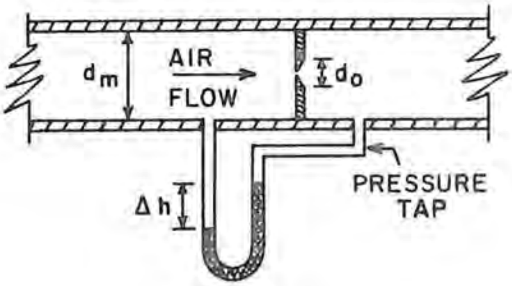


Figure 4. - Drawing of a sharp-edge orifice.

From this equation and the appropriate tables the volume rate of air flow at standard conditions through a thin-plate or sharp-edge orifice with flange taps can be calculated(17). These calculations are usually sufficiently accurate (± 10%) for secondary calibrations; however, if more precision is desired the unit should be compared against a primary standard.

Critical orifice meter. A specialized, but common application of the orifice meter, for both calibration and sampling, is in the form of a limiting or critical orifice(13). (A more detailed discussion of this subject appears in Section C-6.)

Venturi meter. The venturi meter, another form of resistance meter, has the advantage, if properly constructed, of low pressure drop over a wide range of flow. This makes its use for calibration purposes extremely advantageous. They are usually calibrated by comparison with a secondary standard or their flow can be calculated within ± 10%. (See Section C-6 for a more detailed discussion.)

Limitations. The difficulties in using orifice and venturi meters as secondary standards as mentioned previously are:

1. Initial calibration of the units are often difficult in the range desired;
2. the device must be used under the same conditions, i.e., pressure, temperature, gas, etc., as originally calibrated;
3. the possibility of the calibration changing because of damage or dirt on the constriction; and
4. high pressure drop across meter.

Rotameters. The rotameter or variable area meter probably is the most used and misused tool for the measurement of air flow. It consists of a precision-bored, tapered, transparent tube with a solid float inside. The float is carried upward by the flow of air until it reaches a level where the force of the air is offset by the weight of the float. The height of the float above the bottom of the tube is a measure of the air flow rate. It operates on the same principle as the orifice meter, except the area of the orifice varies while the differential pressure remains constant. The motion of the float up or down the tapered tube provides the variable area of the orifice.

Rotameters should be calibrated under the same conditions of pressure, temperature, and density (gas) as they are to be used(11). This is particularly true if the conditions of use would affect the density of the gas passing through the unit. It is always a good policy to have one end of a rotameter open to the atmosphere in a calibration setup unless the instrument has been specially calibrated for operation other than at standard conditions. Extreme care should be exercised in the use of a calibrated standard rotameter to see that particulate matter or vapors of any type do not enter the meter and that the float is not handled or damaged.

The question as to where to read the float always exists. As a general rule, manufacturers calibrate their units using the highest-widest portion of the float. Figure 5 indicates the correct marker point for representative floats.

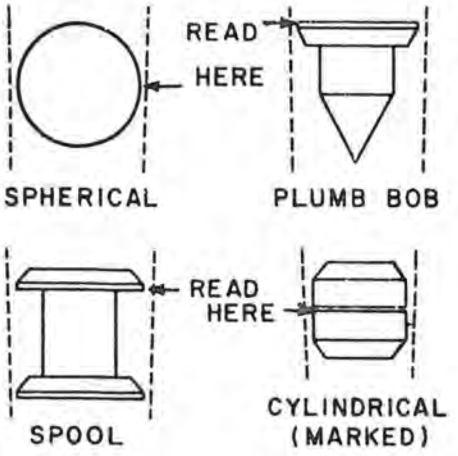


Figure 5. - Typical Rotameter Floats.

Packed plug flow meter. The packed plug flow meter(14,18) is another form of resistance meter. It is a device for both regulating and measuring very low flows, down to 0.01 ml/min. The device consists of a "T" connection, pipet or glass tubing, cylinder and packing material. The outlet arm of the "T" is packed with material, such as asbestos, and the leg is attached to a tube or pipet projecting down into the cylinder filled with water or oil. A calibration curve of the depth of the tube outlet below the water level versus the rate of flow should produce a straight line curve.

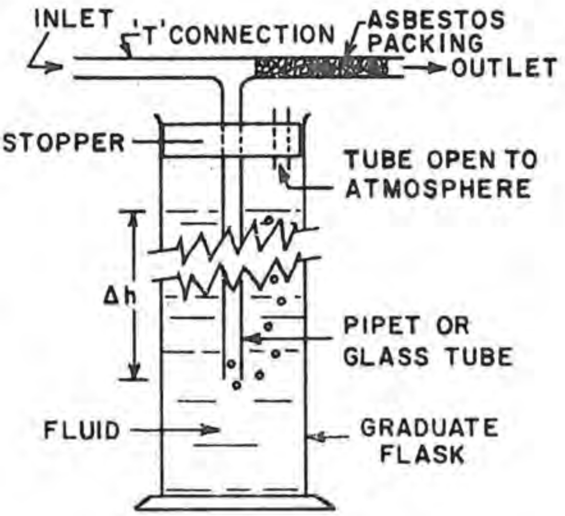


Figure 6. - Drawing of a Packed Plug Flow Meter.

Pressure vacuum gages. Unlike the manometer these devices usually are used on sampling instruments; however, occasionally they may be useful in calibration procedures. They normally consist of a flexible diaphragm connected mechanically or otherwise to a pointer assembly. Naturally, any such device is subject to mechanical damage, deterioration, pressure changes, dirt, moisture, and orientation.

Calibration Procedures

No attempt will be made to describe all of the possible methods or the combinations thereof which have been used for calibration of air sampling instruments. A few classic examples and general procedures will be discussed. For specific methods the reader should consult the numerous references and other sources of literature on this subject.

Precalibration Check

The calibration of a secondary standard

such as a wet test meter, orifice, rotameter, etc., with a gas prover or spirometer is a basic procedure. Before initiating the calibration a few checks on the operation of the spirometer are necessary.

1. Determine that the instrument is level, the fluid is adequate, the mechanical linkage is aligned and that it is free running.
2. With the valves open, move the bell (by means of the counter-weight) to a full down position and then release it. The bell should rise to the center of its traverse. Repeat the procedure by raising the bell to its maximum capacity. Again the bell should drift slowly to the center. Should the bell not come to rest at the mid point of its traverse the counterweight should be adjusted. On models equipped with eccentric pulleys the bell should remain stationary rather than drift.
3. Check the valve closure by applying air pressure and vacuum to the closed valves and noting any changes in the bell position. The bells of spirometers are usually constructed of very light weight material and are easily damaged. Any dent or deformity in the bell changes its capacity and, therefore, its calibration factor. Do not apply high pressure or vacuum to the instrument.

Having established that the primary standard is in operating condition the calibration setup could be as shown in Figure 7.

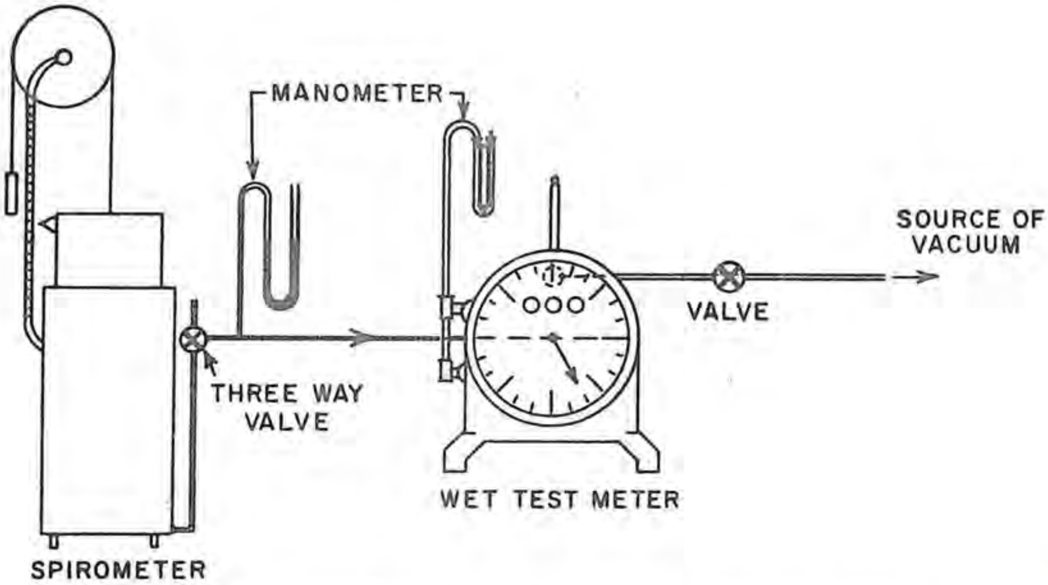


Figure 7. - Calibration Setup for Calibrating a Wet Test Meter.

Calibration of Secondary Standard

The primary standard (spirometer or siphon bottle) is connected to the device to be calibrated by as short a connection as possible. The diameter of the connection should be large enough so that resistance is insignificant. A good rule of thumb is to use the largest diameter connection appearing on the primary standard as the connecting tube diameter. A quick action by-pass valve should be installed at the connection to the standard if one is not present.

This will allow the device being calibrated to be adjusted without being limited by the standard's capacity, and also to facilitate calibration. Temperature and pressure sensing devices should also be available for the standard's air cavity and pressure measurements at the proper location(s) on devices to be calibrated. After all connections have been made, it is a good policy to recheck the level of all instruments and determine that all connections are clear and have minimum resistance. If compressed air is used in a calibration procedure it should be cleaned and dried.

Actual calibration of the wet test meter shown in Figure 7 is accomplished by opening the by-pass valve and adjusting the vacuum source to obtain the desired flow rate. The optimum range of operation is between one and three revolutions per minute. Before actual calibration is initiated the wet test meter should be operated for several hours in this setup to stabilize the meter fluid as to temperature, absorbed gas, and to work in the bearings and mechanical linkage. After all elements of the system have been adjusted, zeroed and stabilized several trial runs should be made. During these runs, should any difference in pressure be indicated, the cause should be determined and corrected. The actual procedure would be to instantaneously divert the air to the spirometer for a predetermined volume indicated by the wet test meter (minimum of one revolution), or to near capacity of the spirometer, then return to the by-pass arrangement. Readings, both quantity and pressure of the wet test meter, must be taken and recorded while it is in motion, unless a more elaborate system is set up. In the case of a rate meter, the interval of time that the air is leaving the spirometer must be accurately timed. The bell should then be allowed to come to equilibrium before making displacement readings. A sufficient number of different flow rates are taken to establish the shape or slope of the calibration curve with the procedure being repeated three or more times for each point. For an even more accurate calibration the setup should be reversed so that air is supplied to the spirometer. In this way any unbalance due to pressure differences would be cancelled.

A permanent record should be made of a sketch of the setup, data, conditions, equipment, results, and personnel associated with the calibration. All readings (volume, temperatures, pressures, displacements, etc.) should be legibly recorded, including trial runs or known faulty data, with appropriate comments. The identifications of equipment, connections and conditions should be so complete that the exact setup with the same equipment and connections could be reproduced by another person solely by use of the records.

After all of the data have been recorded, the calculations such as correction for variations in temperature, pressure and water vapor are made using the gas laws equation:

$$Vs = V_1 \text{ X } \frac{P_1}{760} \text{ X } \frac{273}{T_1}$$

where Vs = volume at standard conditions (760 mm & 0^oC)
V_1 = volume measured at conditions P_1 and T_1
T_1 = temperature of V_1 in ^oA
P_1 = pressure of V_1 in mm Hg

In most cases the water vapor portion of the measurement is disregarded and the temperature of the gas is adjusted to 22^o - 23^oC rather than 0^oC. The manipulation of the instruments, data reading and recording, calculations and resulting factors or curves should be done with extreme care. Should a calibration disagree with previous calibrations or the suppliers' calibration, the entire procedure should be repeated, and examined carefully to assure its validity. Upon completion of any calibration the instrument should be tagged or marked in a semi-permanent manner to indicate the calibration factor, where appropriate, date and who performed the calibration.

Reciprocal Calibration by Balanced Flow System

In many commercial instruments it is impractical to remove the flow indicating device for calibration. This may be because of physical limitations, characteristics of the pump, unknown resistance in the system(19) or other limiting factors. In such situations it may be necessary to set up a reciprocal calibration procedure, that is, where a controlled flow of air or gas is compared first with the instrument flow, then with a calibration source. Often a further complication is introduced by the static pressure characteristics of the air mover in the instrument(20). In such instances supplemental pressure or vacuum must be applied to the system to offset the resistance of the calibrating device. An example of such a system is illustrated in Figure 8.

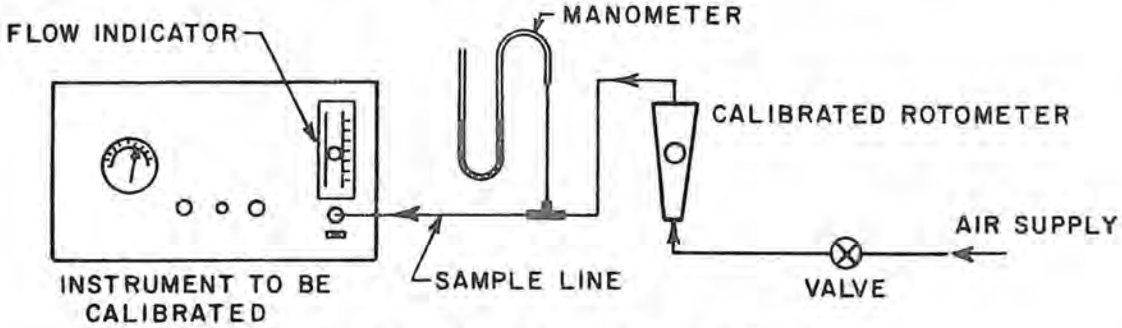


Figure 8. - Setup for Balanced Flow Calibration.

The instrument is connected to a calibrated rotameter and source of compressed air. Between the rotameter and the instrument an open end manometer is installed. The connections, as in any other calibration system, should be as short and resistance free as possible.

In the calibration procedure the flow through the instrument and rotameter is adjusted by means of a valve or restriction at the pump until the manometer indicates "0" pressure difference to the atmosphere. When this condition is achieved the instrument and rotameter are both operating at atmospheric pressure. The indicated and calibrated rates of flow are then recorded and the procedure repeated for other rates of flow.

Dilution Calibration

Normally gas dilution techniques are employed for instrument response calibrations; however, several procedures(20, 21 & 22) have been developed whereby sampling rates of flow could be determined. The principle is essentially the same except that different unknowns are involved. In air flow calibration a known concentration of the gas (i.e., carbon dioxide) is contained in a vessel. Uncontaminated air is introduced and mixed thoroughly in the chamber to replace that removed by the instrument to be calibrated. The resulting depletion of the agent in the vessel follows the theoretical dilution formula:

$$C_t = C_o e^{bt}$$

where C_t = concentration of agent in vessel at time, t
C_o = initial concentration at t = 0
e = base of natural logarithms
b = air changes in the vessel per unit time
t = time

The concentration of the gas in the vessel is determined periodically by an independent method. A straight line plot should result from plotting concentration of agent against elapsed time on semi-log paper. The slope of the line indicates the air changes per minute (b) which can be converted to the rate (Q) of air withdrawn by the instrument from the following relationship: Q = bV; where V = volume of the vessel.

This technique offers the advantage that virtually no resistance or obstruction is offered to the air flow through the instrument; however, it is limited by the accuracy of determining the concentration of the agents in the air mixture.

Samplers Without Flow Indicators

A few sampling units are not equipped with flow indicators, or at the most they may have vacuum or pressure gauges. In most cases these devices are considered to have fixed rates of flow. An example of this is the "Denver" or "Roberts" hand cranked pump which is calibrated by turning the crank at a fixed rate (counting revolutions) and collecting and measuring the pumped air volumetrically. The calibration is then denoted as volume per revolution. This volume will vary somewhat (± 15%), depending on the condition of the pump.

Where vacuum and pressure gauges are involved these units should be checked against an appropriate manometer connected into the system at the same location.

Summary

Because the accuracy of all sampling instruments is dependent on the precision of measurement of the air volume involved, extreme care should be exercised in performing all calibration procedures. The following comments summarize the philosophy of air flow calibration:

1. Protect and handle standard devices with "loving care."
2. All standards should be checked periodically to determine their operating condition.
3. Calibrations should be performed whenever a device has been changed, repaired, received from a manufacturer, subjected to use, mishandled or damaged, and at any time when there is a question as to its accuracy.
4. Understand the operation of an instrument before attempting to calibrate it and use a procedure or setup which will not change the characteristics of the instrument or standard within the operating range required.
5. When in doubt about procedures or data, assure their validity before proceeding to the next operation.
6. All connections should be as short and free of constrictions and resistance as possible.
7. Extreme care should be exercised in reading scales, timing, adjusting, and leveling, and in all other operations involved.
8. Allow sufficient time for equilibrium to be established, inertia to be overcome, and conditions to stabilize.
9. Enough points or different rates of flow should be obtained on a calibration curve to give confidence in the plot obtained. Each point should be made up of more than one reading whenever practical.
10. A complete permanent record of all procedures, data and results should be maintained. This should include trial runs, known faulty data with appropriate comments, instrument identification, connection sizes, barometric pressure, temperature, etc.
11. When a calibration differs from

previous records, the cause of change should be determined before accepting the new data or repeating the procedure.

12. Calibration curves and factors should be properly identified as to conditions of calibration, device calibrated and what it was calibrated against, units involved, range and precision of calibration, date and who performed the actual procedure. Often it is convenient to indicate where the original data is filed and to attach a tag to the instrument indicating the above information.

References

1. Hama, George: Calibration of Air Flow Measuring Instruments. Encyclopedia of Instrumentation for Industrial Hygiene. University of Michigan, Institute of Industrial Health, Ann Arbor, Michigan, pp 703-708, 1956.
2. Beckett, E. G.: A Laboratory Gas Meter. J. Soc. Chem. Ind., 36:52 (1917).
3. Kuznetz, Howard L.: Air Flow Calibration of Direct Reading Colorimetric Gas Detecting Devices. Am. Industr. Hyg. Assoc. J., 21: 340-341 (August 1960).
4. Gage, J. C.: The Calibration of Hand Pumps for Air Sampling. Imperial Chem. Ind., Ltd., Analyst, 84: 519-520 (August 1959).
5. Bloomfield, J. J. and J. M. Dalla Valle. The Determination and Control of Industrial Dust. Public Health Bulletin, No. 217, pp 140-144, 1958.
6. American Society of Mechanical Engineers, Power Test Codes Commission, Flow Measurement by Means of Thin Plate Orifices, Flow Nozzles, and Venturi Tubes. A.S.M.E. Power Test Codes. Supplement on Instruments and Apparatus, Part 5, Measurement of Quantity of Materials, Chap. 4, 2nd Ed., p 91, New York, February 1959.
7. Bruum, J. R.: Capillary Flow with Variable Orifice. Ind. Eng. Chem., Anal. Ed., 11: 655 (1939).
8. National Association of Fan Manufacturers, Standard Code for Testing Centrifugal and Axial Fans. Bulletin 110, Detroit, Michigan, 1950.
9. Brandt, Allen D.: Industrial Health Engineering. John Wiley & Sons, New York, pp 192-193, 1947.
10. Madison, Richard D., Ed., Fan Engineering. Buffalo Forge Company, 5th Ed., New York, pp 125-131, 1948.
11. _____: Cavitation May Cause Erroneous Calibration of Air Samplers. HC Inf. Exchange Bulletin, 1: 1, (September 1961).
12. Polentz, L. M.: Theory and Operation of Rotameters. Instruments and Control Systems. 34: 1048 (June 1961).
13. Hatch, T., Warren, H., and Drinker, P.: Modified Form of the Greenburg-Smith Impinger for Field Use, With a Study of Its Operating Characteristics. J. Ind. Hyg., 14: 301-311 (1932).
14. Avera, C. B., Jr.: Simple Flow Regulator for Extremely Low Gas Flows. Rev. of Sci. Instr., 32: 985-986 (August 1961).
15. American Society of Mechanical Engineers. Fluid Meters, Their Theory and Application. A.S.M.E. Research Publication, 4th Ed., New York, 1937.
16. Perry, John H., Ed., Chemical Engineers Handbook. 3rd Ed., McGraw-Hill, New York, 1950.

17. Brief, R. S.: Chart Speeds Orifice Sizing. Air Cond. Heat. & Vent., 57: 57-60 (August 1960).

18. Saltzman, Bernard E.: Preparation and Analysis of Calibrated Low Concentrations of Sixteen Toxic Gases. Anal. Chem., 33: 1100-12 (1961).

19. Tebbens, Bernard D., and Donald M. Keagy: Flow Calibration of High Volume Samplers. Am. Industr. Hyg. Assoc. Quar., 17:327-329 (September 1956).

20. Morley, Morgan J., and Bernard D. Tebbens: The Electrostatic Precipitator Dilution Method of Flow Measurement. Am. Industr. Hyg. Assoc. Quar., 14: 303-306 (December 1953).

21. Setterlind, Alfred N.: Preparation of Known Concentrations of Gases to Vapors in Air. Am. Industr. Hyg. Assoc. Quar., 14: 113-120 (June 1953).

22. Brief, Richard S., and Franklin W. Church: Multi-Operational Chamber for Calibration Purposes. Am. Industr. Hyg. Assoc. J., 21: 239-244 (June 1960).

Additional References

1. Binder, R. C.: Fluid Mechanics. 4th Ed., Prentice Hall Publishing Company, New York, 1962.

2. Jacobs, Morris B.: The Analytical Chemistry of Industrial Poisons Hazards and Solvents. 2nd Ed., Inter-Science Publishers, Inc., New York, 1949.

3. Silverman, Leslie: Industrial Air Sampling and Analysis. Industrial Hygiene Foundation, Chemistry and Toxicology Series, Bulletin No. 1, Pittsburgh, Pennsylvania, 1947.

4. Yaffe, Byers and Hosey, Editors, Encyclopedia of Instrumentation for Industrial Hygiene. University of Michigan, Ann Arbor, Michigan, 1956.

5. Air Sampling Instruments Committee, ACGIH, Air Sampling Instruments for Evaluating Atmospheric Contaminants. 2nd Ed., Amer. Conf. Gov. Ind. Hyg., Cincinnati, Ohio, 1962.

Laboratory II — Air Flow Measurements

7. CRITICAL ORIFICE METER

An orifice may be defined as a restriction to flow in a duct or pipe. The primary purpose of an orifice in flow work is to provide a measurable change in pressure in the system at the orifice location. This pressure change is then related to the flow rate. When a restricting device, or orifice is not utilized in a flow system, a long section of duct or pipe will be required to develop significant pressure drop.

The parameter of a flow system most often related to flow rate when using an orifice is the pressure change across an orifice. Initially, the section of duct with the orifice will be calibrated with a known standard.

Once an orifice is calibrated it may be used to meter or measure the flow rate in any system. Since calibration of any metering device can be a time consuming process, depending on the accuracy desired, it is wise to know the range at which the meter is to be used.

A calibrated meter should always be used with its calibration curve at stated conditions of temperature, pressure, and media. (i.e., air, water, etc.)

When the temperature remains constant while the pressure is changing, the volumetric flow rate at any other pressure is:

$$V_2 = \frac{V_1 P_1}{P_2} \times \frac{T_2 + 460}{T_1 + 460}$$

Where:

V_2 = Volumetric flow rate at a pressure different from meter calibration pressure = volume unit/unit time.

P_1 = Pressure at which meter was calibrated absolute pressure = force units/unit area

P_2 = Pressure at which meter is being used = $\frac{\text{Force Unit}}{\text{Unit Area}}$

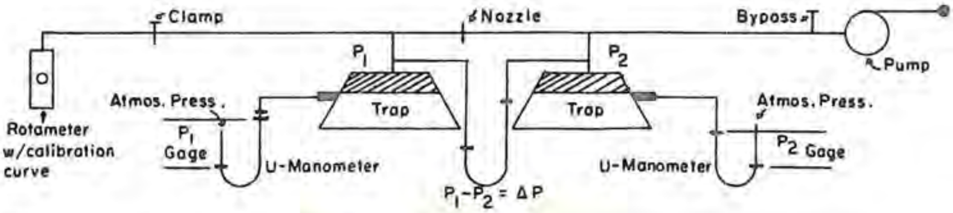
Enter pressure change across orifice in calibration curve to obtain V_1 = volume unit/unit time

T_1 = Temperature at which meter was calibrated, °R °F + 460
K + 273

T_2 = Temperature at which meter is being used, °R °F

In this laboratory exercise a nozzle will be calibrated at a given upstream pressure about its entire range. The maximum flow rate through a nozzle at a given upstream pressure is attained when the absolute pressure ratio is 0.533 for air. At standard temperatures and pressures this numerical value is called the critical pressure ratio. When this ratio is attained, the flow will remain constant even if the downstream pressure is lowered beyond this point. The flow may be changed only by a change in the upstream pressure. This phenomenon does not appear for sharp-edged orifices.

The following procedure will be followed:



Revised by John M. Yacher, Chemical Engineer, Division of Training, NIOSH, 2/73.

1 Set up the calibration train as shown in the sketch.

2 Open by-pass to atmosphere.

3 Turn pump "on".

4 Adjust "clamp" so that U-Manometer at "P_1" reads 1" Hg. by closing "by-pass" as required.

5 On tabulation sheet record the following data:

1	2	3	4	5	6	7
Rot R D'G	Rot Flow	Gage Pressure		Absolute Pressure		$\frac{P_2}{P_1}$ ABS
		P_1	P_2	P_1	P_2	

6 Change the reading on "P_2" U-Manometer by approximately 2" increments.

7 Readjust "clamp" so that "P_1" U-Manometer reads 1" Hg. gage.

8 Read flow rate on rotameter.

9 Record new readings on tabulation sheet.

10 Repeat steps 6-9 until the flow indicated by the rotameter is constant.

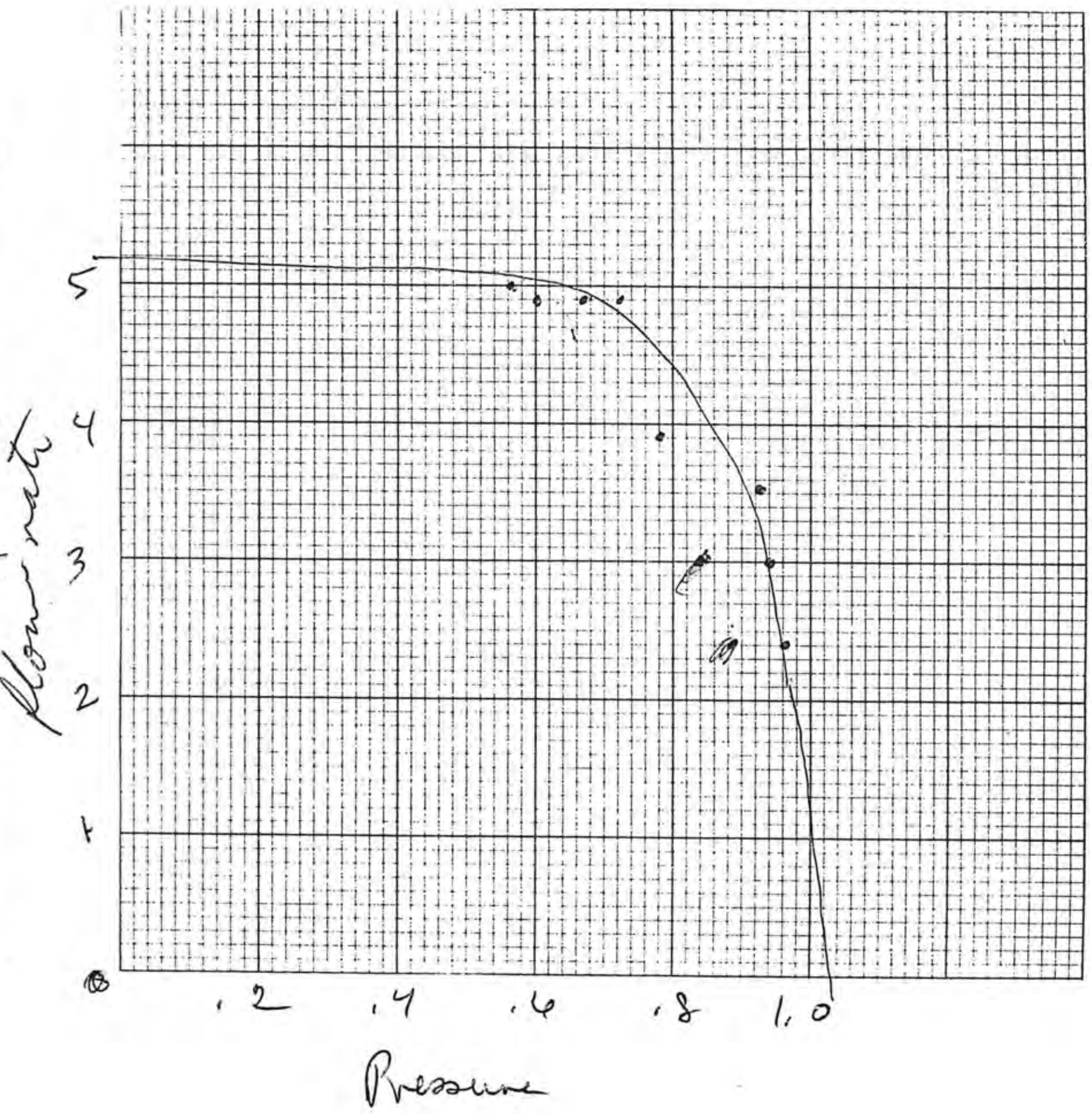
11 Plot on graph paper items 2 and 7. (Item 2 as ordinate and item 7 as the abscissa.)

NOTE: Gage Pressure = change from atmospheric pressure.

Absolute Pressure = atmospheric pressure ± gage pressure.

CRITICAL ORIFICE METER
DATA SHEET

1	2	3	4	5	6	7
Rot Flows ~~RD'G~~	Rot RD'G ~~Flow~~	Gage Pressure		Absolute Pressure		$\frac{P_2}{P_1}$ ABS
		P_1	P_2	P_1	P_2	
2.4	1.8	1	2.4	28.9	27.5	0.95
3.0	2.3	1	3.3	28.9	24.6	0.92
3.5	2.8	1	4.9	28.9	25.	0.86
3.9	3.2	1	6.9	28.9	23	0.795
4.8	3.8	1	8.7	28.9	21.2	0.73
4.8	3.8	1	10.8	28.9	[illegible]	0.66
5.0	3.9	1	12.7	28.9	17.2	0.595



Laboratory II — Air Flow Measurements

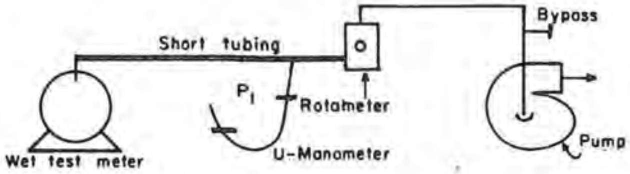
8. ROTAMETER CALIBRATION

Rotameters, midget impingers, and mechanical gages are instruments commonly used for metering and indicating flow rates.

In this laboratory exercise a rotameter will be calibrated with a wet test meter (WTM).

Rotameter:

1. Set up a calibration train for a rotameter calibration with a wet test meter. Since the pressure drop across a wet test meter is less than 0.5" H_2O, we can assume the pressure at the rotameter inlet is atmospheric. Check that the tubing from the wet test meter discharge to the rotameter inlet is short for minimum pressure loss.



2. Open pump by-pass fully.
3. Turn on pump.
4. If wet test meter pointer moves, record reading versus time through two revolutions vs. rotameter reading.
5. If no movement is indicated by the WTM, close "by-pass" at pump slightly until rotameter reads at its lowest mark.
6. Record U-Manometer readings in the event that a pressure correction is required.
7. Record data in tabulation sheet as follows:

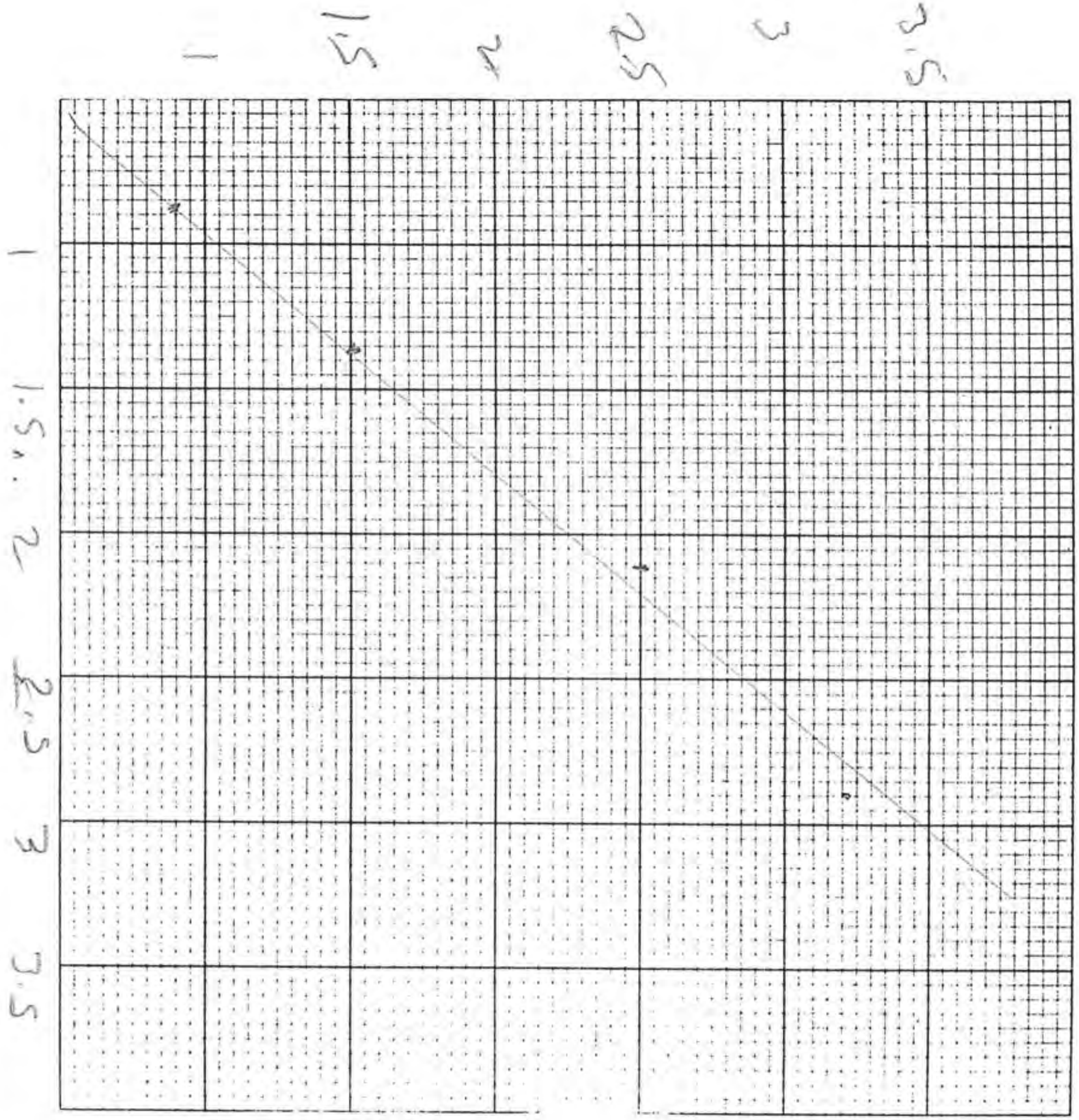
1	2	3	4	5
No. of Rev.'s	Total Time	Flow Rate	Rot Rd'g.	P_1

8. Repeat steps 5-7 for entire range of rotameter.
9. Plot on graph paper the calibration curve for the rotameter with items 3 and 4 from tabulation sheet. Item 3 is abscissa and item 4 is ordinate.

Revised by John M. Yacher, Chemical Engineer, Division of Training, NIOSH, 2/73.

ROTAMETER CALIBRATION
DATA SHEET

1	2	3	4	5
No. of Rev's	Total Time	Flow Rate	Rot Rd'g	P_1



Laboratory II — Air Flow Measurements

9. HIGH VOLUME ORIFICE METER

High volume meters are used for calibration of instruments used in the field for evaluation of ventilation system performance and other high gas volume processes.

A high volume meter can be readily constructed and calibrated by use of duct sections and pitot tube. Preferably eight to ten duct diameters upstream and downstream of the orifice is preferred. Where this condition cannot be met an equal area pitot velocity traverse will compensate for the unstable flow in a shorter duct.

The calibration procedure shall be as follows:

1 Install an orifice plate between the flanges of the two duct sections as shown in the equipment sketch. Use gaskets and tighter bolts and nuts to insure an air tight fit.

2 Turn on the fan. Open fan discharge valve fully open.

3 Perform an equal area velocity traverse with the pitot tube when the duct velocity is above 600 feet per minute. Opening in duct for pitot tube is downstream of the orifice. (See sketch) Use inclined manometer for velocity pressure readings. In a round duct two velocity traverses must be taken at each location at 90 degrees apart in a plane perpendicular to the direction of flow. In this laboratory the velocity in the duct will be below 600 feet per minute at the low range. Therefore, a thermo-anemometer will be used to measure the velocity. Locate the anemometer at the duct center line. The average duct velocity will be 0.90 of this duct centerline reading.

4 Record on data sheet the following information:

1	2	3	4	5	6
Test	℄ Vel. f.p.m.	℄ Vel. X 0.9	Duct Area Ft^2	Flow Rate	$P_1 - P_2$

5 Item 2: Average the total number of velocity pressure readings from the inclined manometer readings. (When using pitot tube only)

6 Item 3: Calculate the average velocity by the equation velocity

(FPM) - 4,005 $\sqrt{\text{VP avg}}$ (When using pitot tube only)

7 Item 4: Duct cross-sectional area is calculated from the equation:

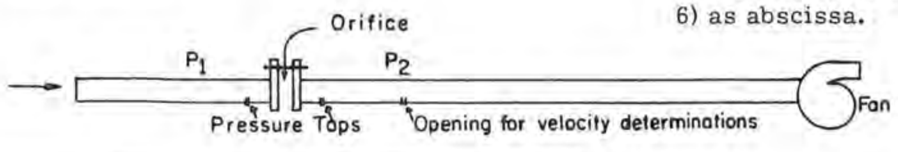
Area - $\frac{\pi D^2}{4}$ or from a table on duct areas.

8 Item 5: The flow rate is expressed as, Q - Avg. Vel. × Duct Area - Ft^3/Minute or Cfm.

9 Item 6: P_1 and P_2 are the pressures directly upstream and downstream of the orifice respectively. They will be measured with a mechanical gage. For more precise calibrations in inclined manometer should be used to record these pressures.

10 Close the fan discharge valve gradually to attain 0.5" H_2O increments in P_1-P_2 of items 3-9 for each setting.

11 Plot calibration on graph paper. Flow rate (item 5) as ordinate; P_1 - P_2 (item 6) as abscissa.



Revised by John M. Yacher, Chemical Engineer, Division of Training, NIOSH, 2/73.

HIGH VOLUME ORIFICE METER DATA SHEET

1	2	3	4	5	6
Test	℄ Vel, fpm	℄ Vel. x 0.9	Duct Area, sq. ft.	Flow Rate, cfm	$P_1 - P_2$, w. c.

Laboratory II — Air Flow Measurements

10. NULL-PRESSURE CALIBRATION METHOD

A problem often encountered in instrument calibration is to calibrate an instrument in the same way it will be used in actual practice. This problem is more prevalent when calibrating instruments having a flow rate indicator downstream of the instrument intake.

It is necessary to establish a condition at the instrument inlet which is similar to the plant ambient atmosphere. This means essentially no change in the static pressure of the ambient air at the instrument intake.

The Null-Pressure Method of calibration establishes a condition at the instrument inlet which duplicates ambient plant conditions. This is done by placing the instrument to be calibrated between two air movers. By varying the supply and discharge at the instrument inlet by static pressure equal to ambient pressure can be developed. By readjustment of the two air movers' flow rates the instrument may be calibrated over its operating range.

This laboratory experiment will be conducted as follows:

1 Set up the Null-pressure calibration system.

2 Turn on both air movers simultaneously.

3 Adjust power to each air mover until the plastic bag shows no difference in its volume configuration. A good check for null pressure or static pressure inside the plastic bag being the same as the atmosphere pressure, is to depress the plastic bag slightly. If it does not return to its original shape a null-pressure condition exists.

4 The flowmeter of a high volume sampler unit "C" will be calibrated over its entire range.

5 Collect data for 25%, 50%, 75%, and 100% open area at the sampler inlet. Flow through sampler will be varied by removing the cardboard cards taped at the inlet to establish the percent open area desired.

6 Record the following data:

1	2	3
Meter "A" w. c.	Orifice Flow	Meter "B" Float Position

a Orifice has been calibrated. The orifice calibration curve will be provided. Orifice flow rate has been plotted versus meter "A" readings.

b Meter "B" is an inherent component of the high volume sampler "C".

7 Plot meter "B" calibration curve using items 2 and 3 from data sheet. Plot meter "B" flow (item 2) as abscissa and meter float position (item 3) as ordinate.

Revised by John M. Yacher, Chemical Engineer, Division of Training, NIOSH, 2/73.

NULL-PRESSURE DATA SHEET

1	2	3
Meter "A" w.c.	Orifice Flow	Meter "B" Float Position

3

DUST

I TYPES

Dust can be divided into two types according to general shape. These are:

1) particles	or	1) fibrous
2) fibrous		2) non-fibrous

II EFFECT ON MAN

Dust causes problems when inhaled in excessive quantities. Serious pulmonary disease results often and have been named a variety of common names, such as miners asthma, miners phthisis, grinders' rot, farmers lung, black lung.

More correctly, these diseases have a general name — pneumoconiosis, (a <u>lung</u> containing <u>dust</u>)

The word originally implied that the lung had been seriously damaged by dust—enough to cause disability--but has been broadened in recent years to include all pulmonary manifestations of dust inhalation whether injurious or harmless.

III BEHAVIOUR IN AIR

Because of certain properties (physical) solid particles may be divided into two groups.

A Settled $>40\ \mu m$.

B Suspended

A particle in a fluid (air) is acted upon by three forces.

1 Buoyancy

2 Drag

3 Gravity

Whenever $-B + D < G$ particle is settled.

If $-B + D \geqslant G$ particle is suspended (for a time).

Suspended — buoyancy, drag are dependent upon

1 Size

2 Shape

3 Density

4 Air currents

5 Humidity

IV RESPIRABILITY

Suspended particles can be divided into two classes mainly according to <u>size</u>.

A Non-respirable Dust

B Respirable Dust

1 Definition - That capable of being breathed (Webster)

2 In general, particles less than $10\ \mu m$ are considered to be respirable.

3 In Johannesburg in 1959, respirable fraction was defined as:

$100\%\ <1\ \mu m$

$50\% - 5\ \mu m$

$0\%\ >7\ \mu m$

4 In 1952, British Medical Research Council defined respirable dust as "that reaching the alveoli."

Prepared by J. S. Ferguson, Chemist, Division of Training/NIOSH, 1/73.

V STANDARDS AND CRITERIA

A AIHA using both BMRC and Johannesburg recommendations specified:

1 "For purposes of estimating airborne dust in its relation to pneumoconiosis, samples for compositional analysis, or for assessment of concentration by a bulk measurement such as that of mass or surface area, should represent only the 'respirable' fraction of the cloud."

2 "The 'respirable' sample should be separated from the cloud while the particles are airborne and in their original state of dispersion."

3 "The 'respirable' fraction is to be defined in terms of the free falling speed of the particles, by the equation:

$$\frac{C}{C_o} = 1 - \frac{f}{f_c}$$

where C and C_o are the concentration of particles of falling speed f in the 'respirable' fraction and in the whole cloud respectively, and f_c is a constant equal to twice the falling speed in air of a sphere of unit density 5 rem in diameter."

B Sampler Performance

1 BMRC- A sampling device which meets these requirements, would generate a curve as follows:

Deposition (%)	Diameter* (μm)
10	2.2
20	3.2
30	3.9
40	4.5
50	5.0
60	5.5
70	5.9
80	6.3
90	6.9
100	7.1

*For spheres of unit density

2 AEC

In 1961, AEC defined "respirable" as that portion of inhaled dust which penetrates to the non-ciliated portions of the lung.

Respirable dust was defined as:

Respirable (%)	Size* (μm)
0	10
25	5
50	3.5
75	2.5
100	2

*Sizes referred to are equivalent to an aerodynamic diameter having the properties of a unit density sphere.

VI INSTRUMENTS FOR SIZE-SELECTIVE SAMPLING

Basically, there are two sampler acceptance curves described here, and they have similar, but not identical characteristics. The BMRC curve was chosen to give the best fit between the calculated characteristics of an ideal horizontal elutriator and lung deposition data.

The AEC curve was patterned after upper respiratory tract deposition data and is simulated by the separation characteristics of cyclone type collectors.

In most cases, samples meeting either criterion will be comparable.

A Two Stage "Respirable Dust Sampler"

1 Consists of a first stage whose collection efficiency varies from very high to very low as the aerodynamic particle size decreases from ~ 10 μm to ~ 2 μm, and a second stage with high E for all sizes.

2 Horizontal elutriators and cyclones have been mostly used for first stage, while filters have been used as the second stage.

B Multi Stage Samplers

1 Consists of a filter pack sampler collecting particles on various stages. No design like this gives accurate estimates of "respirable" fractions.

C Cascade Impactors

1 Utilizes inertial forces to separate particles from an air stream into a series of size classes.

2 Major limitation is that only limited sample masses can be collected without re-entrainment. Also, wall losses occur which further bias any results.

VII LIMITATIONS OF SELECTIVE SAMPLING

The effective application of selective sampling concepts to respiratory hazard evaluation requires: (a) adequate knowledge of the regional deposition and clearance of particles in man and (b) reliable, reproducible and accurately calibrated selective samplers.

A Elutriator

1 Difficult to recover collected material.

2 Operated only in horizontal position

3 Large size

4 Pulsation in flow

B Cyclone

1 Flow rate dependent-$E \alpha F$

2 Independent of orientation

VIII RESPIRABLE DUST SAMPLERS IN USE

A Impinger

1 The G-S impinger developed in 1922-1925 and midget impinger in 1928 efficiently collect particles larger than 0.75 μm in liquid.

2 Particles then "counted" with light microscope at 10 x obj., 10 x ocular.

3 Particles larger than 10 μm are rejected as non-respirable.

4 Exposures measured in mpp cf (millions of particles per cubic foot).

B Filter

1 Membrane filter used to sample for asbestos fibers.

2 Fibers "counted" and sized by light microscope at 40 - 50 x obj., 10 x ocular, phase - contrast illumination.

3 Fibers greater than 5 μm recorded.

4 Exposures measured in fibers/cc greater than 5 μm.

C Two Stage

1 Cyclone and membrane filter or elutriator and membrane filter used.

2 Deposit on filter weighed.

3 Exposure measured in mg/m^3.

IX SUMMARY

Current movement is away from optical determinations and toward mass methods. Exception is asbestos where no correlation between mass and fiber count has been satisfactorily established.

The real problem lies in representative sampling of airborne particles. These may range from condensation nuclei 10^{-3} μm to 10 μm in diameter, the upper limit for respirable particles thus covering four orders of magnitude.

If the smallest size were visualized as a steel ball 1 mm in diameter, then the largest size would be 10 meters. It would be surprising if these particles obeyed the same laws or indeed if they could be measured accurately using the same instrument.

In the production of small particles from a bulk material, the amount of energy required to reduce relatively coarse material to fine particles may be phenomenal and, therefore, many industrial processes such as grinding or crushing may be incapable of producing particles smaller than 0.1 μm in diameter. Welding operations on the other hand may produce copious quantities of 0.01 μm fumes. Any given sample of airborne dust may, therefore, contain a wide variety of shapes as well as sizes of particulate matter.

REFERENCES

1 Lippman, Morton, "Respirable Dust Sampling," American Industrial Hygiene Association Journal, page 130, March-April, 1970.

2 Morrow, Paul E., "Evaluation of Inhalation Hazards Based Upon the Respirable Dust Concept and the Philosophy and Application of Selective Sampling," American Industrial Hygiene Association Journal, Volume 25, page 213, 1964.

CALIBRATION OF PERSONAL SAMPLING PUMPS

WHEN TO CALIBRATE

In normal use, the personal sampling pump should be calibrated after every 200 hours of run time. Because the pump is worn on the person, it is subject to accidental and intentional abuse and normal or abnormal wear on internal parts. In such cases, the sampler should be checked and calibrated more frequently. In those cases in which the sampling and analysis may be called into question, the sampling pump should be calibrated daily, before the survey and checked periodically during the sampling.

PREPARATION FOR CALIBRATION

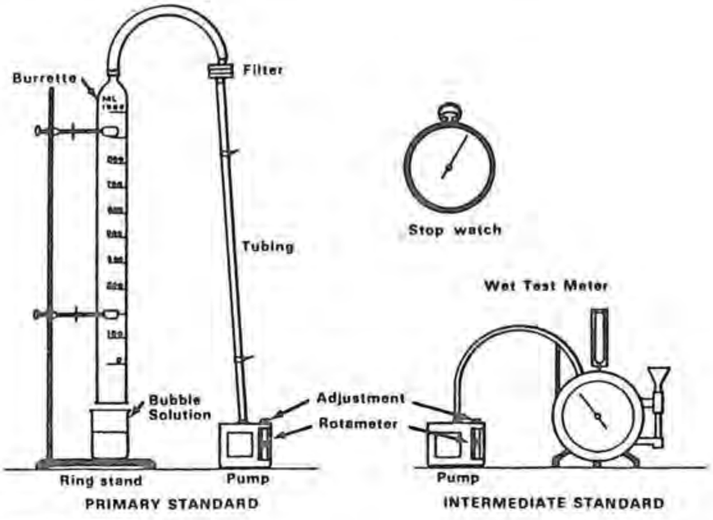
After the sampler has been fully charged, allow the pump to run five to ten minutes so that the high voltage peak of the NI-CAD batteries has a chance to smooth out to normal voltage output. If calibration is necessary on a sampler that needs to be charged, in most cases, the charger that is supplied with the sampler may be used as a secondary power supply so that calibration procedures may be accomplished. Always check with manufacturers specifications for this possibility.

A fully charged sampling pump must be capable of pulling 2.0 liters of air per minute with the sampling head and filter in the line. Larger sampling pumps should pull 3.0 to 4.0 liters of air per minute. If not, maintenance is necessary.

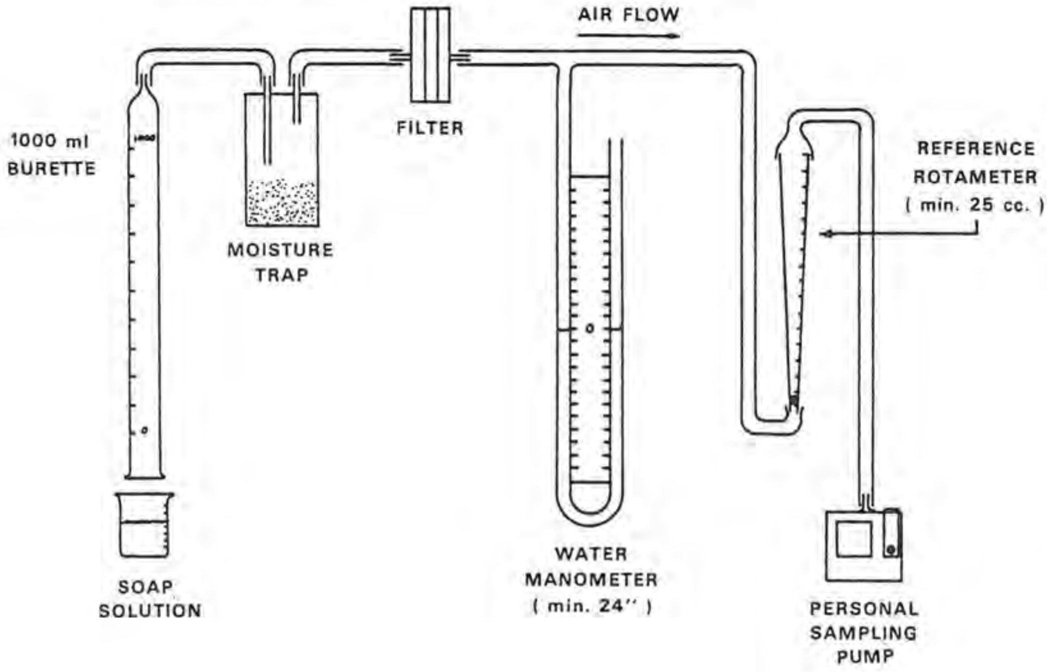
CALIBRATION SET UP

The calibration set up will include the pump, the correct length of tubing, and the sampling head with filter. The rotameter on the sampling pump operates at a reduced pressure and therefore the filter must be in the line for proper calibration. If the resistance of the filter and sampling head is known, a water manometer and a control valve can be employed to simulate the pressure drop at each calibration mark on the pump rotameter.

The instruments used for calibration are a bubble buret (a primary standard) or a wet test meter (an intermediate standard). When using the bubble buret, a water trap or moisture trap should be used to protect the pump.



Prepared by Daniel S. Watkins, Training Instructor, DTMD, NIOSH, 9/76.



ALTITUDE EFFECT ON THE PUMP

In reference to the March 1976 issue of American Industrial Hygiene Association Journal, Volume 37, altitude affects personal respirable dust sampler calibration. If samplers are to be used at an altitude other than that at which they were calibrated, adjustments in calibration must be made. The major factor to be considered when using equipment at locations other than where they were calibrated is the relative change in air density which is usually due to significant changes in elevation (greater than 2,000 feet). Changes in elevation affect both the calibration of the rotameter and the operating performance of the pumps.

A typical rotameter float level of a pump calibrated for a flowrate of 2 liters per minute (lpm) at an altitude of 740 feet might be 3.2 centimeters. At an altitude of 6,000 feet, the flowrate increases to 2.05 liters per minute (lpm) while the float level decreases about 1.5 millimeters. By adjusting the float back to the original 2 liters per minute (lpm) calibration mark, the flowrate increases to 2.26 liters per minute (lpm). Use at even higher altitudes will result in greater errors in flowrate.

SUMMARY

Frequent calibration of personal sampling pumps, dependent on sampling conditions, is necessary for the purpose of evaluating the performance of the pump, the batteries, and that it has sufficient air flow rate. Altitude will effect the performance of the sampler.

For accuracy, the bubble meter (primary standard) is most economical for laboratory and field calibration.

CALIBRATION OF PERSONAL SAMPLER DATA SHEET

1	2		3
Pump Rotameter Setting	1 Liter Travel Time		LPM
	Wet Test	Bubble	
7			
7			
7			
6			
6			
6			
5			
5			
5			
4			
4			
4			
3			
3			
3			

SAMPLING DATA SHEET

LOCATION: ______________________________ Date: ____________

______________________________ Time: ____________

______________________________ Initial: ____________

Operation: ____

____

Description: ________________

____

____

____

____

____

Remarks: ________________

____

____

Sampling Data

Sample #: ______ Type: ______ Contaminant: ______ TLV: ______

Pump #: ______ Rate: ______ Sample initial weight: ______

Time start: ______ final weight: ______

stop: ______ net weight: ______

Sample time: ______

Calculated Concentration: ____________________

Remarks: ____

____

Prepared by: John M. Blankenhorn, Industrial Hygienist

CALIBRATION OF PERSONAL SAMPLING PUMP

NOTES:

DATE-
PUMP NO.-
FILTER SIZE-
CALIBRATION INSTRUMENT

CONDITION
TEMP.-
ALTITUDE-
Hg ________ mm

REFERENCE ROTAMETER
POINT #1. ____ #2. ____
#3. ____ #4. ____ #6. ____
#6. ____ #7. ____ #8. ____

RESISTANSE AT EACH POINT - INCHES H_2O
1. ____ 2. ____
3. ____ 4. ____
5. ____ 6. ____
7. ____ 8. ____

SIPIN PUMP CALIBRATION

PUMPS ARE CALIBRATED AT TWO FLOWS
200 CC/MIN AND 50 CC/MIN

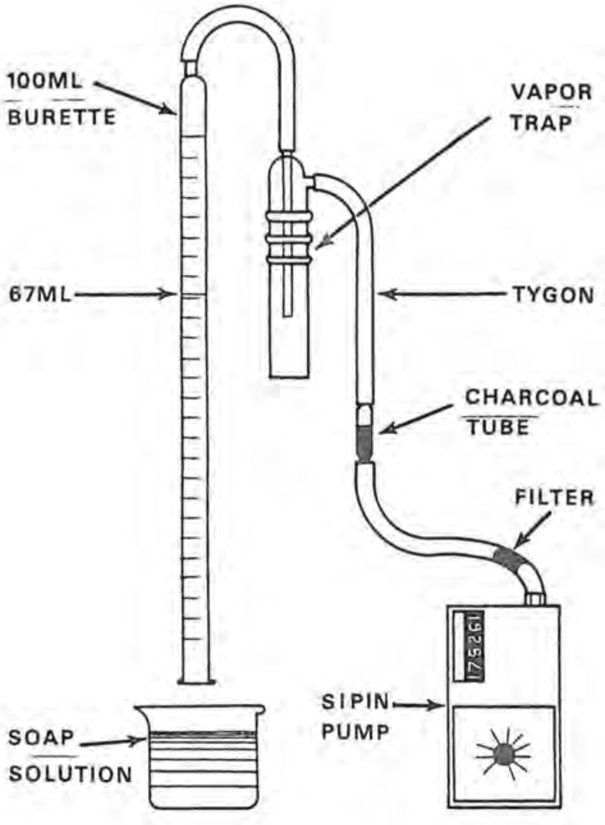
200 cc/min Flow

Set dial at approximately 8. Start bubble up buret at zero on buret. Start stop watch time bubble to 67 ml and adjust dial to get a flow rate of 67 ml in 20 seconds. (Three (20 sec) times 67 = 201)

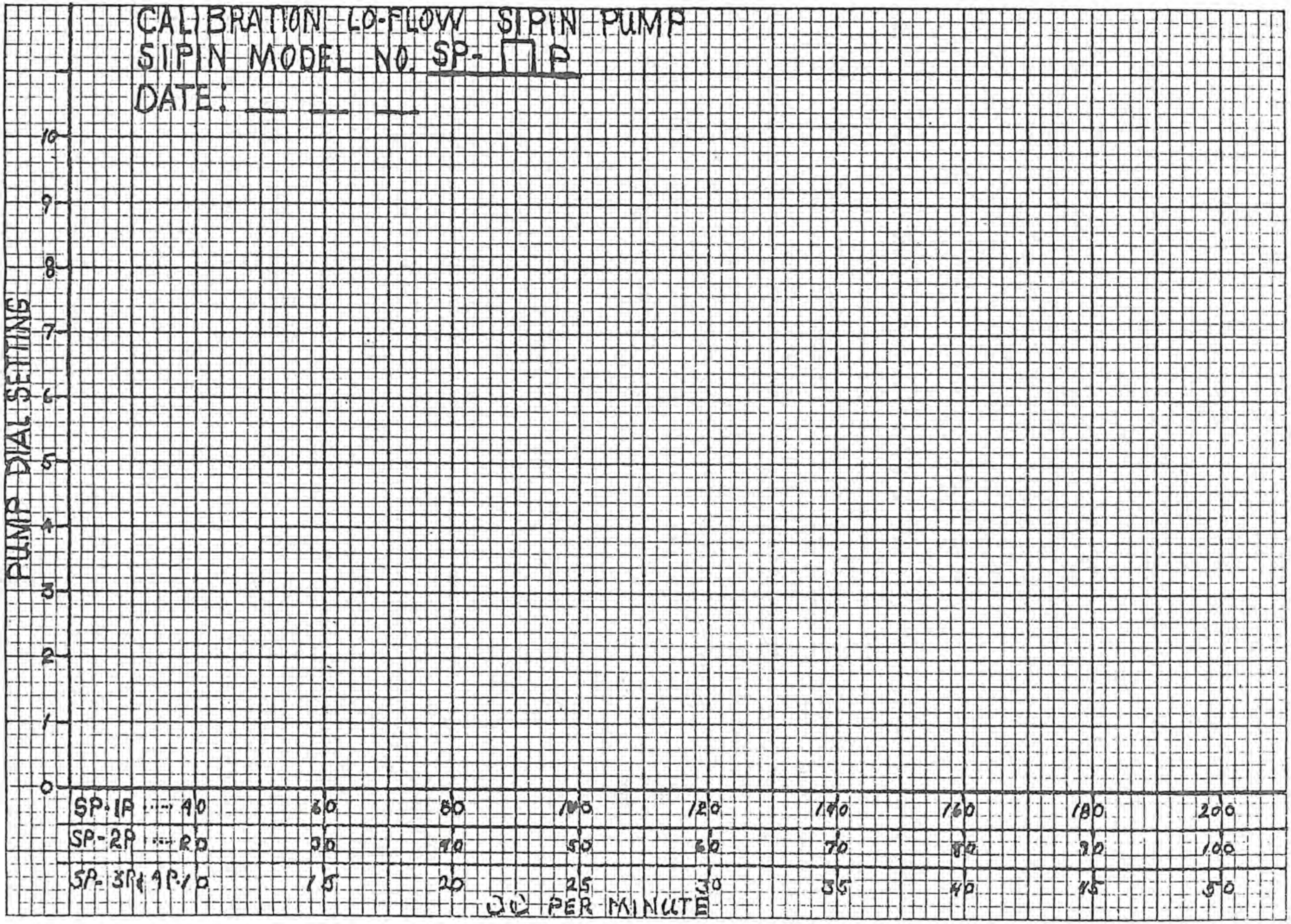
Start bubble up buret holding pump near buret. Note counter last three digits when bubble passes zero. Run for 100 counts and note position of bubble in buret. (Should be between 50 and 65 for a pump in good condition.) This is the cc/stroke, i.e., 55 ml/100 counts = .55 cc/stroke.

50 cc/min Flow

Set dial at approximately 2. Start bubble up buret at zero on buret. Start stop watch and note last three digits on counter. Adjust dial as needed to get a flow rate of 50 ml in one minute. Read counter for 100 counts for cc/stroke.



Prepared by Daniel S. Watkins, Training Instructor, DTMD, NIOSH, 9/76.


CALIBRATION LO-FLOW SIPIN PUMP
SIPIN MODEL NO. SP-☐P
DATE: __ __ __
PUMP DIAL SETTING
10
9
8
7
6
5
4
3
2
1
0
SP-1P ··· 40
60
80
100
120
140
160
180
200
SP-2P ··· 20
30
40
50
60
70
80
90
100
SP-3P & 4P-10
15
20
25
30
35
40
45
50
CC PER MINUTE

FIELD CALIBRATION OF A MAGNEHELIC GAGE

PURPOSE:

To calibrate a magnehelic gage against a primary standard.

DISCUSSION:

The magnehelic gage is widely used to measure small differences in pressure. It is frequently used in place of a U-tube manometer or draft gage when ventilation measurements are being made. It must be zeroed for a given position but it does not have to be leveled or filled with a liquid to be operational. Once it has been zeroed for a vertical or horizontal operation, no further adjustment is necessary.

Like all instruments that are not primary standards, the magnehelic gage must be calibrated against a primary standard. This calibration can be performed with the following laboratory set-up.

PROCEDURE:

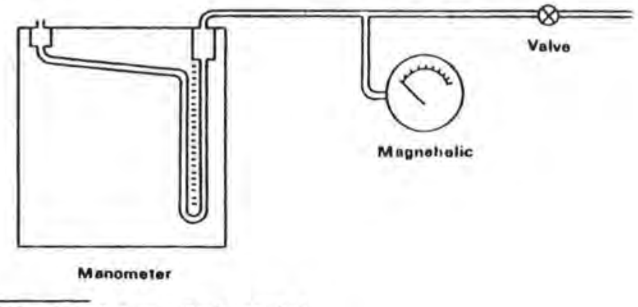
With the tubing attached to the negative pressure side of the magnehelic gage, open the needle valve and apply suction to the system until the gage reads slightly above the top of the scale. Close the needle valve while maintaining the negative pressure on the system. Remove the source of suction. Open the needle valve very slightly and allow air to enter the system until the needle on the magnehelic gage is on the highest scale marking. Record this reading and the corresponding reading on the U-tube manometer. Repeat the procedure given above for several scale markings, covering the full range of the gage, and complete the tabulation given below.

Place the tubing on the positive pressure side of the magnehelic gage and the manometer and repeat the above procedure, applying sufficient positive pressure to bring the needle to the highest scale reading. Complete the following tabulation.

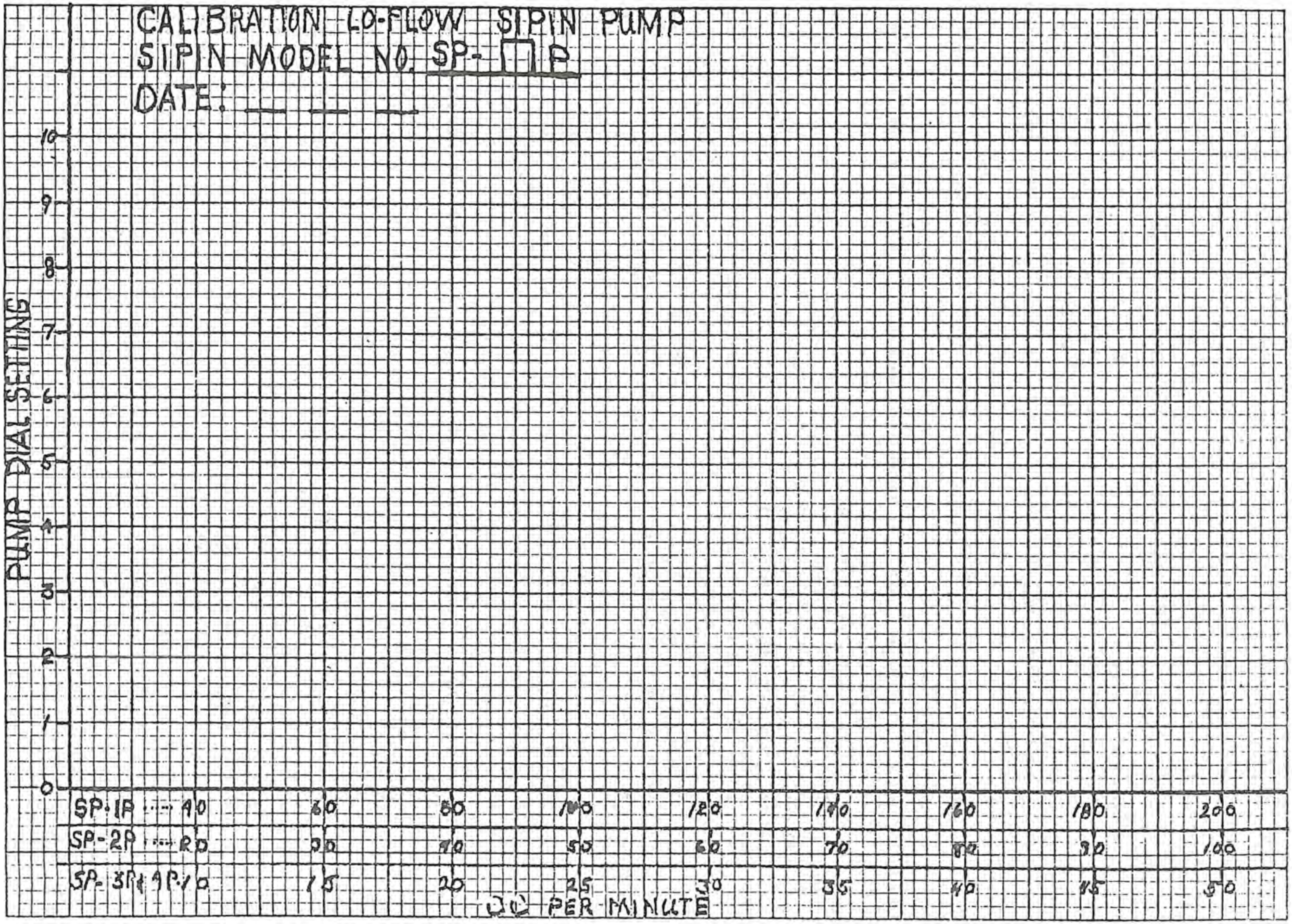
Magnehelic gage	Manometer
-8	
-7	
-6	
-5	
-4	
-3	
-2	
-1	
-0	

Magnehelic gage	Manometer
+8	
7	
6	
5	
4	
3	
2	
1	
0	

Construct a calibration curve on the accompanying graph.



Prepared by John M. Blankenhorn, Industrial Hygienist, DTMD, NIOSH, 8/76.


CALIBRATION LO-FLOW SIPIN PUMP
SIPIN MODEL NO. SP-☐P
DATE: __ __ __
PUMP DIAL SETTING
10
9
8
7
6
5
4
3
2
1
0
SP-1P ... 40
60
80
100
120
140
160
180
200
SP-2P ... 20
30
40
50
60
70
80
90
100
SP-3P & 4P 10
15
20
25
30
35
40
45
50
CC PER MINUTE

FIELD CALIBRATION OF A MAGNEHELIC GAGE

PURPOSE:

To calibrate a magnehelic gage against a primary standard.

DISCUSSION:

The magnehelic gage is widely used to measure small differences in pressure. It is frequently used in place of a U-tube manometer or draft gage when ventilation measurements are being made. It must be zeroed for a given position but it does not have to be leveled or filled with a liquid to be operational. Once it has been zeroed for a vertical or horizontal operation, no further adjustment is necessary.

Like all instruments that are not primary standards, the magnehelic gage must be calibrated against a primary standard. This calibration can be performed with the following laboratory set-up.

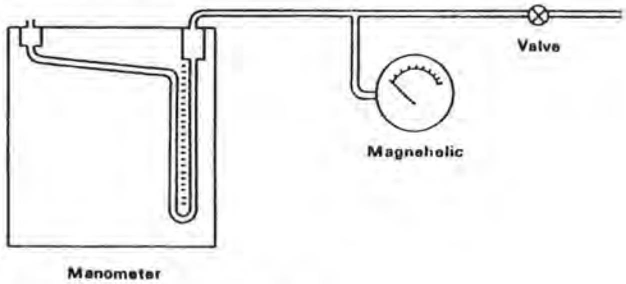
PROCEDURE:

With the tubing attached to the negative pressure side of the magnehelic gage, open the needle valve and apply suction to the system until the gage reads slightly above the top of the scale. Close the needle valve while maintaining the negative pressure on the system. Remove the source of suction. Open the needle valve very slightly and allow air to enter the system until the needle on the magnehelic gage is on the highest scale marking. Record this reading and the corresponding reading on the U-tube manometer. Repeat the procedure given above for several scale markings, covering the full range of the gage, and complete the tabulation given below.

Place the tubing on the positive pressure side of the magnehelic gage and the manometer and repeat the above procedure, applying sufficient positive pressure to bring the needle to the highest scale reading. Complete the following tabulation.

Magnehelic gage	Manometer	Magnehelic gage	Manometer
-8		+8	
-7		7	
-6		6	
-5		5	
-4		4	
-3		3	
-2		2	
-1		1	
-0		0	

Construct a calibration curve on the accompanying graph.



Prepared by John M. Blankenhorn, Industrial Hygienist, DTMD, NIOSH, 8/76.

Laboratory III — Particulate Sampling

12. FILTER MOUNTING PROCEDURE

This lecture has four objectives, and they are expressed in terms of what you will be able to do after the lecture is completed. The objectives are:

1 List all equipment necessary for sample mounting.

2 Explain how the mounting solution is prepared.

3 Explain how the filter is mounted on a slide.

4 Draw a good slide mount and explain why it is good.

The lecture will be considered successful if, at the end, you are able to correctly answer those four objectives. At the end of each lecture segment that applies to the objective, the appropriate objective will be shown.

For better understanding, the lecture is divided into two segments:

Part I: Preparing the Mounting Solution

Part II: Mounting the Filter

Part I: Preparing the Mounting Solution

The mounting solution that is used for this procedure is specific for mounting cellulose-esther membrane filters made by the Millipore Corporation. At the time of this taping, it is the only certified solution for mounting these filters. Criteria are being developed for other filters and mounting solutions.

This visual is a schematic of the slide mount. Mounting solution is placed on the slide, the filter is placed on the solution dust side up. The cover slip is placed on the sample. Here you see the dissolving filter being immersed in the solution which contacts the cover slip. The solution actually dissolves the filter and becomes an optically-homogeneous plastic mount which holds the sampled particulates in place. Note that I said the solution dissolves the filter. This is contrasted against a technique of refractive-index matching for light-field microscopy. With phase contrast this technique only makes the filter more visible. The mounting solution is a mixture of two reagents containing enough filter material to increase to a suitable level the viscosity of the solution.

Here is the equipment you will need for preparation of your mounting solution:

1 A bottle of dimethyl pthalate.

2 A bottle of diethyl oxalate.

3 A supply of clean filter material.

4 A 25 ml. graduated cylinder.

5 A Wheaton balsam bottle.

6 A chemical balance.

7 Some silicone stopcock grease.

One thing to constantly keep in mind is cleanliness. The work area should be clean— and likewise, all the equipment. Acetone serves as a solvent for cleaning off old mounting solution. This will be necessary when cleaning the Wheaton balsam bottle for re-use in the future.

Your mounting solution is made by dispensing at a 1:1 ratio by volume dimethyl pthalate and diethyl oxalate. I would recommend that you make no more than 25 ml. at a time. Under frequent use this will last several months. To prepare the solution,

---

Prepared by Stephen G. Bayer, Physical Science Technician; assisted by Anne Stirnkorb; music by Mark Conrad.

first dispense 12-1/2 ml. of dimethyl pthalate into the burette. Now, pour in the diethyl oxalate until it reaches the 25 ml. mark. Cap the bottles and set them aside. Remember the criteria? We must thicken the solution by adding .05 grams of clean filter material for each milliliter of solution. You will now need a balance to weigh the filters —in this case 1.25 grams. Generally, the filters weigh about .04 grams; therefore, you will need about 31 filters— but weigh out the quantity. When you remove new filters from the case, you will see that between each filter there is a blue separator. These are discarded. You can use your fingers to manipulate the filter— but be sure your hands are clean. If you drop the filters, throw them out. Take the solution in the cylinder and pour it into the Wheaton balsam bottle-- leave the bottle open. Remove the weighed filters from the balance pan and shove them, a few at a time, into the Balsam bottle. Use the glass rod to push them down into the bottle if necessary. The filters will now dissolve slowly. You may want to stir the solution every hour or so. The mouth of the lid should be coated with stopcock grease to assure a good seal. Within 24 hours, the solution will be ready to use. As you can see, this pre-made solution is somewhat cloudy— but quite useable. The mounting solution has a normal shelf life of about six months. (There is speculation that refrigeration may extend that.)

So, to summarize, we have prepared the mounting solution by adding dimethyl pthalate to diethyl oxalate in a one-to-one volumetric ratio. Then we added .05 grams of filter material to each milliliter of prepared solution to increase the viscosity. At this point, you should be able to perform these objectives:

1 List all equipment necessary for sample mounting.

2 Explain how the mounting solution is prepared.

Part II: Mounting the Filter

Now that the mess has been cleaned up from part one, we are ready to progress to mounting the sample. Here is the equipment you will need:

1 Your slides will be 25 x 75 mm. or 1 x 3 inches with one end frosted.

2 A scalpel with a #10 curved blade works well to cut out a filter segment. A pair of micro-scissors works just as well.

3 You will need a pair of fine-pointed tweezers to lift the filter segment from the cassette.

4 A spatula or fire-polished glass rod is used to spread the mounting solution upon the slide.

5 Buy quality # 1-1/2 cover slips which are 25 mm.

6 You'll also need your mounting solution.

7 A supply of lint-free lens tissue is needed for cleaning slides, etc.

8 You'll need a pencil with which to label the slide.

9 Finally, you'll need the sampled filter.

Let's go on to the mounting procedure. Keeping in mind that cleanliness is important, keep open bulk samples— or anything else that is dusty— away from the mounting area. First, lay a couple of sheets of lens paper in front of you on the work surface. The slides will be placed on one, and the mounting utensils on the other. Clean the slides by breathing on them and wiping them with lens tissue. Until you become proficient, mount one slide at a time. Your slides should be cleaned whether or not they are sold to you "precleaned." Cover slips are cleaned in the same manner. Lay the cover slip so that one edge rests upon the non-frosted end of the slide. This eliminates the possibility of lint contaminating the cover slip. Using the glass rod in the Wheaton balsam bottle, apply some mounting solution to the center of the slide. The quantity of solution you use will depend on how large or small you cut your filter segment. Usually, it will be about a drop. Upon withdrawal from the solution, one may note that several drops fall readily from the rod. The size of the second or third drop will be more consistent than the size of the first. Do not touch the Wheaton balsam bottle rod to the slide. Now that we have the drop on the slide, return the glass rod to the bottle and replace the cap. Take the spatula or supplemental glass rod and clean it with lens tissue. Then redistribute the solution into a triangular shape about 1/2 inch on each side. Open the field monitor at the bottom and center section. This reveals the filter. The gridded filter is being used for demonstrative purposes -- they are not recommended in the procedure. Clean the scalpel and cut a wedge that is the same size as the mounting solution triangle on the slide. Very little pressure is needed to cut the filter. Cut it with a rocking motion starting from the center and working to the circumference. Clean the tweezers and use them to lift the filter wedge from the cassette. Note how the wedge is held by the filter circumference. Do not touch the wedge with your fingers. The wedge is now placed dust side up on the mounting solution. You may wait about twenty seconds before placing the cover slip on the wedge. If your work area is dusty, cover the filter right away. Once the cover slip is in place, do not re-position it for any reason. After the normal waiting time of ten to fifteen minutes is past, the filter mount should be perfectly transparent. If it isn't, it's because a thin layer of air exists between the solution and the cover glass. This is remedied by pushing lightly on the coverslip with a clean surface — such as tweezer tips; but pushing on the cover glass is not — I repeat not — a normal part of the procedure. Do not forget to label the slide with the sample number and current date before progressing to the next slide.

In mounting your slides, you will need to strive for an "ideal" filter mount. After the filter is dissolved, the mounting media should extend only slightly beyond the original filter's dimensions. Here you see both extremes of bad filter mounting. The black areas around the filter represents how far the solution has spread. The bottom filter did not completely dissolve because too little solution was used. The top filter was mounted in too much mounting solution. It has spread to the edges of the cover glass. Here you see that the use of too much mounting solution produces particle migration — which will directly lessen the apparent dust concentration on the filter. Migration will most likely start at the edges — so stay away from the sample's edge while counting. This shows an ideal slide mount. Note that the solution extends only slightly beyond the filter. After your slide is mounted, you should count it within three days. After this time, crystals may grow — and sometimes they form in a fibrous shape. The lack of a permanent slide mount worries some people; but, remember, the filter is permanent and another mount can be made at any time. In summary, a proper quantity of mounting solution is applied to a slide. The filter is placed dust side up upon the solution. A number 1-1/2 coverslip is placed on the preparation and the slide is then labeled. At this conclusion of the lecture, let's review the last two objectives:

1 Explain how the filter is mounted on a slide.

2 Draw a good slide mount and explain why it is good.

Laboratory III — Particulate Sampling

13. MEMBRANE FILTER PREPARATION

I This laboratory provides an example of particulate evaluation by gravimetric analysis. The session will include disassembly of the filter cassettes, and the re-weighing of pretared filter units. The cassettes are made by MSA and Unico and are used in coal dust sampling. The same principles used for these units are applicable to a large variety of other filter holders.

A The Unico cassette consists of the following:

1 A mine data card showing the cassette number, and initial (tare) weight expressed in grams.

2 Two (2) plastic plugs which seal the filter.

3 A protective clear plastic shell which separates at the base and allows access to the filter unit.

4 The translucent filter unit which houses the filter.

B The MSA cassette consists of the following:

1 A mine data card which shows the cassette number and tare weight expressed in milligrams.

2 Two (2) plastic plugs which seal the filter.

3 Adhesive tape to hold the cassette together and seal possible air leaks.

4 The two (2) protective, clear plastic shells which separate to reveal the filter unit.

5 The filter unit consisting of a filter and aluminum backing.

II PROCEDURE

A Follow the Instruction Sheet of the Microbalance.

1 Disassemble the cassette, exposing the filter unit.

2 Remove the filter unit and place it upon the balance pan. (Tweezers may be necessary to extract the MSA filter unit)

3 By carefully following the balance directions, weigh the filter unit.

4 When completed, arrest the balance pan and return all settings to zero.

5 Subtract the gross weight from the tare weight to determine the sample weight.

6 The amount of dust loading is calculated from the following formula:

$$\text{Total Volume} = \frac{\text{Pump Flow Rate (L/M)}}{\text{1000 L/M}}$$

$$\text{Dust Loading} = \frac{\text{Weight of Sample (milligrams)}}{\text{Total Volume}}$$

Prepared by Stephen Bayer, Division of Training, 2/4/72.

MEMBRANE FILTER PREPARATION DATA SHEET

1. Filter Type ______________________________

2. Weight (before sample) ______________________________

3. Weight (after sample) ______________________________

4. Sample calculations (formulae on preceding page):

4

PRINCIPLES OF VENTILATION

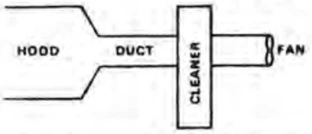
Ventilation is used to:

1 Remove a contaminant

2 Heat or cool a space

3 Supply make-up air

In order to do any of these jobs it is necessary to have 4 basic components assembled into one system. These are: 1) a hood; 2) a duct; 3) a cleaner; and 4) a fan.



A pressure is required to start and maintain flow. This pressure is called total pressure (TP) and has two components - static pressure (SP) and velocity pressure (VP).
$TP = SP + VP$.

I STATIC PRESSURE

Static pressure produces the initial air velocity. It is the forces on the walls of the duct having a tendency to burst or collapse the duct. When taking ventilation measurements, it is usually expressed in inches of H_2O and can be either negative or positive, depending on which side of the fan the reading is taken on.

II VELOCITY PRESSURE

Velocity pressure is kinetic pressure in the direction of flow necessary to cause a fluid at rest to flow at a given velocity. It is also expressed in inches of H_2O and is always positive in sign.

Again, the total pressure at any cross-sectional area of a duct system is described by the VP + SP.

The total pressure will change only by the duct frictional losses.

$$\underbrace{SP_1 + VP_1}_{\text{Upstream}} = \underbrace{SP_2 + VP_2 + \text{Losses}}_{\text{Downstream}}$$

Before principles of air flow can be developed, basic assumptions must be made.

A Air will be considered as an incompressible fluid in the design of most ventilation systems.

B Air flow will be in the turbulent range. Turbulent range is defined by the Reynolds Number. Formulas and tables used in ventilation work assume turbulent flow.

C The five variables which completely define any ventilation system are:

1 Q - Quantity of Air (CFM)

2 V - Velocity of Air (FPM)

3 SP - Static Pressure (inches of H_2O)

4 VP - Velocity Pressure (inches of H_2O)

5 A - Area of Duct (ft^2)

III QUANTITY - CFM

The basic formula used to measure the quantity of air flow at any point in a ventilation system is the mass or weight continuity equation.

The equation states that the mass rate of flow remains constant along the path taken by a fluid.

Prepared by Edward D. Leininger, Industrial Hygienist, Division of Training, NIOSH, 10/73, 10/76.

Let A = Cross sectional area of the duct at point #1

V_1 = Velocity at point #1

σ_1 = Specific weight (lbs./1 ft^3) at point #1 and

A_2, V_2, σ_2 be the same variables at point #2.

Then, $A_1 V_1 \sigma_1 = A_2 V_2 \sigma_2$

Remembering the basic assumption that air is incompressible, then $sigma_1 = sigma_2$ and the formula becomes:

$$A_1 V_1 = A_2 V_2 \text{ or } Q = VA$$

IV VELOCITY AND VELOCITY PRESSURE

Air traveling at a specific velocity creates a definite pressure known as the Velocity Pressure.

There is a definite relationship between the velocity of air and the Velocity Pressure and the basic statement of this relationship is:

$$V = \sqrt{2gh}$$

Where:

V = velocity - ft./sec

g = gravitational acceleration - ft./sec./sec.

h = head of air - ft.

At standard air conditions where the temperature is 70°F, the barometric pressure is 29.92" of Hg, the relative humidity is 0 to 50%, the gravitational acceleration is 32.174 ft/sec^2, and the air density is 0.075 pounds per cubic foot, the formula converts to

$$V = 4005 \sqrt{VP} \text{ or}$$

$$Q = 4005 \quad A \sqrt{VP}$$

Ventilation engineers and industrial hygienists generally <u>consider air to be at standard conditions</u>.

Figure 6-16 in the Ventilation Manual is a velocity vs. velocity pressure table for standard air. The table can also be used for air at densities other than standard conditions by correcting the measured velocity pressure inversely as the density factor as in the following equation:

$$\text{Corrected VP} = \text{Measured VP} \times \frac{1}{d}$$

If the temperature of the air stream varies more than 30°F from the standard temperature and the altitude is greater than 1000 ft and/or the moisture content of the air is 0.02 lb/lb of dry air or greater, it is advisable to make corrections. (Correction factors can be found on pages 9-28 and 9-29, Ventilation Manual, 14th ed.).

V STATIC PRESSURE

Air in motion encounters resistance along the surfaces confining the flow. Some of the energy of the air is given up in overcoming the resistance and manifests itself as heat. The rougher the surface or the higher the flow rate or the greater the surface to volume ratio, the higher the duct friction loss will be.

The loss varies directly as the length, inversely as the diameter, and directly as the square of the air velocity. It can be calculated for any fluid flow in circular ducts from the <u>Fanning</u> or <u>Darcy</u> equation.

$$F = 4f\left(\frac{V^2}{2g}\right)\left(\frac{L}{D}\right)$$

Where:

F = frictional loss in feet of fluid flowing

V = fluid velocity (ft/sec)

g = gravitational acceleration (ft/sec^2)

L = duct length (ft)

D = duct diameter (ft)

f = friction factor - a dimensionless function of Reynolds Number

At standard conditions, the Fanning equation can be reduced to the convenient form:

$$h_f = .000298 \frac{f\ V^2}{D}$$

Where:

h_f = friction loss per 100 feet of duct (inches of H_2O)

f = Fanning friction factor

V = air velocity (ft/min)

D = duct diameter (inches)

This equation is used to plot frictional loss, air velocity, duct diameter, and air volume. A chart is available and is more convenient than performing the mathematical manipulations.

VELOCITY FORMULA

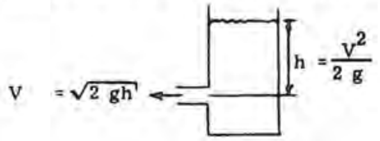
$$V = 4{,}005 \sqrt{VP}$$

$$V_{(feet/sec)} = \sqrt{2\ gh}$$

Where:

g = acceleration of gravity = 32.174 ft/sec^2

h = velocity head or initial static head in feet of flowing fluid



$$V_{(fpm)} = 4{,}005 \sqrt{VP}$$

Where:

VP = velocity pressure in inches H_2O

From:

$$V_{(fpm)} = 60 \sqrt{2\ gh_{(VP)}}$$

$$= 60 \frac{sec}{min} \left(2 \times 32.174 \frac{ft}{sec^2} \times 62.316 \frac{lb\text{-}H_2O}{ft^3} \times \frac{ft\text{-}H_2O}{12''\ H_2O} \times \frac{VP,\ ''H_2O}{\rho,\ \frac{lb\text{-}Air}{ft^3}} \right)^{\frac{1}{2}}$$

$$= 1096.8 \sqrt{\frac{VP}{\rho}}$$

At standard conditions, $\rho = 0.075$ lb/ft^3:

$$V_{(fpm)} = 1096.8 \sqrt{\frac{VP}{0.075}}$$

$$= 4005 \sqrt{VP,\ ''H_2O}$$

USE OF THE REYNOLDS NUMBER

The Reynolds Number (R_e) can be used as a criterion to determine if the stable form of flow in a pipe, with given conditions, is streamline or turbulent.

CRITERIA

$R_e < 2100$ - streamline (laminar) flow

$2100 < R_e < 4000$ - transition region (laminar or turbulent)

$R_e > 4000$ - turbulent flow

NOTE: The above numbers are approximate.

EXAMPLE (English Units)

The Reynolds Number is defined* as

$$\boxed{R_e = \frac{DV\rho}{\mu}}$$

Where:

D = Duct diameter (feet)

V = Average linear velocity (ft/sec) of fluid

ρ = Fluid density (lbs/ft^3)

μ = Fluid viscosity (lbs/ft sec)

GIVEN: Air flowing in a 6" duct at 4005 fpm at 70°F.

Remember that both density (ρ) and viscosity (μ) change with temperature. Most tables give viscosity in centipoises (cp). Multiply (cp) by (6.7197×10^{-4}) to convert to (lbs/ft. sec).

Then:

$$D = 0.5 \text{ feet}$$

$$V = \left(4005 \frac{\text{ft}}{\cancel{\text{min}}}\right)\left(\frac{\cancel{\text{min}}}{60 \text{ sec}}\right) = 66.75 \text{ ft/sec}$$

$$\rho = 0.075 \text{ lbs/ft}^3$$

$$\mu = 0.0178 \cancel{\text{cp}} \left[6.7197 \times 10^{-4} \frac{\text{lb/ft. sec}}{\cancel{\text{cp}}}\right]$$

$$= 1.196 \times 10^{-5} \text{ lb/ft. sec (at } 70^{\circ}\text{F)}$$

$$R_e = \frac{(0.5 \cancel{\text{ft}})(66.8 \frac{\cancel{\text{ft}}}{\text{sec}})(0.075 \frac{\cancel{\text{lbs}}}{\cancel{\text{ft}^3}})}{(1.2 \times 10^{-5} \frac{\cancel{\text{lb}}}{\text{ft} \cancel{\text{sec}}})}$$

$$= \underline{\underline{2.09 \times 10^5}} = 209{,}000$$

which is greater than 4000, thus we have turbulent flow.

Remember that (R_e) is dimensionless and all the units must cancel out.

---

*This definition applies only to circular ducts.

AREA VENTILATION MEASUREMENTS

I AREA VENTILATION

Definition - Ventilation of the plant area to reduce contaminated or stagnant air to establish concentration levels below the TLV of the contaminant.

II TYPES OF INDUSTRIAL VENTILATION

A Local Ventilation - Control of the contaminant at the source.

B Area Ventilation - Ventilation of the entire plant area to control contaminants in the plant.

III INDUSTRIAL VENTILATION TERMINOLOGY FOR AREA VENTILATION

A Volumetric Flow Rate - Cubic feet per minute - cfm.

B Velocity - Volumetric flow rate per unit area - cfm/ft^2 = fpm

C Face Velocity - Velocity at opening of duct hood, grille, at a place normal to the direction of flow.

D Hoods - Any opening in a ducted ventilation system designed to move air into the system.

1 Types of hoods

a Plain hood - pipe of any configuration open to admit air into a duct system.

b Slot hood - a slotted opening, in the end of a duct system, with a minimum width to length ratio - see ACGIH Ventilation Manual.

E Make-up Air - The air which is required to replace the amount of air being exhausted out of the plant.

F Air Change - Equivalent to the effective volume of the space being ventilated - cubic feet.

G Air Change Schedule - Air changes per unit time, i.e., air changes/hr.
air changes/min.

V INSTRUMENTS FOR MAKING AREA VENTILATION MEASUREMENTS

A Thermoanemometer

1 A heatstone bridge electrical circuit - change in temperature at sensing element caused by air flow will change resistance in circuit causing current flow.

2 Current flow expressed on dial as Velocity - fpm

3 Non-directional reading - instrument will indicate similar reading for flow from either direction.

4 Not to be used in explosive atmosphere.

B Swinging Vane Anemometer

1 Balanced vane calibrated to read velocity of air exerting force on one of its two sides.

2 Opening in housing may be adjustable to vary velocity range - low or high.

3 Instrument accuracy may be affected by corrosive gases or humid and dusty atmosphere.

C Rotating Vane Anemometer

1 Speed of rotation is a function of air velocity.

Prepared by Paul F. Alvarado, P.E., Mechanical Engineer, Division of Training. 6/72.

2 Readings in lineal feet

3 Timing device required to obtain linear flow rate - fpm

D Smoke Tubes, Smoke Gun

1 Best indicator of flow pattern.

2 Difficult to obtain velocity - although possible by observing movement of airbourne indicator.

VI AREA VENTILATION MEASUREMENTS LOCATIONS

A Openings Into Plant

1 Doors - normally opened or closed - periodically opened (seasonal).

2 Windows - opened, leakage, broken glass.

B Hoods

1 Measurement at point where captive velocity is calculated - 1-1/2 diameter from hood face.

2 Insure that flow is flowing in direction of hood at (a).

3 Volumetric flow - b × area of opening.

D Opening in Roof - skylight, roof ventilation, stacks.

VII PRINCIPLES OF AREA VENTILATION DESIGN

A Piston Effect Horizontally - air brought into plant uniformly in one side through cross-section of plant and exhausted on opposite side.

<u>Disadvantages</u> - other areas of plant will be contaminated.

B Piston Effect Vertically - air exhausted upwardly or downwardly uniformly.

1 Ideal way to exhaust

2 Will not contaminate other area in plant floor.

3 Upward exhaust will increase concentration for above floor work location - crane operators, maintenance men.

4 Expensive - requires below floor ventilation system to supply or exhaust air.

C Make-up Air

Make-up air should equal amount being exhausted.

1 Measure amount at discharge(s) by equal area traverse. Use effective area of grilled discharges.

2 Allow for temperature difference in air supplied versus air exhausted. Volume may differ by the absolute temperature correction.

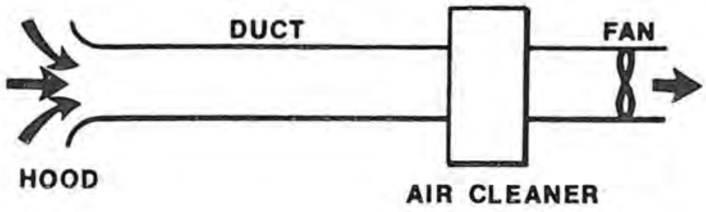
$$Q\,\text{Discharge} = Q_{in} \times \frac{T_{discharge}}{T_{in}}$$

Where:

Q = Volumetric flow

T = ^{o}F + 460

VENTILATION MEASURING INSTRUMENTS



$TP = SP + VP$

$Q = VA$

Pitot tubes

Manometers

- U-tube
- Inclined
- Inclined-vertical

Pitot traverse

Swing Vane Anemometer

Alnor 6000 Velometer

Alnor Velometer Jr.

Dwyer Air Meter

Thermal Anemometer

Magnehelic gage

Rotating Vane Anemometer

Smoke tube

Testing systems

Prepared by John M. Yacher, Chemical Engineer, Division of Training, NIOSH.

AIR-FLOW MEASUREMENTS

Introduction

To determine the effectiveness of environmental control by any ventilation system, an evaluation of the air movement must be made. In some instances, a qualitative determination, such as observing a vapor trail or the smoke from a smoke tube, may be sufficient to evaluate the effectiveness of control. In most cases, however, quantitative measurements are needed for proper evaluation. Various physical properties of moving air are used to make this evaluation.

In many cases the velocity of the air is determined by use of the various instruments. Then the quantity of moving air can be calculated by the formula:

$$Q = AV$$

where: Q = Volumetric rate of flow, cfm
A = The cross-sectional area through which the flow takes place, ft^2
V = average linear velocity in cross-section A, lfm

This formula is applicable where the cross-sectional area A can be defined.

All flowmeters, with the possible exception of well-designed Pitot tubes, should be calibrated against a primary or reliable secondary standard before use, and periodically checked for calibration thereafter.

Air-flow Measuring Devices

Pressure Sensing Instruments

Pitot Tube. The Pitot tube is the standard instrument for measuring the velocity of air. A standard Pitot tube, carefully made, will need no calibration. It consists of two concentric tubes - an impact tube whose opening faces axially into the flow, and the static pressure tube, a larger tube with circumferential openings. The difference between the impact and the static pressures is the velocity pressure. Bernoulli's theorem applied to a Pitot tube in an air stream simplifies to the formula:

$$V = \sqrt{\frac{2p}{\rho}} \qquad (2)$$

where: V = velocity of the airstream
p = velocity pressure measured by the Pitot tube
ρ = density of the air

The pressure, p, may be expressed in terms of a head of some fluid by:

$$p = \rho_f g h_f$$

where ρ_f = density of the fluid
g = acceleration of gravity
h_f = head of fluid

Expressing V in feet per minute, and p in inches of water (h_v), formula (2) becomes:

$$V = 1097\sqrt{\frac{h_v}{\rho}}$$

where ρ = density of air or gas in lbs/ft^3.

If the Pitot tube is to be used with air at standard conditions (70°F. and 1 atm.), formula (2) reduces to:

$$C\ V = 4005\sqrt{h_v} \qquad (3)$$

where V = velocity in ft/min.
h_v = velocity head in inches of H_2O

The Pitot tube measures pressure in the location in which it is placed. One measurement of pressure is usually insufficient to define the rate of air flow through a duct. However, if a dircular duct is straight for at least

---

Prepared by: Morton Lippmann
Revised by: George W. Fisher

10 diameters upstream from the point of measurement, a single center-line Pitot reading may give a fairly accurate estimate of the flow rate. It has been found that under such conditions, the average velocity is about 90% of the center-line velocity, or:

$$Q = 0.9\ AV_c$$

where V_c = center-line velocity

When accuracy is required, however, a Pitot traverse should be made. In a rectangular duct, the cross-section should be divided into at least sixteen equal areas, and a velocity measurement made at the center of each. The average of the velocities measured is the average velocity in the duct. For a traverse of a round duct, the cross-sectional area should be divided by means of concentric circles into regions of equal area. Measurements should then be taken at radii whose circles divide each region into two equal areas. A ten point traverse is frequently made. It consists of a set of ten measurements along one line, and another set of ten measurements along a line perpendicular to the first line - both lines being perpendicular to the axis of the duct. The velocities are then averaged to get the average velocity in the duct. Tables of distances from pipe wall for 6 and 10 point traverses in round ducts of various sizes are given on page 9-4 of Industrial Ventilation.(1)

The Pitot tube is used largely for measuring air velocity in ducts, or at high velocity supply and exhaust openings. Its accuracy in the low velocity range is limited by the sensitivity of the pressure sensing device used with it. At 3000 lfm, the velocity pressure is 0.56" H_2O; at 2000 lfm, 0.25" H_2O; at 1500 lfm 0.14" H_2O; and at 1000 lfm 0.062" H_2O. Therefore, a vertical water manometer should not be used for velocities below about 2000 lfm. An accurately balanced inclined manometer may be used down to about 600 lfm. Various accurate low pressure measuring devices may be used with a Pitot tube, but their use is usually limited to the laboratory where they can be carefully set up and balanced.

Pitot tubes can be used under a wide range of conditions; there are no moving parts to get out of order, and if made of stainless steel, they are resistant to corrosion and high temperatures. Standard Pitot tubes cannot be used in dusty atmospheres because they will become plugged, but modified Pitot tubes for use in such atmospheres have been made.(1) This type of Pitot tube should always be calibrated before use.

Further discussion of the Pitot tube can be found in many standard references.(2,5,7,8)

Deflecting Vane Anemometer (Velometer). This type of instrument is widely used for air flow and static pressure measurement by industrial hygienists and heating and air conditioning engineers. Various uses of this device are illustrated on page 9-8 of Industrial Ventilation.(1) Commercial Velometers are available with one pressure and one, two, three or four velocity ranges with a variety of jets for each range. The Velometer has the advantage of being a direct-reading instrument with ranges as low as 50 lfm or as high as 24,000 lfm, although readings below 100 lfm are not very accurate.

The Velometer operates by the pressure of an air stream against a spring loaded swinging vane. It is fairly rugged, and if calibrated regularly, the readings are sufficiently accurate for most field work. If the temperature of the air stream is outside the range 70°F ± 30° or the altitude is greater than 1000 feet, density corrections should be made. Dust or corrosive gases should not be permitted to enter the instrument. Velometers can be ordered with dust filters which will retain light dust loadings. If the instrument is calibrated with a dust filter in place, it must always be used in this manner.

In order to measure air flow or total pressure in a duct with a Velometer, a hole is required in the duct large enough to accommodate the appropriate probe. Such a hole is larger than that required for a Pitot tube and may be difficult to provide. When measuring static pressure, a minimum 3/8-inch diameter hole is needed, and it must be free from burrs in order to obtain accurate measurements.

Rotating vane anemometer. This instrument consists of a propeller connected through gears to a dial which counts rotations. The dial reads in linear feet, which when divided by the time interval of the measurement, gives linear feet per unit time. The instrument is available with 3, 4, or 6-inch wheels.

The rotating vane anemometer is useful for measuring air velocities in the range 200 to 2000 lfm. It is largely self-averaging for fluctuating flows and for traversing large openings. Readings are little affected by deviations in alignment with the direction of air flow up to about 20°. The instrument is delicate and should be calibrated frequently. It cannot be used in dusty or corrosive air. Since this type of instrument is rarely used in temperatures or pressures far from standard, pressure-temperature corrections are seldom needed.

For a more complete discussion of the rotating vane anemometer see Chapter 7, The Measurement of Air Flow.(5)

Other pressure actuated anemometers. One type of commercially available anemometer is a direct reading instrument designed primarily for measuring air velocity at discharge grilles in the range of 30 - 2700 lfm. It has a rotating impeller whose motion is opposed by a spring. When the velocity pressure on the impeller and the spring tension balance, the velocity can be read from the dial indicator. Another type of anemometer available is the cup anemometer used in meteorological work. It consists of four hemispherical cups mounted on light arms from a hub which turns freely on a vertical axis. This type of instrument has little application to ventilation work.

Thermal Anemometers

Heated thermometer anemometer. The heated thermometer anemometer is based on the principle that the rate of heat loss from an object at elevated temperature is a function of air movement over the object. The instrument consists of a pair of thermometers, one with an electric resistance coil about the bulb to which a known voltage may be applied. The other is an ordinary thermometer. In use, the two thermometers are placed in the air stream to be measured, and the applied voltage adjusted to give a difference of 15° to 30° in the two thermometer readings. The thermometers are then allowed to come to equilibrium. Velocity of the air stream can be determined from a calibration chart using the temperature difference between the two thermometers, or by application of the temperature difference in the following equation:

$$\frac{\text{net milliwatts}}{\Delta t} = K + K'\sqrt{V}$$

where: net milliwatts = fixed value for each thermometer at each voltage. A table is supplied with each instrument by the manufacturer.

Δt = temperature difference between thermometers.

K and K' = constants; values for each supplied by manufacturer.

V = velocity of air stream.

(Instead of constants for the above equations, some manufacturers supply a calibration curve).

The instrument indicates the cooling power rather than the velocity of an air stream. It is affected by radiant heat and convection. In the absence of radiant heat sources, it is very accurate as a velocity measuring device when carefully used. The instrument is nondirectional and has a range of 15 to 500 lfm. It is fragile and its use is time consuming. A more complete discussion of the heated thermometer anemometer is given by Yaglou.(9)

Heated thermocouple anemometer. This instrument works in the same manner as the heated thermometer anemometer, but uses thermocouples in place of thermometers. The advantages gained are a reduction in size, increased ruggedness of the sensing elements, faster response time, and it can be readily calibrated as a direct reading instrument. Several commercial instruments of this type are available. One has a range of 10 to 2000 lfm. Another has a range of 10-5500 lfm plus a static pressure scale of 0-4" H_2O. A third type has a range of 0-8000 lfm, a static pressure range of 0-10" H_2O, and also a Fahrenheit temperature scale. The calibration of this type of instrument should be checked regularly. Most of these instruments use batteries which must be replaced periodically.

Hot-wire anemometer. A hot-wire anemometer consists of a fine, electrically heated wire which is placed in the air stream to be measured. The cooling effect on the wire will depend on the velocity of the air stream. As the wire cools, its resistance changes, and this change can be measured with a bridge circuit. If calibrated properly, this type of instrument can be used to measure a wide range of air velocities. Pannell(6) gives a detailed discussion of this type of instrument.

Kata thermometer. The Kata thermometer is a special thermometer with a large bulb, containing alcohol, and a stem with marks at 95 to 100°F. It is heated above 100°F. and the time required for it to cool from 100 to 95°F. is a measure of the nondirectional air velocity in the room. It was designed for comfort ventilation measurement, and its surface to volume ratio is similar to that of the human body. The useful velocity range is 25 to 500 lfm. It has the disadvantage of being fragile and having large radiation and convection areas.

Ionization Anemometer

The ionization anemometer consists of a duct section having polonium on one surface and an alpha ray counter on the opposite surface. As the air flow increases, fewer α particles reach the counter, and the instrument can be calibrated in terms of velocity. Extremely low velocities can be measured with this instrument. Lovelock and Wasilewska(4) give further information about this instrument.

Air Quantity Measurement

Orifice Meter

An orifice meter is simply a restriction in a pipe between two pressure taps. There are several types of orifice meters used, but the simplest and most common is the square edged orifice, which is a very short cylindrical passage in a thin metal plate. If it is properly constructed, the orifice plate will be at right angles to the flow and the surface will be carefully smoothed to remove burrs and other irregularities. Since the square edged orifice is easily constructed and the meter as a whole is simple and comparatively inexpensive, it is widely used as an accurate flow meter. Orifice meters are seldom used as permanent flowmeters in ventilation systems because of their high permanent pressure loss. They are more typically used in the ventilation laboratory for calibration purposes. Permanent head loss will vary from 40 to 90 percent of the static pressure drop across the orifice as the ratio of orifice diameter to pipe diameter varies from 0.8 to 0.3. Orifices have been intensively studied and their performance characteristics can be predicted if they are constructed to standard proportions. Detailed discussions of orifices and orifice equations are contained in standard references.(2,5,7) On pages 191-193 of Industrial Health Engineering(2) Brandt gives a simplified formula for calculating the flow rate through a thin-plate orifice with flange taps for air at standard conditions. In it, Q is a function of the orifice diameter, the pressure drop across the orifice, and a factor K which varies with the Reynolds number and the ratio of orifice to duct diameter. A table of K's is given in this discussion.

Critical Flow Orifice

For a given set of upstream conditions, the discharge of a gas from a restricted opening will increase with a decrease in the ratio of absolute pressures P_2/P_1, where P_1 is the upstream pressure, and P_2 the downstream, until the velocity through the opening reaches the velocity of sound. The value of P_2/P_1 at which the acoustic velocity is just attained is known as the critical pressure ratio. The pressure in the throat will not fall below the throat pressure attained with the critical pressure ratio, even if a much lower downstream pressure exists. Therefore, when the pressure ratio is less than the critical, the rate of flow through the restricted opening is dependent only on the upstream pressure.

It can be shown(7,8) that for air flowing through rounded orifices, nozzles and Venturis, when $P_2 < 0.53\ P_1$, and $S_1/S_2 > 25$, the flow rate of air, w, is determined by:

$$w = 0.533 \frac{C_v S_2 P_1}{\sqrt{T_1}} \text{ in lb/sec}$$

where: C_v = coefficient of velocity (normally 1)

P_1 = upstream absolute pressure in lb/in^2

T_1 = upstream temperature in $^{\circ}$R

S_1 = upstream cross-sectional area in in^2

S_2 = orifice area in in^2

Critical flow orifices are widely used with industrial hygiene sampling instruments.

Flowmeters

The term flowmeter is often used to designate any restricted opening through which the rate of flow has been determined by calibration. One can be made by inserting a restriction in a pipe section, or for smaller flows by using a piece of glass capillary tubing as the restriction. A typical laboratory flowmeter consists of a U-tube manometer with a capillary connected across its legs.

Venturi Meters

A Venturi meter consists of a 25° contraction to a throat, and a 7° re-expansion to the original size. This differs from the orifice meter where the changes in cross section are sudden. The great advantage of the Venturi meter over the standard orifice is that the permanent reduction in static pressure is small, because the velocity head in the throat is largely reconverted to static pressure by the gradual re-enlargement. A well designed and constructed Venturi will have a permanent static pressure loss of only 0.1 to 0.2

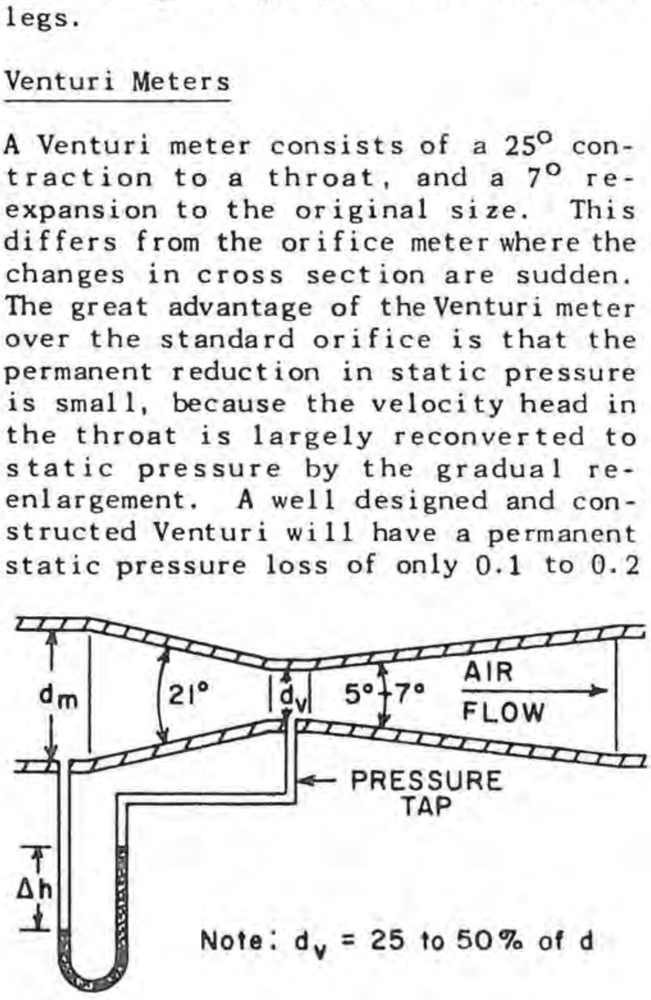


Figure 1. - Standard Venturi Meter.

of the Venturi reading as compared to 0.4 to 0.9 with a square-edged orifice. Standard references(5,7,8) discuss Venturi meters and Venturi equations. In Industrial Health Engineering(2), Brandt gives a simplified formula for flow through a Venturi which is applicable to air at 70°F. and 1 atm. when the ratio of throat diameter to duct diameter is between ¼ and ½ as follows:

$$Q = 21.2\ r^2 d^2 \quad h$$

where:
Q = flow in cfm
r = ratio of throat to duct diameter
d = duct diameter in inches
h = pressure drop in inches of water

Rotameters

A rotameter consists of a vertical transparent tube, increasing in cross-sectional area from bottom to top, in which an upward flowing fluid stream supports a float at a level determined by the flow rate. The underlying principle of operation is the same as that of an orifice or Venturi meter. The float is the restriction, but instead of a variable pressure drop and a constant area of opening, there is a constant head (the weight of the float) and a variable area.

Rotameters are available for measuring a wide range of air flow rates, from as little as 10 cc/min. of air, to as much as 350 cfm. They are used rarely to measure ventilation air flow, but find wide use in laboratory calibration and metering.

Thermal Meters

A thermal meter measures mass of air or gas flow rate with negligible pressure loss. It consists of a heating element in a duct section between two points at which the temperature of the air or gas stream is measured. The temperature difference between the two points is dependent on the mass rate of flow and the heat input.

Mixture Metering

The principle of mixture metering is similar to that of thermal metering. Instead of adding heat and measuring temperature difference, a contaminant is added and its increase in concentration is measured; or clean air is added and reduction in concentration is measured. This method is useful for metering corrosive gas streams. The measuring device may react to some physical property such as thermal conductivity, or vapor pressure.

Other Meters

Other meters include wet gas meters, dry gas meters, and spirometers which are discussed in Section B-3, Air Flow Calibrations.

Indirect Measurement of Air Flow

Air volume flowing into a standard exhaust hood can be determined fairly accurately from a measurement of throat suction. The volume of air entering a branch can be calculated from the formula:

$$Q = 1097\ C_e A \sqrt{\frac{h_s}{\rho}}$$

or for air at 70°F. and 1 atm.

$$Q = 4005\ C_e A \sqrt{h_s}$$

where: Q = air flow rate in cfm
C_e = coefficient of entry
A = area of duct in ft²
h_s = suction pressure in inches of water
ρ = density of air in lb/ft³

The suction pressure should be measured one to three pipe diameters downstream from the throat of the exhaust inlet in a straight section of duct. Coefficients of entry for standard exhaust hood types are tabulated in various references.(1,2,3) For hoods not listed, an estimate may be made by breaking down the hood into component simple shapes, and combining the coefficient of the simple shapes. This method is valid if the hood does not accumulate deposits, or become dented before the point of measurement, which would affect the magnitude of the entry loss. Very little expense is involved in making throat suction measurements. It is a very useful method for periodic inspections since it will quickly show how the exhaust rate compares with previous values. Since the only equipment required is a piece of rubber tubing and a manometer or pressure gage, determinations can be made quickly and easily even by nontechnical inspectors.

For further discussion of flow measurement by throat suction see Industrial Health Engineering(2) and Plant Process Ventilation.(3)

References

1. _____: Industrial Ventilation - A Manual of Recommended Practice. ACGIH Committee on Industrial Ventilation, P. O. Box 453, Lansing, Michigan, 8th Ed., 1964.

2. Brandt, A. D.: Industrial Health Engineering. John Wiley and Sons, New York, 1947.

3. Hemeon, W.C.L.: Plant and Process Ventilation. The Industrial Press, New York, 1955.

4. Lovelock, J. E.; and Wasilewska, E. M.: An Ionization Anemometer. J. Sc. Inst., 26:367-370 (Nov.1949).

5. Ower, E.: The Measurement of Air Flow. Chapman and Hall, London, 3rd Ed., 1949.

6. Pannell: The Measurement of Fluid Velocity and Pressure. Arnold, London, 1924.

7. Perry, J. H., Editor: Chemical Engineers' Handbook. McGraw-Hill Book Company, New York, 3rd Ed., 1950.

8. Walker, W.E.; Lewis, W. K.; McAdams, W. H.; and Gilliland, E. R.: Principles of Chemical Engineering. McGraw-Hill Book Company, New York, 3rd Ed., 1937.

9. Yaglou, C. P.: The Heated Thermometer Anemometer. J. Ind. Hyg. & Toxic., 20:497 (1938).

LOCAL EXHAUST VENTILATION

AIR FLOW CHARACTERISTICS

EQUATIONS OF FLOW INTO A HOOD

TYPES OF HOODS

HOW MUCH Q?

VELOCITY

- Capture
- Transport
- Slot

Losses, hood entry, h_e

$$\boxed{SP_h = VP + h_e}$$

$$\boxed{h_e = F \times VP}$$

Coefficient of entry, C_e

$$C_e = \frac{\text{actual flow}}{\text{theoretical flow}}$$

$$\boxed{Q = VA} \quad \boxed{V = 4005 \sqrt{VP}}$$

$$C_e = \frac{Q_a}{Q_t} = \frac{4005\ A\ \sqrt{VP}}{4005\ A\sqrt{SP_h}} = \frac{\sqrt{VP}}{\sqrt{SP_h}}$$

$$\boxed{C_e = \sqrt{\frac{VP}{SP_h}}}$$

$$\sqrt{VP} = C_e\sqrt{SP_h}$$

then

$$\boxed{Q = 4005\ A\ C_e\sqrt{SP_h}}$$

Prepared by John M. Yacher, Chemical Engineer, Division of Training, NIOSH.

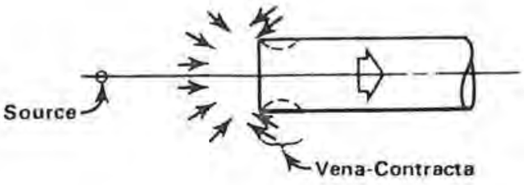
Laboratory IV - Industrial Ventilation

14. EVALUATION OF INDUSTRIAL HOODS

The effectiveness of a local exhaust system is largely dependent on the design and characteristics of the hoods used to direct the gases into the ductwork. In this laboratory session the plain, flanged, and tapered hoods will be evaluated. The capture velocity, hood entry loss and coefficient of entry will be calculated for each hood.

I PLAIN HOOD

The plain hood is the least efficient hood for directing air into the ductwork. The flow pattern is that of a spherical area about the face of the hood. (See Sketch 1)

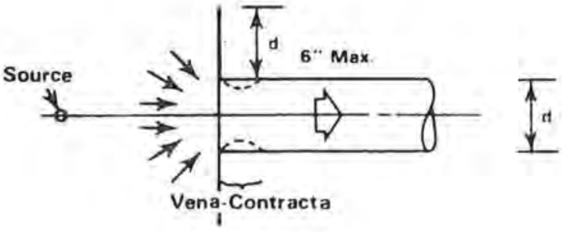


Sketch 1

The air being drawn in such a profile will result in a reduction of the capture velocity at the source, and significant hood entry losses.

II FLANGED HOOD

The flanged hood is more efficient than the plain hood simply because the flow pattern is from the front of the hood or in the direction of flow into the duct. Also since the air is being drawn from the direction of the source or problem area a higher capture velocity will be realized. (See Sketch 2)



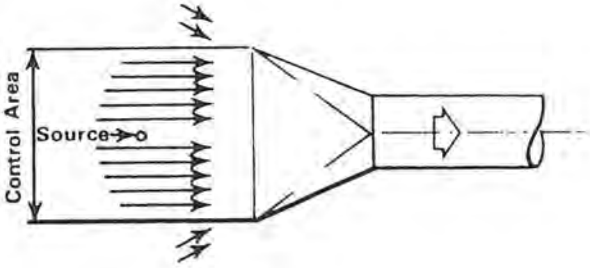
Sketch 2

The flange should extend one duct diameter beyond the wall of the duct but not exceed 6" for larger hoods.

III TAPERED HOOD

The tapered hood is the most efficient of the three hoods being evaluated.

In the tapered hood the air is directed gradually into the straight duct instead of the abrupt contraction which occurs in the plain and flanged hoods. Therefore, the vena contracta or reduction in duct effective area near the end of the duct is virtually eliminated. (See Sketch 3)



Sketch 3

The capture velocity at the source using a tapered hood is less compared to the plain and flanged hoods when the same flow rate is used for the three hoods. The advantage of the tapered hood is that the control area is larger and the hood entry losses are less.

Revised by John M. Yacher, Chemical Engineer, Division of Training, NIOSH, 02/73, 09/74-IHE(551)-02.

EVALUATION OF INDUSTRIAL HOODS DATA SHEET

			PLAIN HOOD	FLANGED HOOD	TAPERED HOOD ___° included angle
1	$VP_{\text{℄}}$ in. H_2O	Measured with std Pitot tube			
2	$\overline{VP}$ in. H_2O	Average velocity pressure $0.81 \times VP_{\text{℄}}$			
3	$\overline{V}$ fpm	Average velocity Fig. 6-16(1)			
4	Q cfm	$\overline{V} \times A_d$ $A_5 = 0.136$ sq. ft.			
5	Q_s cfm	Volumetric flow rate $4005\ A_d\ C_e \sqrt{SP_h}$			
6	SP_h in. H_2O	Measured with Magnehelic at ___ D			
7	V_{cc} fpm	$\frac{Q}{y\,(10x^2 + A_o)}$ $x < 1.5$ D $y = 1$ for flanged hood: $y = 0.75$ x in feet 1/2			
8	V_{cm} fpm	Measured at ____" with thermoanemometer			
9	h_e in. H_2O	$k \times \overline{VP}$, k from Fig. 6-10(1)			
10	h_e in. H_2O	Hood Entry Loss $h_L =$ $SP_h - \overline{VP}$			
11	C_e	$\sqrt{\frac{\overline{VP}}{SP_h}}$			
12	C_e	Coefficient of Entry Fig. 6-10(1)			

(1)INDUSTRIAL VENTILATION, A Manual of Recommended Practice, ACGIH Committee on Industrial Ventilation, Lansing, MI 48902.

A_d = cross sectional area of duct.

A_o = open area of hood face.

SP_h = hood static pressure.

V_c = capture velocity.

Laboratory IV — Industrial Ventilation

15. STANDARD PITOT TUBE METHOD FOR MEASURING AIR VELOCITY IN DUCTS

PURPOSE:

To determine the velocity of air moving inside a duct, from which the quantity of air can be calculated.

EQUIPMENT USED:

1 Pitot tube with rubber hoses attached.

2 Vertical and inclined manometers.

3 Tape measure.

4 Wax crayon.

5 Welding rod or long thin rod.

PROCEDURE:

1 Locate a hole on the duct 7 to 10 duct diameters downstream and 3 duct diameters upstream from a fan or nearest major bend (over 30°). These conditions should be approached as closely as possible.

2 Using the welding rod and tape measure, determine the duct diameter.

3 Mark off pitot tube as indicated on the attached chart. (From Industrial Ventilation Manual, 12th Edition, Pg. 9-6) See attached.

4 Set manometer up level as is determined by bubble. The vertical manometer is used for higher velocity pressures.

5 Open both ends of the manometer.

6 Adjust the movable calibrated slide so that the zero mark is at the edge of the liquid.

7 Attach pitot tube to manometer.

8 Insert pitot tube in stack.

<u>NOTE</u>: Always pinch rubber hoses until tube is in stack as the VP will force oil into the lines, thus giving erroneous readings.

9 When taking readings, the long section of the pitot tube must be perpendicular to the center of the duct, while the short section points into the air flow and is parallel to the walls of the duct.*

10 Calculate average velocity (fpm) and total volume (cfm) in the following way:

  a From the Industrial Ventilation Manual, 12th Edition, Pg. 6-33, convert the velocity pressure readings to velocity readings ($V = 4005\sqrt{VP}$ at standard air). See attached.

  b Average the velocity readings.

  c Total volume (CFM) = Average Velocity (FPM) x Area of Duct (Ft^2). See Pg. 6-35 Area and Circumference of Circles from Ventilation Manual, 12th Edition. See attached.

---

*Take a reading at each mark on pitot tube (if a stack sampler is to be located at this point on the duct, a centerline reading must also be taken). Again pinch the hoses when removing pitot tube from duct.

Prepared by Edward D. Leininger, Industrial Hygienist, Division of Training, NIOSH, 6/72.

Plant________________ Dept.________________ Date________

Operation exhausted______________________________ By________

Line sketch showing points of measurement

Date system installed________

Hood and transport velocity

Point	Duct		VP	SP	FPM	CFM	Remarks
	D	Area (Fig. 6-18)	in. H_2O	in. H_2O	(Fig. 6-16)	Q = VA	

Pitot traverse

Pitot readings - See Fig. 6-16 & Tables 9-1, 9-2, 9-3

Points	VP	Vel.	VP	Vel.	VP	Vel.
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
Total Vel.						
Average Vel.						
CFM						

Fan

Type________

Size________

Point	Dia.	SP	VP	TP	CFM
Inlet					
Outlet					

Fan SP________ (See Section 6)

Motor

Name________ Size________

HP______ E______ I______ W______

Collector

Type & size________

Point	Dia.	SP	ΔSP
Inlet			
Outlet			

Notes________________________

Fig. 9-17

PITOT TRAVERSE
10 POINT

VERTICAL

VP	VEL
ΣV	
$\bar{X}V$	

HORIZONTAL

VP	VEL
ΣH	
$\bar{X}H$	

add $\bar{X}V + \bar{X}H$ = ________ average duct velocity

multiply average duct velocity by duct area =

________ cfm

Laboratory IV — Industrial Ventilation

16. COMFORT VENTILATION SYSTEM MEASUREMENTS

OBJECT

To become familiar with the technique used to measure the flow through grilles, registers and diffusers.

THEORY

The airflow in cubic feet per minute across the face of a grille or register is determined by measuring the air velocity through the open area of the grille and using this velocity in the equation:

$$Q = VA$$

Q = cubic feet per minute

V = velocity in feet per minute

A = area of the grille in square ft.

The airflow through a circular diffuser may be determined by measuring the air velocity at the specific locations given by the manufacturer and using the equation given above with "a free area" factor given by the manufacturer.

EQUIPMENT

Alnor Velometer, with attachments

Dwyer Air Meter, with attachments

Alnor Jr. Velometer

Rotating Vane Anemometer

Stopwatch

PROCEDURE FOR GRILLES AND REGISTERS

1 Measure the grille and calculate the free (open) area of the grille.

2 Divide the grille into several small equal areas.

3 Measure the average air velocity in each of the smaller areas.

4 Average the air velocity for all of the smaller areas of equal size.

5 Calculate the total air volume as indicated under the paragraph on the theory of airflow measurement.

ALTERNATE PROCEDURE

In the case of diffusers, it is impossible to calculate the gree area of the unit. Therefore, the manufacturer has determined an "equivalent free area" for each of his diffusers so that the preceding equation can be used.

For example, the diffuser used in this laboratory exercise has a throat diameter of eight inches or an open area of 50.5 square inches (pi x R^2), but the "equivalent free area" given by the manufacturer is 39.8 square inches due to the air resistance of the diffusing vanes.

The manufacturer has also given the free area of the other units used in this exercise so that Step One of the procedure is not necessary.

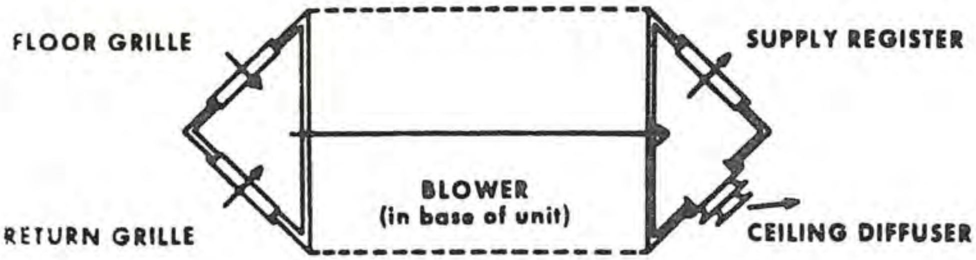
MEASUREMENTS LABORATORY

The laboratory set-up consists of a box containing two air return grilles, one air supply grille, and one air-supplying ceiling diffuser. The set-up is made as shown in the schematic diagram below.

Using the equipment provided, estimate the total volume being handled by each of the four units. Compare the total volume entering the set-up with the total volume leaving it, i.e., sum of two supply volumes compared to sum of the two return volumes.

If time permits, compare three types of air flow measuring instruments in regard to accuracy, ease of use, sensitivity, and results obtained. Note the limitation on each type of instrument.

Prepared by John M. Blankenhorn, Industrial Hygienist; Revised by Daniel S. Watkins, Physical Science Technician, Division of Training, NIOSH, 3/73.



	Free Area		Velocity	Volume
Unit	sq. in.	sq. ft.	fpm	cfm
Ceiling Diffuser				
Supply Register				
Return Grille				
Floor Grille				

Velocity Through Grille			
A	B	C	D

17. SLOT HOOD MEASUREMENTS

Slot hoods are used to control the work area where a high generation rate of contaminants is present. The slot hood provides a resistance to air at the hood face causing the flow pattern to distribute itself throughout the hood inlet area. The result will be a larger control area in a plane normal to the direction of air flow as shown in the sketch.

Slot hoods should not be located near strong wind currents since the cross-draft producing the control area is very sensitive to velocities higher than normal plant air movement.

The critical capture velocity should be measured at the furthest edge of the gank from the hood face.

To insure good control throughout the tank opening a velocity contour should be performed on the plan view. Make measurements at the edge of all the exposed sides of the tank and at the slot opening.

The slot velocity should be approximately 2,000 fet per minute. A slot velocity of 2,000 feet per minute is considered to be standard although this value may vary depending on the particular hood design.

The velocity at the furthest edge from the hood face should be from 50 to 100 feet per minute depending on the plant air disturbance near the tank.

This laboratory exercise will be conducted as follows:

1 Turn fan on.

2 Adjust the hood slot opening until a velocity of 2,000 feet per minute is realized. (Location 4)

3 Measure the slot width and length.

4 Read the velocity at location (1) - (4) (Take readings at 3" increments).

5 Determine the distance above the tank edge at location (2) where the velocity is 1/2 of the velocity 1/2" above the edge.

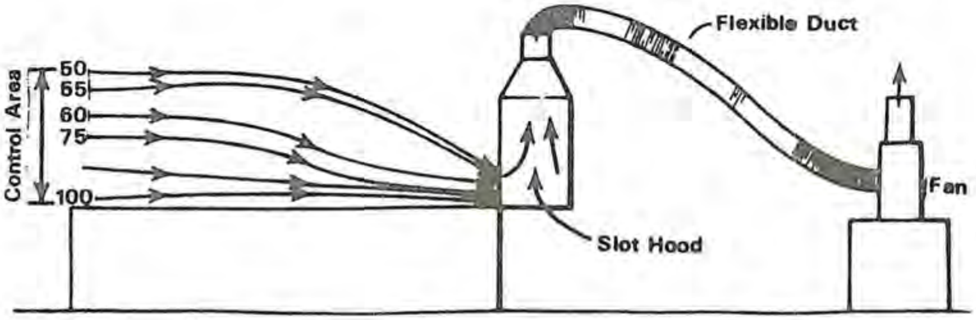
6 Develop a flow contour similar to the sketch.

7 Tabulate data — see Data Sheet.

8 Record data for slot velocity at 2,000 FPM and 1,000 FPM slot velocity.

9 a) At 2000 FPM, measure hood static pressure (SP_h) and hood flow (Q) and calculate hood loss (h_e).

b) Using Q from a), calculate hood static pressure (SP_h) using physical hood measurements and data from <u>Industrial Ventilation</u> Manual.



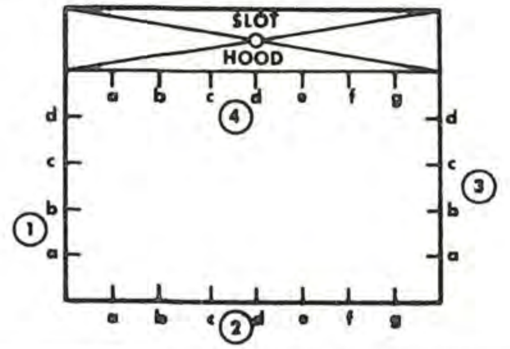
Revised by Robert T. Hughes, Mechanical Engineer, Division of Laboratories and Criteria Development, NIOSH, 01/73, 09/74-IHE(551)(550)-02.

SLOT HOOD MEASUREMENTS DATA SHEET

A.	1	2	3	4
	Velocity along sides 1,2,3 at 3" intervals	Average Velocity (fpm) at Sides	Side 4 (slot)	Average Slot Velocity, V_{slot}
	1. a 170 b 183 c 215 d 475 Σ_1 = 1043	$\frac{\Sigma_1}{4} = \frac{1043}{4}$ $\bar{x}_1$ = 261	4. a b c d e f g $\Sigma 4$ = 13830	$\frac{\Sigma_4}{7} = \frac{12274}{7}$ $\bar{x}_4$ = 1984
	2. a 74 b 108 c 110 d 97 e 100 f 90 g Σ_2 = 689	$\frac{\Sigma_2}{7} = \frac{689}{7}$ $\bar{x}_2$ = 98	5	6
			Slot Area LxW=A slot .19 ft²	Average Total Flow Q=V A
	3. a 150 b 165 c 180 d 335 Σ_3 = 850	$\frac{\Sigma_3}{4} = \frac{832}{4}$ $\bar{x}_3$ = 208	$(L_{ft})(W_{ft})=A_{ft}^2$ 2.43 sq ft tank area	$Q = (V_{slot})(A_{slot})$ 0.19 X 1984 ≈ 377 ft³

B. Velocity$_{\text{(fpm ave.)}}$

1. Recommended 100
2. Measured -- __________



C. $\frac{377}{2.4}$ Flow per ft²
155 open tank

1. Recommended 125 cfm/ft²
   (Ind. Vent. Man. Fig VS 502
   12 cd. A.C.G.I.H.)
2. Measured

$$\frac{Q}{\text{Side } 1_{ft.} \times \text{Side } 2_{ft.}}$$

__________ =

155 cfm/ft²

PROBLEM SET: GENERAL PRINCIPLES OF VENTILATION

1 The VP in a duct is 0.9 inches of water. What is the velocity?

2 A fan is exhausting air from a duct. The TP is -0.60 inches of water and the SP is -1.40 inches of water. What is the VP?

3 A fan is exhausting air from a duct. The TP is -0.60 inches of water and the SP is -1.24 inches of water. What is the velocity in the duct?

4 A local exhaust system in which wood dust is being exhausted requires an air flow of 600 cfm. If the minimum transport velocity is 3500 fpm, what would be the best available duct size to use in the system?

5 Given the following information, draw in the correct fluid level on the manometers on the enclosed drawings and indicate the direction of the air flow by placing an arrowhead on the flow line.

Pressure Measurements on Discharge Side of Fan

Total Pressure = 6" W.G.
Static Pressure = 4" W.G.

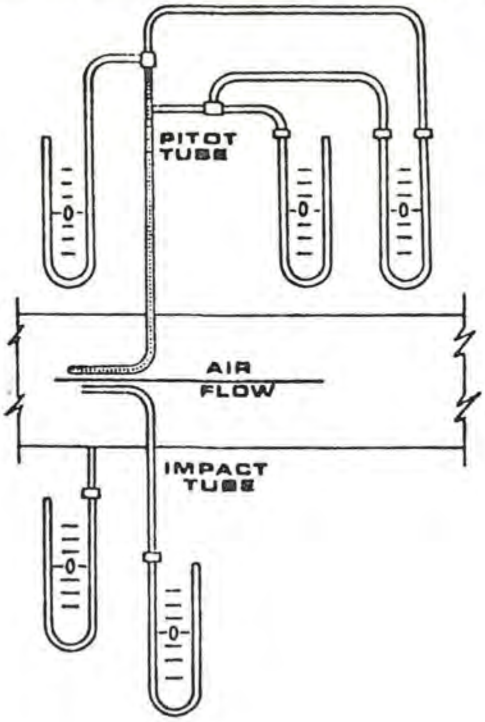
Pressure Measurements on Suction Side of Fan

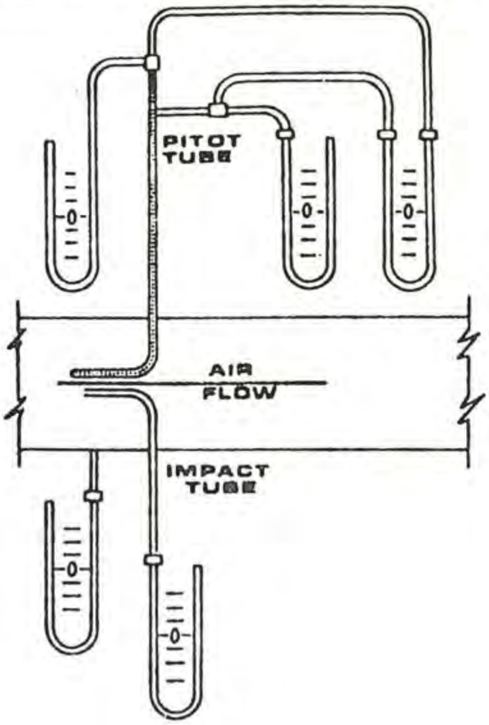
Static Pressure = -8" W.G.
Velocity Pressure = 3" W.G.

6 Using the following data, calculate Q at standard conditions:

Air Temp. = 150°F
Wet Bulb Temp. = 80°F
Barometer = Std.
Duct = 24" D.
V_s = 2370 fpm

Prepared by Robert B. Weidner, J.D., P.E., Division of Training, NIOSH, 10/73.


PITOT TUBE
-0-
-0-
-0-
AIR FLOW
IMPACT TUBE
-0-
-0-


PITOT TUBE
-0-
-0-
-0-
AIR FLOW
IMPACT TUBE
-0-
-0-

5

HEAT STRESS - EFFECTS ON MAN

I INTRODUCTION

II OBJECTIVES

- A Biologic Effects
- B Metabolic and Environmental Measurements
- C Methods of Control

III BACKGROUND

- A Cornish Tin Miners
- B Military Services in World War II

IV SOURCES OF HEAT

- A Metabolic
- B Environmental

V METHODS OF HEAT EXCHANGE

- A Conduction
- B Convection
- C Radiation

VI Thermoregulation in Man

- A Vasodilation
- B Sweating

VII HEAT LOAD ON MAN

- A Metabolism
- B Conduction - Convection
- C Radiation
- D Evaporation

VIII EFFECTS OF HEAT ON MAN

- A Learning
- B Fatigue
- C Emotions
- D Accidents

IX CLINICAL DISORDERS

- A Heat Stroke
- B Heat Exhaustion
- C Heat Cramps
- D Heat Syncope
- E Heat Rash

X RECOMMENDED WORK PRACTICES IN HOT ENVIRONMENTS

- A Acclimatization
- B Work and Rest Regimen
- C Distribution of Work Load
- D Scheduling Hot Jobs for Coolest Part of Day
- E Regular Breaks
- F Physical Examinations
- G Drinking Water
- H Salt Replacement

Prepared by A. F. Schaplowsky, Public Health Advisor, Division of Training/NIOSH, 3/74.

HEAT STRESS - ENVIRONMENTAL MEASUREMENTS

I INTRODUCTION

II FACTORS IN HEAT STRESS CONTROL

A Temperature

B Air Motion

C Humidity

D Radiant Heat Sources

III INSTRUMENTATION FOR ENVIRONMENTAL MEASUREMENTS

A Dry Bulk Thermometers

B Natural Wet Bulb Thermometers

C Psychrometers

D Globe Thermometers

E Thermal Anemometers

IV INDICES OF HEAT STRESS

A Effective Temperature

B Corrected Effective Temperature

C Wet Bulb Globe Temperature

D Other Indices

1 Heat Stress Index (Belding-Hatch)

2 Predicted 4-Hour Sweat Rate

V CALCULATING INDICES

A Psychrometric Chart

B Effective Temperature Nomogram

C Time Weighted Average WBGT

VI RADIANT HEAT CONTROL

A Surface Temperature

B Shielding

C Maintenance

VII HEAT REMOVAL

A Substitution

B Isolation

C Dilution

D General Area Cooling

VIII PERSONAL PROTECTION

A Conventional Work Clothing

B Special Clothing

C Aluminized Reflecting Clothing

D Thermally Conditioned Clothing

Prepared by A. F. Schaplowsky, Public Health Advisor, Division of Training/NIOSH, 3/74.

PHYSIOLOGY OF HEAT

I BODY TEMPERATURE

Fluctuations in body temperature beyond a rather narrow range can result in serious alterations in health, functional efficiency, and performance capacity. A resting body temperature of about 37°C is accepted as "normal" but individual variation may be as much as 1°C above or below this value. Each individual also has a variation in body temperature of ± 0.5°C with the highest values in early afternoon and the lowest values in the early morning hours.

When physical work is performed the body temperature will be higher than at rest. However, whenever the body temperature exceeds 38°C the cause for the increased temperature should be sought. Body temperatures above 39°C are not acceptable for long periods and may be associated with serious health consequences. Acute heat disorders can be expected when the body temperature exceeds 39°C and temperatures above 41°C are intolerable.

Just as the body must not be permitted to overheat, it also must not be cooled. At body temperatures below 34°C normal functioning starts to deteriorate. One hundred percent survival is limited to a range of body temperature 33°C to 39°C.

II SOURCES OF HEAT

The heat which keeps the body warm (or may cause overheating) comes from the environment and from the biochemical reactions of life. The environmental heat sources are the industrial processes and the climatic heat. The metabolic heat includes the heat produced in the body while at rest (75-100 kgCal/hr) and the extra heat resulting from physical work which may add as much as 300-400 kgCal/hr additional heat.

III HEAT EXCHANGE

Heat is exchanged between the body and the environment by the usual heat transfer processes of convection, conduction and radiation. In addition, the evaporation of sweat from the skin surface is a uniquely and effective human procedure for increasing heat loss. The thermodynamics of heat exchange will be covered more fully by others.

IV PHYSIOLOGICAL ADJUSTMENT TO HEAT

The physiological mechanisms which are used to regulate the rate of heat exchange between the environment and the skin are (1) increasing or decreasing the amount of blood flow in the skin and (2)wetting the skin surface with sweat. Control of blood flow through the skin is the usual way we regulate body temperature under temperate conditions. The blood flow through the skin may be varied by a factor of 10. However, when the environmental heat load or metabolic heat production exceeds the amount of heat that can be exchanged with the environment by convection and radiation, sweating starts and evaporative cooling of the skin increases the rate of heat loss. Sweat rates of 1 liter per hour are not unusual in hot industries. Evaporation of 1 liter of sweat from the skin will result in the loss of about 500-600 kgCal of body heat.

V FAILURES OF PHYSIOLOGICAL ADJUSTMENTS

Under some levels of heat stress and/or other circumstances the physiological adjustment mechanisms may fail or be inadequate to maintain normal thermal balance or physiological functions. The three major heat illnesses are (1) heat exhaustion, (2) heat cramps and (3) heat stroke. Heat exhaustion is manifest as a circulatory collapse from insufficient blood flow to the brain and internal organs because most of the blood is being sent to the skin, or from a reduction in blood volume due to loss of water from the blood in heavy sweating without adequate water replacement. Body

---

Prepared by Austin F. Henschel, Ph. D.

temperatures is normal and the skin is cool and wet. Dizziness, weakness and nausea are major symptoms. Rest in a cool environment and water replacement will bring about full recovery.

Heat cramps result from loss of salt in the sweat without adequate replacement by an increased salt intake. Heat cramps involve mainly the hands, arms, abdominal muscles and legs. Heat cramps are not very common and occur mostly when sweating is excessive, water replacement is adequate but the salt intake is low. Salt added to the drinking water or to the food is an effective treatment and prevention.

Heat stroke results from the high temperature that follows a failure of the heat regulatory mechanisms. High body temperatures of 41-42°C or above may be fatal if the high temperatures persist for more than a short time. Usually collapse and coma with high body temperature are the first recognized symptoms. Treatment consists of rapid reduction of the body temperature to below 40°C by cold water bath, alcohol bath or fans and wet sheets. Age, obesity, lack of physical fitness and hard physical work are factors that increase the chances of heat stroke.

VI ACCLIMATIZATION

Heat acclimatization consists of a series of physiological adjustments in response to exposure to heat which permit the individual to work in the heat with no greater physiological strain than if comparable work were performed in a temperate environment. During the first day of work in the heat the pulse rates and body temperature may be very high and reach limiting values of 180 beats per minute or 39°C. If exposure to the heat is continued, on each succeeding day the work pulse rate and body temperature is maintained at progressively lower levels until at the end of about two weeks the acclimatization process is about complete. The acclimatization will be 75% complete in 5-7 days. When no longer exposed to heat, acclimatization is rapidly lost, so that after two weeks little effective acclimatization remains. The magnitude of the physiological benefits derived from acclimatization will depend on many factors including the total heat load and the adaptive capacities of the individual. In a moderately severe work-in-heat situation after acclimatization the pulse rate will be about 40 beats per minute and the body temperature about 1°C lower than before acclimatization.

VII ENVIRONMENT DEPENDENT AND INDEPENDENT CONDITIONS

Under a rather wide range of environmental conditions the body temperature is not influenced by the environmental heat load but is dependent mainly on the level of physical work. Within this environment independent range the body temperature will be 0.5 to 1°C higher during hard physical than during light physical work. However, for each level of physical work a point will be reached where as the environmental heat load increases the body temperature starts to be higher and thereafter is dependent on any further increase in heat load. The beginning of the environment dependent zone is about 5°C lower for hard physical work than for light work. Reduction in the level of physical work can therefore be a very effective procedure for reducing the heat stress and for keeping the individual in the environment independent range. Once the environment dependent zone is reached any increase in environmental heat stress will result in rapidly progressively higher body temperatures. The relationship of body temperature and heat load is exponential in the environment dependent range.

VIII EFFECTS OF DEHYDRATION

The water lost from the body as sweat must be replaced by fluid ingestion if dehydration is to be prevented. Water balance must be achieved every day because dehydration rapidly leads to deterioration of performance and heat illnesses. Sweat productions of 8 to 10 liters a day are common in hot industries. Consequently, the large amounts of water lost in the sweat must be replaced on at least an hourly basis. A better practice is to drink 100-200 cc of water every 15-20 minutes when sweating is profuse. The water should be neither too warm or too cold

--about 50-60°F is preferable. Withholding water during heavy sweating may result in an increase in body temperature of about 1°C in 1-1/2 hours. Pulse rates and body temperatures start to increase when a body water deficit of 1 to 1-1/2 liters has occurred as can happen in one hour. Most of the physiological benefits of acclimatization will be lost when a body water deficit of 3 liters is reached. Pulse rates during a high heat load may be as much as 50 beats per minute higher when water is withheld for only four hours.

IX INDIVIDUAL DIFFERENCES IN HEAT TOLERANCE

Heat tolerance varies greatly between individuals whether acclimatized to heat or not. Under identical combinations of work and heat, within a group of exposed individual body temperatures may vary by 1-1/2°C and work pulse rates by 50-60 beats per minute. While for some individuals the situation may be beyond tolerance for others it may pose no serious threat. Some information on the heat tolerance of each worker can be an important health and safety factor for assignment of workers to hot jobs.

X EFFECTS OF PHYSICAL FITNESS ON HEAT TOLERANCE

The total strain on an individual working in the heat is a combination of the physical work and the environmental heat. For any level of physical work the strain will depend on the fitness of the individual to do the work. The strain will be much greater for an unfit individual than for one who is in good physical condition. For any given combination of work and heat, the work level part of the total stress will be less for the physically fit than for the person in poor physical condition. If hard work must be performed in the heat, physically fit individuals or a physical conditioning program can be a useful approach to reduce the total stress.

XI HEAT STRESS AND HEAT STRAIN

The terms heat stress and heat strain are not always used in a way to convey the same concept. This has frequently lead to misunderstandings and poor communications. It has recently been agreed by heat physiologists that heat stress is the total of the metabolic and environmental heat imposed on the individual. Heat strain is the sum of the biochemical, physiological and psychological adjustments made by the individual in response to the stress. The most readily recognized and easily measured heat strain responses are pulse rate, body temperature and sweat production. Significant changes in blood volume, total body water, kidney and liver function, electrolyte concentration in the body fluids, hormone production, blood pressure, work capacity, and behavior may also reflect the level of heat stress.

XII EFFECTS OF AGE ON HEAT TOLERANCE

Physical work capacity decreases with age so that any job which requires physical work will be harder for the older worker. It would then be expected that any combination of work and heat would be a greater stress for the older than the younger worker. Low or medium levels of heat-work stress can be tolerated by the older workers if they are otherwise healthy. However, because the older worker has a low reserve capacity, high levels of work-heat stress will be poorly tolerated. Illnesses and diseases will reduce heat tolerance in all age groups. Age per se does not drastically alter the ability to acclimatize to heat unless the heat stress is extreme. In general, however, the older worker may be at some disadvantage in hot jobs.

XIII EFFECTS OF AGE ON ACCIDENTS IN HOT JOBS

For low or medium levels of heat stress age does not appear to influence accident rates. But industrial accidents for all age groups are higher when the heat stress is high. At the high heat stress jobs there are more accidents among the older than the younger (but experienced) workers.

XIV MALE-FEMALE DIFFERENCES IN HEAT TOLERANCE

The amount of strain that results from heat stress will be greater for the female than for the male because as in age and heat tolerance, the physical work capacity of women is lower than for men. Men start to sweat at lower skin temperatures than women and for equal levels of heat stress men tend to maintain a slightly lower body temperature. Even though there may be differences in responses to a heat stress, women acclimatize to heat and can effectively function in the heat. However, if the physical work component of the heat stress is large, the female would experience greater strain than the male.

XV BENEFITS FROM WORK-REST CYCLE

Reducing the physical work component of a hot job will lower the metabolic heat production and thereby, the total heat stress and the resulting strain. It is also possible to reduce the strain of a stress by the introduction of rest pauses or by changing the length of each work and rest cycle. Short work-rest cycles are more effective in reducing strain than long work-rest periods even though the total work time and the rest time are constant. An ergonomics challenge to management is to devise a work-rest regimen for hot jobs which will permit maximum work time while limiting physiological strain to acceptable levels.

XVI HEAT AND TOLERANCE TO TOXIC CHEMICALS

The toxicity of a substance appears to vary with the environmental temperature at the time of exposure. The lowest level of toxicity is 20-25°C with toxicity increasing at lower and higher temperatures. Some substance at exposure concentrations which at 20°C will be 10% lethal may at 40°C cause 100% fatalities in animals. This phenomenon of temperature-toxicity interaction has not been studied extensively in man but for animals the effect is present for most substances. The question is raised whether heat stress levels must not be considered when acceptable exposure concentrations are established.

XVII PERMISSIBLE WORK IN HEAT LIMITS

The 1973 ACGIH Threshold Limit Values for Physical Agents includes a notice of intent to establish a TLV Heat Stress. This TLV sets levels on heat exposure for different levels of physical work to which workers can be exposed with reasonable assurance that the level of resultant strain will not constitute a health or safety hazard. A work practices standard is being written by a committee for the Department of Labor. It is assumed that the heat stress limits set forth in the standard will be in agreement with the TLV.

HEAT STRESS

Introduction

Some of the problems that confront man when he is exposed to a hot environment and some of the physiological mechanisms he can bring to bear in meeting the problems will be discussed in this Section.

There are two sources of heat which are important to man working or living in a warm or hot environment. These are:

(1) The internally generated metabolic heat, and
(2) The externally imposed environmental heat.

Metabolic heat is a byproduct of the chemical processes occurring within the cells, tissues, and organs. Under resting conditions the metabolic heat production of an adult is about 75 KCal per hour (300 BTU). Muscular activity is the major source of increased heat production. During very hard physical work heat production may reach 600-750 KgCal per hour (2400-3000 BTU). Thus under conditions of physical work large quantities of heat must be removed from the body if an increase in body temperature is to be prevented. Environmental heat is important because it influences the rate at which body heat can be exchanged with the environment and consequently the ease with which the body can regulate and maintain a normal temperature.

An internal body temperature of 99°F (98.6°F mouth temperature) is usually considered to be "normal". However, body temperature varies from time to time during the day and with changes in physical activity. Consequently body temperatures of 97 to 102°F are frequently and normally obtained. Body temperature over 102°F in otherwise healthy individuals must be viewed with some concern and a temperature over 105°F is critically serious. Consequently, the regulation of body temperature is an important physiological function and the ease with which it can be successfully accomplished is determined by the individuals' ambient environment -- by the air temperature, the humidity of the air, air movement, long wave radiation and solar radiation.

Prepared by: Austin F. Henschel, Ph.D.

Heat Exchange

The metabolic heat produced by the body is exchanged with the ambient environment by the processes of convection (and conduction), radiation and evaporation. If the contact substance, whether it be air, water, clothing, or an external object, is at a lower temperature than the skin, heat will be lost; but if the contacting substance is at a higher temperature, heat will be gained. The rate at which transfer takes place is determined basically by the difference between the two temperatures, but if the contacting substance is fluid, like air or water, movement in the fluid accelerates the transfer. This additional transfer process is termed convection.

Heat Transfer by Conduction-Convection

Nearly all transfer of "sensible" heat between skin and air is by the combined process of conduction-convection, in which convection plays by far the greater part. Heat transfer by conduction-convection from the skin to air may be expressed quantitatively by the equation:

$$(1) \qquad H_c = \frac{K_c\,(t_s - t_a)}{I_a + I_c} \qquad \text{where:}$$

H_c is the rate of heat loss per unit area of exposed surface
K_c is a constant whose value depends upon the units used
t_s is the temperature of the skin surface
t_a is the temperature of the ambient air
I_a is the resistivity of the ambient air to the outward passage of heat
I_c is the resistivity of the clothing to the outward passage of heat.

To this exchange between the skin and the air must be added heat exchanged between the respiratory tract and the inspired air, since the former behaves in this respect simply as an inward extension of the body surface, with a special mechanism--respiration--moving the air away when it is heated.

Heat Loss by Evaporation - Convection

Heat may be lost also from the surface of the body to the air by evaporation of water diffusing through the skin from deeper tissues (perspiration), produced by sweat glands (sweating), or applied from without. The rate of evaporative heat loss is determined basically by the difference between the effective vapor pressure of the water on the skin and that of the air, but once again movement of the air greatly accelerates the rate of loss, so that the combined process is properly termed evaporation-convection.

The vapor pressure of such water as is present on the skin is determined by the temperature of the skin, but the extent of the water film varies between something less than 10 percent and 95 percent of the maximum. The effective vapor pressure of water on the skin is thus a function of these two factors. The extent of the water film is variously termed "skin wetness" or "skin relative humidity". It represents a balance between evaporation on the one hand and addition of water on the other. It is high only when the sweat glands are active, evaporation is inhibited, or water is applied from without.

Humidity. The vapor pressure of the air is determined by the amount of water vapor present in (unit volume of) the air and corresponds closely to the absolute humidity of the air. Unfortunately, atmospheric humidity is usually expressed in terms of relative humidity, which is something quite different, namely, the ratio between the amount of water vapor actually in the air and the amount the air could hold at that temperature. To determine the vapor pressure from the relative humidity one also needs to know the air temperature and to have tables or a graph by which to make the transformation. A great deal of misunderstanding and confusion has arisen from the use of these two measures of atmospheric humidity, between which the relationships are far from obvious. A vapor pressure of 15 mmHg corresponds to 100% relative humidity at 63°F, 50% at 84°F, and 30% at 100°F, since the holding capacity of the air increases with temperature while the amount of water vapor remains the same. Another measure of humidity sometimes used, the dew point, is the temperature at which air, on being cooled, becomes saturated and moisture begins to be deposited from it. Dew point is closely related to vapor pressure and to absolute humidity. The various combinations of dry-bulb temperature and relative humidity just cited as having the same vapor pressure (15 mmHg) also have the same dew point (63°F).

A generalized equation for heat loss by evaporation from the skin to air is:

$$(2)\quad H_e = \frac{K_e\,(P_s - P_a)}{r_a + r_c}\,w \qquad \text{where:}$$

H_e is the rate of heat loss per unit area of exposed surface

K_e is a constant whose value depends upon the units used

P_s is the saturation vapor pressure at skin temperature

P_a is the vapor pressure of the ambient air

r_a is the resistivity of the ambient air to the outward passage of water vapor

r_c is the resistivity of the clothing to the outward passage of water vapor

w is the proportional wetness of the skin.

To this loss must be added that from the respiratory tract into the inspired air.

Heat Exchange by Radiation

Heat will be exchanged by radiation between the surface of the body and all of the surfaces in its surroundings which are at temperatures different from its own. (The term "surface" is easily understood for solid objects, but for such things as the sky it must be regarded as that hypothetical surface which would exhibit the same radiative behavior as the sky is observed to exhibit). The details of radiative exchange can become very complex, but the following simplified explanation will illustrate the principles involved.

The intensity of the energy emitted from a surface by radiation increases as the fourth power of its absolute temperature. The intensity is usually diminished below the theoretical maximum, however, by the physical nature of the surface, the relative effect being known as its emissivity. The wavelengths of the emitted radiation are usually distributed over a range, with a model length which decreases as temperature increases.

Radiation incident upon a surface is absorbed by it in proportion to its emissivity for the wavelength involved. The absorptivity for a particular wavelength is the same as the emissivity for that wavelength. From an opaque surface, the incident radiation which is not absorbed must be reflected, so that its reflectivity is the converse of its absorptivity and thus of its emissivity -- for the particular wavelength involved.

A substance whose surface emits at maximum intensity for its temperature is termed a "black body." (This is an unfortunate term, since it inevitably suggests a visual observation which relates to reflectivity rather than to emissivity, and then only in the portion of the spectrum to which the eye is sensitive). In general, most conventional surfaces other than highly polished metals are classified as "black bodies" in the long infrared; but many of them are obviously far from black bodies in the visible range. Thus, the apparently paradoxical statement can be made that a white shirt may be a black body (in the long infrared).

The surface of the human body and its clothing emit only in the long infrared range; and in this range virtually all such surfaces act as black bodies. Emission from surrounding surfaces, however, is far more complex. Many conventional surfaces at normal temperatures are emitting long infrared radiation as essentially black bodies; but some, at the same temperature, may be emitting less intensely (for example, polished metal surfaces). Some surfaces at higher temperatures may be emitting short infrared radiation, and others at still higher temperatures visible or even ultraviolet radiation. The exchange between the body and surrounding infrared emitters is fairly simple, being complicated only by the geometrical relationships of the opposing surfaces, which often can be approximated by a single sphere at a uniform temperature. For such a situation the appropriate equation for radiant energy exchange is:

$$(3)\quad H_r = K_r\,(T_W^4 - T_S^4) \qquad \text{where:}$$

H_r is the rate of exchange per unit area of exposed surface
K_r is a constant whose value depends upon the units used
T_W is the absolute temperature of the surrounding sphere
T_S is the absolute temperature of the skin.

Net Heat Exchange

The net heat exchange between the man and his ambient environment can be expressed by:

$$(4)\quad H = M \pm C \pm R_1 + R_S - E \qquad \text{where:}$$

H = net heat gain or loss by the body
M = metabolic heat production
C = heat exchange by conduction-convection

R_1 = heat exchange by long wave radiation
R_s = solar heat gain
E = heat loss by evaporation.

If the body temperature is to be maintained at an acceptable normal level then H must equal zero. Small fluctuations in total body heat are, of course, permissible. They normally occur as a result of rapid changes in metabolic heat production or in the rate of heat exchange with the ambient environment. Metabolic heat production may increase by a factor of 10 within seconds as one goes from a state of rest to maximum physical effort (from 75 to 750 KgCal per hour or 300 to 3000 BTU). Metabolic heat production can be calculated since about 5 Kg Calories are liberated for each liter of oxygen used by the body cells.

The heat exchanged by convection-conduction can be calculated from equation (1). The rate of exchange depends on skin temperature, air temperature and insulation value of the clothing and air surrounding the skin. The insulation value of the air-clothing system will vary with the rate of air movement. For practical purposes these relationships have been derived in simplified form and put in graphic form for conditions of a constant nude skin temperature of 95°F (see Figure 1).

Evaporative heat loss from the clothed man as indicated in equation (3) can be a rather complex phenomenon. However, evaporation of sweat from the skin surface is a very effective means of losing body heat. Each liter of sweat requires 580 Kg Calories to evaporate it. The major factors that influence rate of heat loss by evaporation are the vapor pressure of the ambient air, the saturation vapor pressure of the skin, air movement and the resistance of the clothing to vapor movement. The simplified relationships for conditions of a nude wet skin at 95°F have been derived in graphic form and are presented in Figure 2.

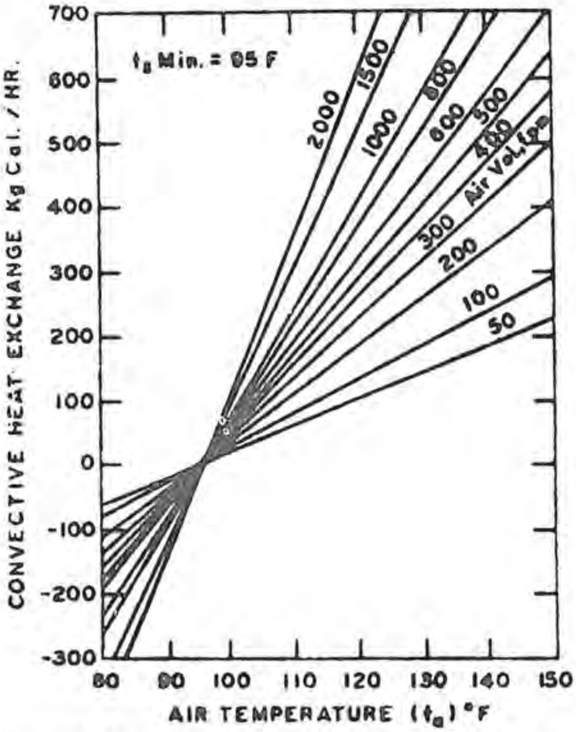


Figure 1. - Heat exchange by convection between man (skin temperature 95°F) and surrounding air.

To calculate radiant exchange from equation (3) requires more complex mathematical manipulation than may appear from the form of the equation. This is due primarily to the complexity of shapes of most surrounding objects. If the surrounding is assumed to be a sphere, the mean temperature of which can be measured, the rate of heat exchange with the nude individual with a skin temperature of 95°F can be obtained readily from a graphic representation of the relationships as shown in Figure 3.

The equation $H = M \pm C \pm R_1 + R_s - E$ can be solved using Figures 1, 2 and 3 provided the data on metabolic rate, air temperature, radiant temperature, vapor pressure and air movement are available. These data can be obtained at the work-site in an industrial environment, in a field situation, and in a controlled laboratory set-up. In Figures 1, 2 and 3 certain basic assumptions were made in order to simplify the presentation. Interindividual differences in sweating, (vapor pressure, at skin temperature) blood flow to the skin, muscular efficiency, body volume-surface ratio and others make it hazardous to apply data derived from these figures to specific situations.

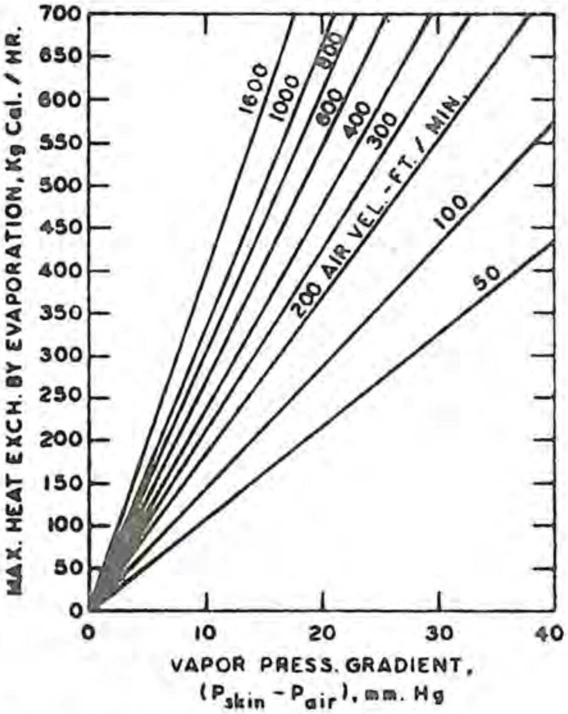


Figure 2. - Maximum evaporative capacity as related to air velocity and vapor pressure gradient.

Responses to Heat

Since radiant energy exchange, air temperature, humidity, and air movement all affect, in quantitative fashion, the same physical process -- heat balance of the body -- their operations are largely interchangeable. An alteration in one can be duplicated or compensated by an appropriate change in another. The effect of a rise in radiant heat gain can be duplicated by that of a rise in air temperature; a rise in humidity may be offset by an increase in air movement; and so on.

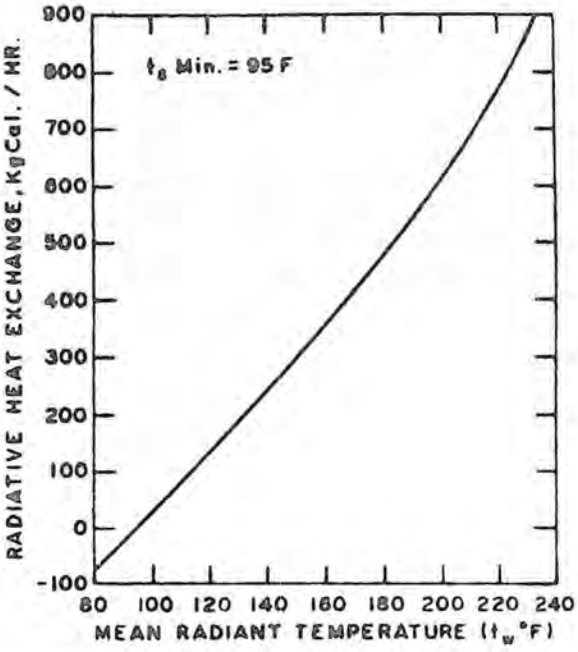


Figure 3. - Heat exchange by long wave radiation.

Certain schemes for assessing the net effect of all four thermal factors will be mentioned in Section B-29; it will suffice at this stage to point out some of the major inter-relationships. At temperatures below 70°F sweating is not called into play, the skin is comparatively dry, and changes in humidity are of little consequence. As temperature rises, sweating is called more and more into play, and humidity becomes of increasing importance. As long as air temperature is lower than skin temperature, all movement will facilitate heat loss by both conduction and evaporation, but when air temperature exceeds skin temperature a mixed situation is created. Air movement will still increase heat loss by evaporation, but it will now also increase heat gain by conduction-convection. The higher the air temperature, the more important the latter will become, until it may actually override the increase in evaporative cooling. For each set of conditions in which air temperature exceeds skin temperature, there will be an optimal air movement.

Lower rates of air movement will result in sweat accumulation, higher rates will result in additional heating and place a bigger burden on compensatory sweating.

To the extent that the body has to take action to step up heat loss in the face of an environmental heat load, a burden is placed upon the body. This burden is represented primarily by the physiological reactions designed to promote heat loss, but these reactions in turn may provoke other changes which add to the total physiological disturbance. The ultimate consequences of this chain of events are illustrated in Figure 4.

Increased Flow of Blood

When the heat loss from the body by radiation and convection becomes less than the metabolic heat production, the first corrective action initiated by the body is a vasodilatation of the blood vessels near the surface of the skin, which results in an increased flow of blood to the area and an increase in skin temperature. This results in an increase in both convective and radiative heat loss from the body when the ambient air temperature and the average radiant temperature of the surroundings are less than skin temperature; if these are higher than the skin temperature the heat gain through these channels is decreased. The flow of blood in the human body carries heat from the interior of the body, where it is produced, to the surface of the skin where heat transfer occurs.

Sweating

Sweating, the second defense mechanism, is brought into action when there is an insufficient flow of blood to the skin to meet the requirements for heat loss. This occurs usually when there is anything more than a minor thermal imbalance. The number of sweat glands activated and the rate of secretion of sweat are graded to meet the magnitude of the imbalance. Sweat production of more than two liters an hour has been observed but continuous sweat rates of about one liter an hour over several hours each day are considered to be maximum production rates. This means that, except for short periods of time, about 600 KgCal per hour is the maximum amount of heat that will be lost from the body surface by sweat evaporation. Sweat that is not evaporated has no value for heat loss.

Sweat production results in a drain on the water and salt in the body. The water lost in sweat is usually replaced by an increase in water intake. In most situations the thirst mechanism is sufficient to keep the water intake and water loss in balance. However, under conditions of heat stress with large sweat production (6-12 liters a day), enough fluids are not voluntarily consumed to replace the water lost in the sweat. This "voluntary" dehydration may amount to two to three liters or more during an eight hour working day. The "voluntary" water deficit is usually replaced during meals and non-working hours if an adequate supply of drinking water is available. Dehydration in excess of three liters may have serious physiological and clinical consequences.

Heat Induced Illness

If the normal responses of increased skin blood flow and sweat production are not adequate to meet the needs for body heat loss or if the mechanisms fail to function properly, physiological breakdown may occur. There are four major categories of heat-induced illnesses: heat exhaustion, dehydration, heat cramps, and heat stroke.

Heat exhaustion. This is a state of collapse brought about by an insufficient blood supply to the cerebral cortex as a result of dilatation of blood vessels in response to hot conditions. The failure here is not one of heat regulation, but an inability to meet the price of heat regulation. A low arterial blood pressure is the critical event,

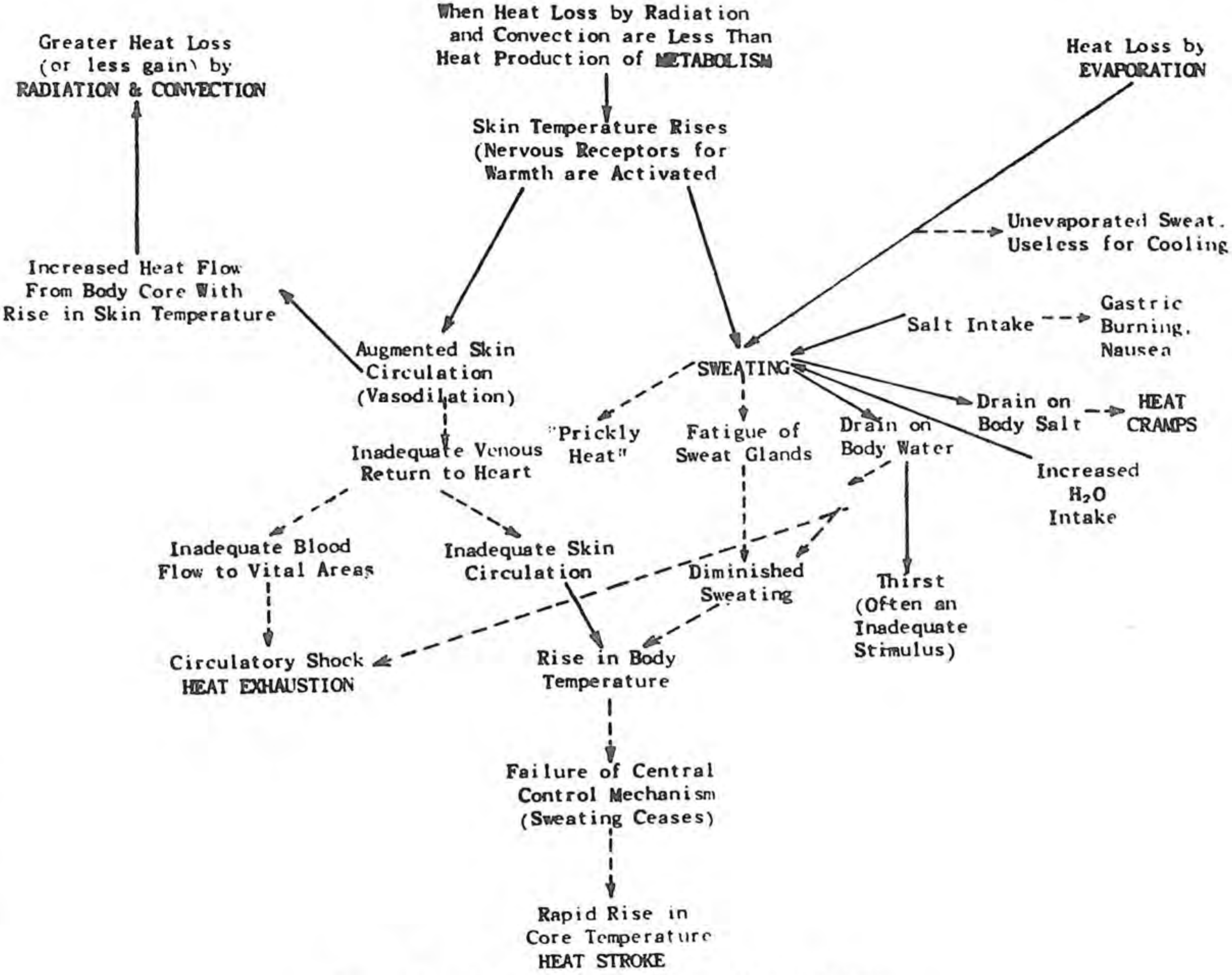


Figure 4. - Physiological effects of heat stress.

resulting partly from inadequate output of blood by the heart, partly from the widespread vasodilation. Inadequate cardiac output results in turn from a fall in the volume/capacity ratio below unity. The chief factors which may bring about this state of affairs may be classified as follows:

1. Increasing vascular dilatation and decreasing the capacity of the circulation to meet the demands for heat loss to the environment, exercise, and digestive activities.
2. Decreasing blood volume by dehydration, gravitational edema, adrenal insufficiency or lack of salt.
3. Reducing cardiac efficiency by emotion, malnutrition, lack of physical training, infection or intoxication, cardiac failure.

Dehydration. In its early stages, dehydration acts mainly by reducing the blood volume and promoting heat exhaustion. But in extreme cases it brings about disturbances of cell function which increase and reinforce each other with worsening deterioration of the organism. Muscular inefficiency, reduced secretion (especially of the salivary glands), loss of appetite, difficulty in swallowing, acid accumulation in the tissues, and nervous irritability followed by depression, will occur in increasing strength; while uremia, fever and death will terminate the picture. A surprising feature is the persistence of urine excretion in small amounts (5 cc/hr.) in the face of dehydration. Water to drink is the primary treatment, clinical experience suggests carefulness in administration, while the addition of chloride, glucose and perhaps alkalies is to be recommended.

Heat cramps. This is a condition of cramp-like spasm in the voluntary muscles following a reduction of the concentration of sodium chloride in the blood below a certain critical level. Just why cramps should follow a fall in blood chloride is not clear, but the association is certain and the relief obtained by the administration of chloride may be spectacular. A high chloride loss is facilitated by high sweating rates and lack of acclimatization. Depletion of chloride reserves is facilitated by low dietary intakes of salt, and by adrenal cortical insufficiency. A high water intake makes dilution of the remaining chloride easier. The actual critical level of blood chloride concentration seems to vary, and may be affected by factors such as general health which are not as yet understood.

The abdominal as well as the limb musculature may be affected, the exact site not necessarily being related to the preceding exercise. Abdominal cramps may simulate acute surgical conditions, while limb cramps may resemble exercise or nocturnal cramps. Their persistence without saline therapy and their abolition by it provide the clue. Heat cramps can be prevented by taking extra salt whenever heavy work is to be carried out in hot dry environments, especially by unacclimatized persons.

Heat Stroke (Hyperpyrexia). This is reached when the mean temperature of the body is such that the continued functioning of some vital tissue is endangered thereby. It represents, of course, a marked failure of the heat regulating mechanism to maintain a proper balance between the two sides of the heat balance. The chief factors which may bring this about may be classified as follows:

1. Reducing heat loss -- lack of sweat glands, inhibition of sweating, inadequate peripheral circulation, high environmental temperature, high humidity with restricted convection.
2. Increasing heat reception -- radiant energy absorption, environmental temperatures above skin temperature.
3. Increasing heat production -- muscular exercise, pyrogenic agents,

over-activity of the thyro-adrenal apparatus, rising body temperature, agitation.

4. Interfering with the heat regulating center -- brain injuries or infections.

The critical body temperature for man lies between 108 and 112°F, depending upon the length of time that the tissues are so exposed. The cause of tissue damage and finally death is probably a mixture of protein denaturation, enzyme degradation, alteration in the physical structure of the cell membranes, and changes in the viscosity of the cellular protoplasm. It is unlikely that this crisis will be reached in a healthy, acclimatized man carrying out normal activities in a natural climate. But under severe emotional and physical stress and very hot conditions, heat production may reach a level high enough to produce heat stroke without prior onset of the usual escape provided to man, that is, heat exhaustion.

Relief is secured only by an early and effective reduction of body temperature. This is usually obtainable by wrapping the patient in wet sheets and playing a fan on him, but it is sometimes necessary to resort to packing in ice. A resistance to gentler cooling methods is particularly likely to occur in cases where the hyperpyrexia is partially due to infection. It sometimes seems in such cases that the effect of the infection is to set the heat regulating "thermostat" at an abnormally high level, so that gentle cooling results only in vasoconstriction, with negation of the cooling effects. When drastic cooling is used, however, care has to be taken that the temperature is not lowered too fast or too far.

Acclimatization to Heat

The fact of acclimatization is well attested by both experience and scientific observations and some of its features are known but as yet much of the basic mechanisms are still elusive. With the onset of a heat wave or when one is suddenly transported to a hot environment, it is common experience to observe impairment in performance capacity and strong heat discomfort and distress. Tasks that were easily performed in a cool environment became difficult and heat discomfort may interfere with rest and eating. If, however, the exposure to the heat is continued for several days, performance gradually returns to normal and heat discomfort subsides at least to some extent; acclimatization to heat occurs. The improvement in performance and sense of well-being is more than accustomization; rather, it is the result of certain well defined and other more obscure, physiological adaptations.

Acclimatization to heat results at least in part from increased protection against hyperthermia since some of the initial distress of heat exposure results from the hyperthermia. However, other adaptations occur; e.g., improved cardiovascular function. The acclimatized individual is able to work in the heat with a lower body temperature, a lower heart rate and a more stable blood pressure than before acclimatization. Some increase in sweat production also may occur. Other alterations that have been implicated but are as yet still not fully proved include changes in adrenocortical activity, blood volume and venomotor tone. Regardless of which changes are most important, the improvement in performance that occurs with heat acclimatization is referable to the increased ability to maintain adequate cardiovascular function in the face of a high heat load.

The fully heat acclimatized individual, then, shows no important decrease in capacity to do physical work in the heat as compared to the amount he can do in comfort temperature conditions. This does not mean, however, that he is insensitive to the heat. Also, there may be some psychological effects even in the heat acclimatized individual including:

(1) some loss of mental initiative,

(2) decrease in accuracy particularly in poorly motivated individuals,

(3) need for greater concentration to do a given task, and

(4) possible personality change.

Climate, however, is a convenient bogeyman to be blamed for psychological and physiological difficulties whose real origin may be much more personal.

Susceptibility to Disease

Early studies of mortality during hot weather in a large American city have been supplemented recently by an analysis of records over nine and a half years, with the following conclusions:

1. Tolerance to climatic change decreases with increasing age past 25;
2. Mortality increases notably in hot summer months;
3. The mortality is at a minimum in normally hot summer months, but high peaks are superimposed by hot spells;
4. Rapid fluctuations in temperature during summer months are accompanied by a significant increase in mortality;
5. In the total period the highest single daily mortality occurred in an exceptionally hot period; and
6. Temperature is the most significant environmental factor in summer mortality.

Taken together with previously familiar evidence, this places the responsibility for increased mortality firmly on temperature fluctuations, and exceptionally hot periods, but absolves continued "normal" heat. It would seem that attempts to control atmospheric conditions should be directed at the rather exceptional peak conditions, and that extension of such controls to lower degrees of heat might not be only unnecessary, but even undesirable, in that it would impose rapid fluctuations upon those who have to alternate between conditioned and natural environments.

EVALUATION OF HEAT EXPOSURE

I ORIENTATION

A Familiarize yourself with the environment in which the employee works. Find out what the employee's daily regular and irregular tasks are, where the employee spends his time during the different tasks and at break times and watch the employee long enough to get an idea how hard he works on the different tasks.

B Classify the areas where the employee spends his time into "zones" of similar heat stress. A zone may be a very large area; e.g., outside in the sun, or it may be a very small area; e.g., in the cab of a moving truck. Some examples of zones which are part of the exposures of many employees are:

1 Outside in the sun

2 Outside in the shade

3 Employees' cafeteria

4 Rest area

5 Machine vending site

Designate each location by a letter. Different zones having identical climatic conditions all the time can be marked by the same letter.

It is often helpful to draw a map of the work area on which you can draw in the zones of similar heat stress rather than trying to describe them in words.

II TIME AND LOCATION STUDY

A Determine the time the employee spends in each zone by performing a time-study. It is suggested that the employee be observed for the entire shift. This is the recommended practice even if you only want to determine the employee's exposure during the last hour or so of the shift. The reason is that employees often work harder than usual when you first start watching them, but after a few hours they tend to slow down to a pace that is close to normal for them.

B Prepare a data sheet with the following column headings from left to right.

1 Stopwatch Readings (location)

2 Zone

3 Activity

4 Stopwatch Reading (activity)

C When the observation period begins, note the time of day and start a stopwatch. On the data sheet in Column A record a zero. Next, record in Column B the letter designation for the zone where the employee is located at the time of observation. Then describe the employee's activity in Column C.

1 Each time the activity is changed the time shown on the stopwatch is recorded in Column D to the right of the description of the activity which was just completed.

2 Each time the employee moves from one zone into another, the time shown on the stopwatch is recorded in Column A and the zone into which he moved is described by its letter designation in Column B.

III PLACEMENT OF ENVIRONMENTAL INSTRUMENTS

A Where possible, the instrumentation should be in the same place as the employee at the same time as the employee so that the actual conditions of the employee's exposure are measured. There are work-places in which this is impossible or at least impractical.

Examples: (1) Where the work area is so small that the instruments would interfere with the employee; (2) Where an employee is driving a vehicle with the windows open, it is impossible to place the instruments in a position which has the same wind velocity and sunlight as the position occupied by the driver; (3) A furnace tender in a foundry who is usually shielded from the direct radiant heat of the molten metal but who must frequently open the furnace door and work very close to the metal for a short time. The environmental instruments would not only be in his way but in most cases would not reach equilibrium before he closed the door.

B In workplaces where it is impossible or impractical to measure the environmental conditions at the same time as the employee is in the zone, an estimate of the environmental conditions at the time the employee was in the zone may be obtained by any of the following methods:

1 Set up the environmental instrumentation in the "zone" where the employee has been working immediately after the employee left that zone. This measurement of conditions shortly after the employee left the zone is generally an adequate estimate of the actual conditions to which the employee was exposed; however, this is not a reliable estimate if conditions change rapidly. In some cases it will be necessary to ask the employee to maintain the heat sources in the same conditions as they were when he performed the task.

2 In those zones where the employee spends a substantial amount of time, take measurements periodically; e.g., once per hour or once per half-hour. However, in those zones where the employee spends only a few minutes each shift it is only necessary to take two or three environmental readings during each work shift. After completion of the shift plot the measured values on a graph with time of day as the abscissa. Connect the plotted data points with straight lines as shown in Figure 1. The estimated environmental heat level in the zone can be read off the graph for any time in the shift.

3 Where the employee moves through a hallway or through a large transport area he may pass through several zones. It is permissible to estimate his exposure from environmental data for zones which have heat levels similar to those the employee passed through, provided that the time it took to walk through the area was short. For example, if the employee leaves his regular work area to go to the restroom, it is not necessary to take environmental measurements in every zone he passed through. Instead, his average exposure for the few minutes of walking can be estimated from other available data.

4 In the case of a truck driver, satisfactory environmental measurement may be obtained from the seat next to the driver if it is assured that window openings and impinging sunshine are substantially similar.

5 In workplaces in which there are numerous similar heat sources, a sampling procedure is permissible. An example of a workplace where this procedure is very useful is an aluminum reduction plant where it is common to find several hundred "pots." The procedure requires the CSHO to prepare a random sampling schedule before the shift begins. This can be done in either of two ways. The first method is to decide on a systematic sampling procedure; e.g., every tenth pot in a pot-line. This sampling procedure is sufficiently random if the first heat source to be measured is randomly selected by using random number tables. This is recommended for use in large industrial plants because it minimizes the total number of measurements required. The alternative method is to use random number tables to determine the order in which the heat sources will be sampled. This method is best in small plants where

you plan to sample a large percentage of the total number of individual heat sources. However, measurements at each site have to be repeated at least in every two hours if conditions change during the shift.

C Where the employee is exposed to hot environments continuously, the environmental heat shall be considered in series of hourly time-weighted averages. Where the employee's exposure is intermittent, i.e., interrupted at least each 15 minutes by breaks spent in cool areas, the time weighting should be performed for intervals of two hours.

The time-weighted average is calculated by the following equation:

$$\text{Temp. Ave.} = \frac{(\text{Temp}_1)\,t_1 + (\text{Temp}_2)\,t_2 + \ldots : (\text{Temp}_n)\,t_n}{t_1 + t_2 + \ldots\, t_n}$$

Where:

Temp_1, Temp_2, Temp_n, are the measured levels of environmental heat for the various zones occupied during the one- or two-hour period

t_1, t_2, t_n, are the elapsed times (in minutes) spent in the corresponding zones during the one- or two-hour period.

IV ASSESSMENT OF WORK LOAD

During physical work, metabolic heat (M) is generated within the body which has to be considered when assessing an employee's heat exposure.

A For preliminary estimation of heat exposure it is satisfactory to rank the job into one of the following three categories:

1 Light work

Activities carried out in sitting or standing position, or combined with walking, but not requiring systematical physical efforts, raising or moving about of heavy loads (basic activities in sewing production, tool making, machine building, lithography, supervising activities, in runners and office workers).

2 Moderate work

Activities performed in continuous walking position with lifting up of lighter loads (up to 20 lbs) or continuous standing (basic processes in weaving-textile industry, mechanical assembly work, mechanical processing of wood and welding).

3 Heavy work

Jobs requiring systematic physical efforts by continuous moving or lifting about of loads of 20 lbs or more (basic processes in melting, smelting, foundry and rolling productions, and similar work). Heavy work is rarely performed for eight continuous hours. The employees in such jobs take more frequent breaks for resting than is customary in lighter jobs. Often, heavy work tasks are alternated with light or moderate work. In order to establish the proper category for a job, one has to determine the percent of time spent at each of the M categories; i.e., heavy work, moderate work, light work, rest. For instance, if the job consists of a heavy work task lasting 30 minutes each hour and the employees are resting or engaged in light work tasks for the rest of the hour, i.e., 30 minutes, the work should be classified as moderate work. If heavy work is performed for a full hour or longer time continuously it has to be classified as heavy work (at least for that particular period), even if it is followed by a long rest period or easier tasks.

Sample calculation: Using a heavy hand tool on an assembly line

Walking along	3.0 Kcal./min.
Intermediate value between heavy work with two arms and light work with the body	3.0 Kcal./min.
Total	6.0 Kcal./min.

Table 3. METABOLIC HEAT LOAD FOR A 76 kg MAN DOING SELECTED ACTIVITIES

Adopted from Bioastronautics Data Book, 2nd Edition, NASA 1973

Activity	Metabolic Heat Load (Kcal/min)
Sitting	
at rest	1.7
writing	1.8
riding in an automobile	2.0
typing	2.3
playing musical instruments	2.9
repairing boots and shoes	3.0
driving a car in light traffic	2.5
driving a car in heavy traffic	3.2
driving truck	3.3
assembling weapons	3.6
rowing for pleasure	5.0
Standing	
relaxed	1.8
drafting	1.9
peeling potatoes	2.1
entering ledgers	2.6
washing clothes	3.7
ironing	4.4
shoveling sand	6.0 - 8.0*
digging (continuously)	8.9
Engineering Tasks	
medium assembly work	2.9
welding	3.0
sheet metal work	3.1
machining	3.3
punching	3.5
machine fitting	4.5
heavy assembly work - non-continuous	5.1
Moving	
slow movement about rooms	2.5
vehicle repairs	3.4
walking slowly	3.8
walking at a working rate	4.8
walking carrying a load	3.8 - 8.0*

*Values may be chosen between extremes depending on size of shovel or weight respectively and on rate of work.

The elapsed times are determined by finding the difference in the time recorded at the beginning of the activity and the time recorded at the beginning of the succeeding activity.

E The time-weighted average metabolic heat load is determined by the equation:

$$\text{Av. kcal/hr} = \frac{\left[(M_1)\, t_1 + (M_2)\, t_2 + \ldots.\ (M_n)\, t_n\right] 60}{t_1 + t_2 + \ldots.\ t_n}$$

Where:

M is metabolic heat load expressed in kcal/min

t_1, t_2, t_n are the elapsed times in minutes spent at the associated activity.

REFERENCES

1 Botsford, J. H. "A Wet Globe Thermometer for Environmental Heat Measurement." AIHAJ Volume 32, pp. 1-10, January 1971.

2 Brief, R. S., Confer, R. G. "Comparison of Heat Stress Indices." AIHAJ, Volume 32, pp. 11-16, January 1971.

3 Minard, D., Goldsmith, M., Farrier, P. H., Lambiotte, B. J. "Physiologic Evaluation of Industrial Heat Stress. AIHAJ, Volume 32, pp. 17-28, January 1971.

4 Minard, D., Belding, H. S. "Guide for Assessing Heat Stress and Strains" (in accordance with suggestions from) Workshop on Evaluation of Hot Jobs, June 7,8, 1971. Pittsburgh, Pennsylvania.

5 "Heating and Cooling for Man in Industry," Published by American Industrial Hygiene Association, 1970. Copies available at $11.50 from George D. Clayton, 25711 Southfield Road, Southfield, Michigan 48075.

6 "Ventilation for Heat Control," Section 3 in Industrial Ventilation. Available at $4.00 per copy from Committee on Industrial Ventilation American Conference of Governmental Industrial Hygienists, P.O. Box 453, Lansing, Michigan 48902, 12th Edition, 1972.

7 Hatch, T. F. Heat Control in the Hot Industries. Chapter XXI in "Industrial Hygiene and Toxicology." Edited by Frank A. Patty, Volume 1, 2nd Edition, 1958.

8 "Heat Stress" (Section B-28), "Measurement of the Thermal Environment" (Section B-29) and "Comfort Ventilation and Control of the Thermal Environment" (Section C-3), in "The Industrial Environment ... Its Evaluation and Control," Public Health Service Publication No. 614, U.S. GPO, Washington, D.C. 1965.

9 Current TLV Booklet, American Conference of Governmental Industrial Hygienists.

10 "Effects of Temperature Extremes." E. L. Alpaugh, Chapter 8, pp 271-300, in "Fundamentals of Industrial Hygiene," National Safety Council, Chicago, Ill. 1971.

11 Criteria for a recommended standard --- Occupational Exposure to Hot Environments, HSM 72-10269, 1972, GPO Order No. 1733, 00010, $1.25 ea.

SOURCES OF MEASUREMENT INSTRUMENTATION

1 Mercury thermometers and cotton wicks for wet-bulb measurements are available from:

Taylor Instruments
Consumer Products Division
Sybron Corporation
Arden, North Carolina 28704

The cotton wick material can be obtained in continuous lengths and cut to lengths as needed.

2 Copper spheres, 6-inch diameter, are available from:

Naugatuck Manufacturing Company
Avenue of Industry
Box 3175
Waterbury, Connecticut 06705

A globe thermometer can be prepared by painting such a sphere with a flat black paint and fitting it with a mercury thermometer.

3 The Wet Globe Thermometer is available from:

Howard Engineering Company
Box 3164
Bethlehem, Pennsylvania 18017

4 A "Deluxe Heat Stress Measurement Outfit #172 is available from:

Suncoast Safety and Health Laboratories
P. O. Box 1405
Largo, Florida 33540

This consists of a rings stand with a buret clamp holding a natural wet bulb thermometer, and an unshielded dry bulb thermometer. A globe thermometer is supported on the stand with a thermometer clamp.

5 Hygrometers and Psychrometers are available from many laboratory equipment suppliers.

Laboratory V

18. EVALUATION OF HEAT STRESS

Object

To familiarize the student with the equipment and procedures used to evaluate heat stress in the working environment.

Theory

The industrial hygienist is frequently called upon to evaluate environmental conditions in a plant in terms of the heat stress which will be experienced by the workers. The four environmental factors which influence heat stress are temperature, humidity, air velocity and radiant heat intensity.

A number of schemes have been proposed for evaluating heat stress: seven of these are discussed in the previous section. Some or all of the above mentioned environmental factors are employed in each of the methods of heat stress evaluation, and in some cases these are combined with physiological factors such as metabolic heat production.

Field measurements of the various factors involved are usually made as outlined below:

1 Air temperature and humidity are usually determined from the dry-bulb and wet-bulb readings taken with a psychrometer. In using this instrument, the precautions discussed on pages 5 and 6 of the previous section should be observed. If a numerical value of humidity is required, it can be obtained from a psychrometric chart or table.

2 Air velocity should be measured with some non-directional type of anemometer. This is important because the direction of air movement in most enclosures is quite random. Heated thermocouple, hot wire, or heated thermometer type anemometers are usually satisfactory.

In most cases the measured air velocity should be corrected to compensate for the additional velocity created by the activity of the worker. In general, as the work rate increases, the workers' movements and the air velocity correction increase. However, considerable judgment must be used by the investigator. The following table[1] may serve as a guide in making air velocity corrections. The values given in the table are to be added to the measured velocity of the ambient air.

Activity	Air Velocity Correction (fpm)
Sleeping	0
Lying awake	20
Sitting still	20
Standing still	30
Desk work	50
Occasional stroll	100
Walking 2 mph	200
Walking 3 mph	300
Walking 4 mph	400

3 The globe thermometer reading is used as an indication of radiant heat intensity. If desired, the mean radiant temperature (MRT) at a given work site can be calculated from the globe temperature and the air velocity. Fifteen to 25 minutes are usually required for the globe temperature to reach equilibrium.

4 The measurement of metabolism requires special skills and equipment, and it is seldom done in the field. The following table[2] will be helpful in estimating the metabolic rate of the average man at various work rates.

Prepared by Clark M. Humphreys.

Activity	Metabolic Rate Btu/hr.
Seated, at rest	390
Standing, at ease	430
Seated, very light work	450
Moderately active office work	475
Walking, 2 mph	760
Light bench work	800
Moderate dancing	900
Walking, 3 mph	980
Walking, 4 mph	1400
Heavy work	1500
Maximum exertion	3000 - 4000

Equipment

1 Psychrometers, aspirated and sling.

2 Globe thermometer and supporting stand.

3 Thermal anemometer.

4 Heat stress chamber (will be discussed in lab.)

5 Charts - Psychrometric, Effective Temperature, Heat Stress Index.

Procedure

1 Using the instruments provided, measure the dry-bulb, wet-bulb, and globe temperatures and the air velocity at a designated location in the heat stress chamber.

2 From the data gathered in 1 above, determine the heat stress index, the normal effective temperature, the effective temperature corrected for radiation, and the relative humidity.

The corrected effective temperature is determined by the following procedure:

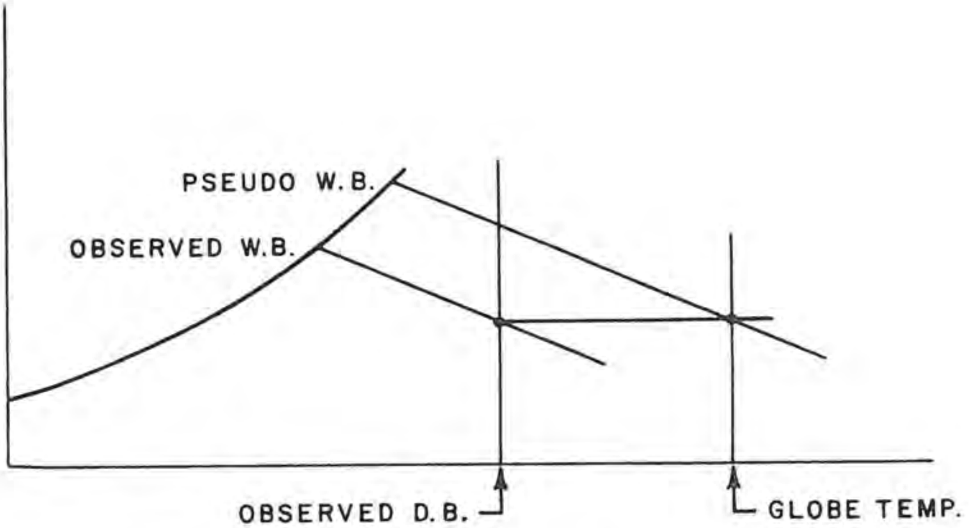
a On the psychrometric chart locate the intersection of the observed dry-bulb and wet-bulb temperature lines.

b From this intersection move horizontally (at constant specific humidity) to a dry-bulb temperature equal to the observed globe temperature.

c At the intersection of the horizontal line and the globe temperature line, read the wet-bulb temperature. This may be termed the "pseudo wet-bulb."

d From the effective temperature chart determine the E. T. using the globe temperature as the dry-bulb, the pseudo wet-bulb temperature, and the corrected air velocity. This will be the E. T. corrected for radiation.

The following sketch illustrates the method of determining the pseudo wet-bulb



References

1. Lee, D.H.K., and Austin Henschel, "Evaluation of Thermal Environment in Shelter," TR-8, U.S. Public Health Service, Division of Occupational Health.

2. ASHRAE Guide and Data, Fundamentals and Equipment, 1965-66, American Society of Heating, Refrigerating and Air-Conditioning Engineers, and Haines, G.F., Jr., and Theodore Hatch, "Industrial Heat Exposures - Evaluation and Control," Heating and Ventilating, Nov. 1952.

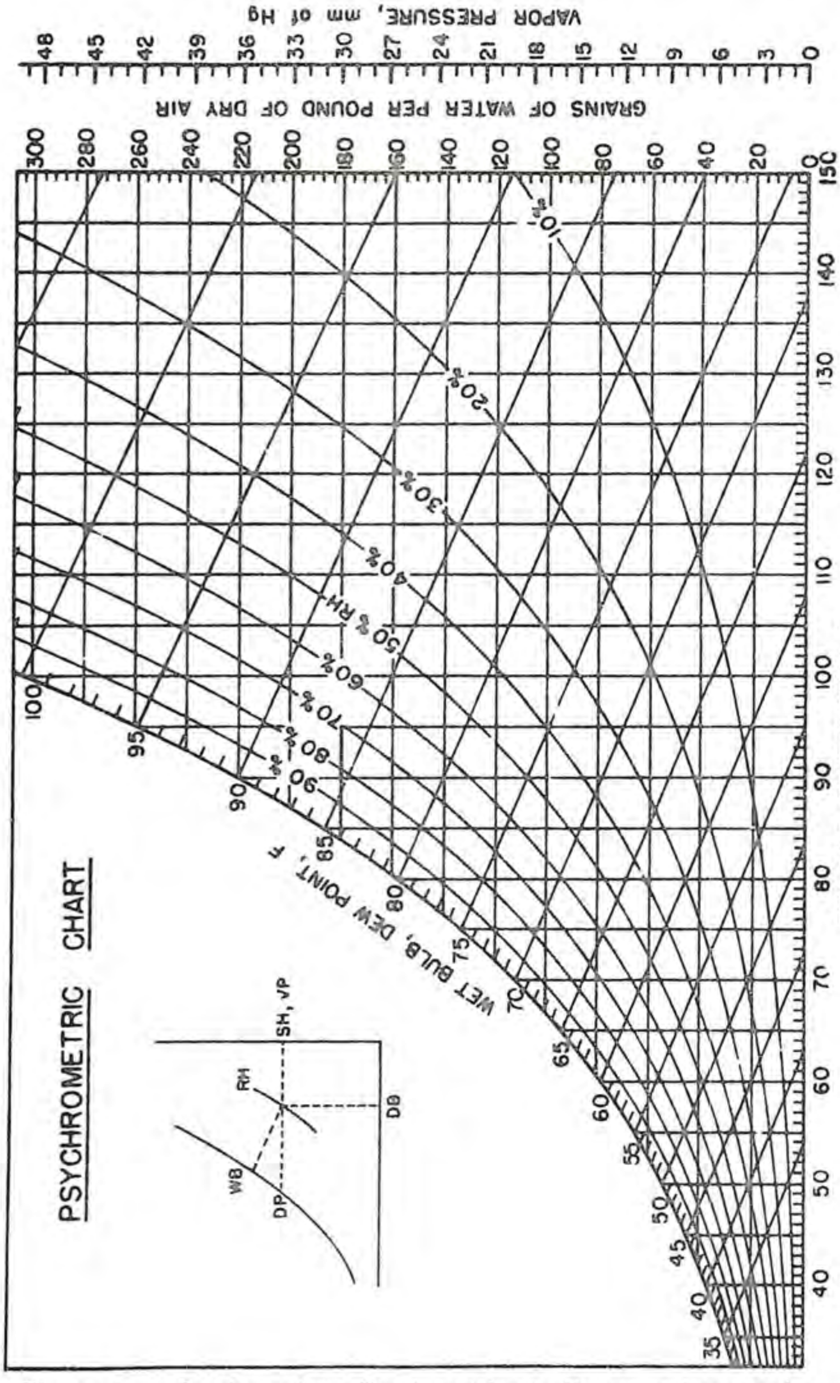
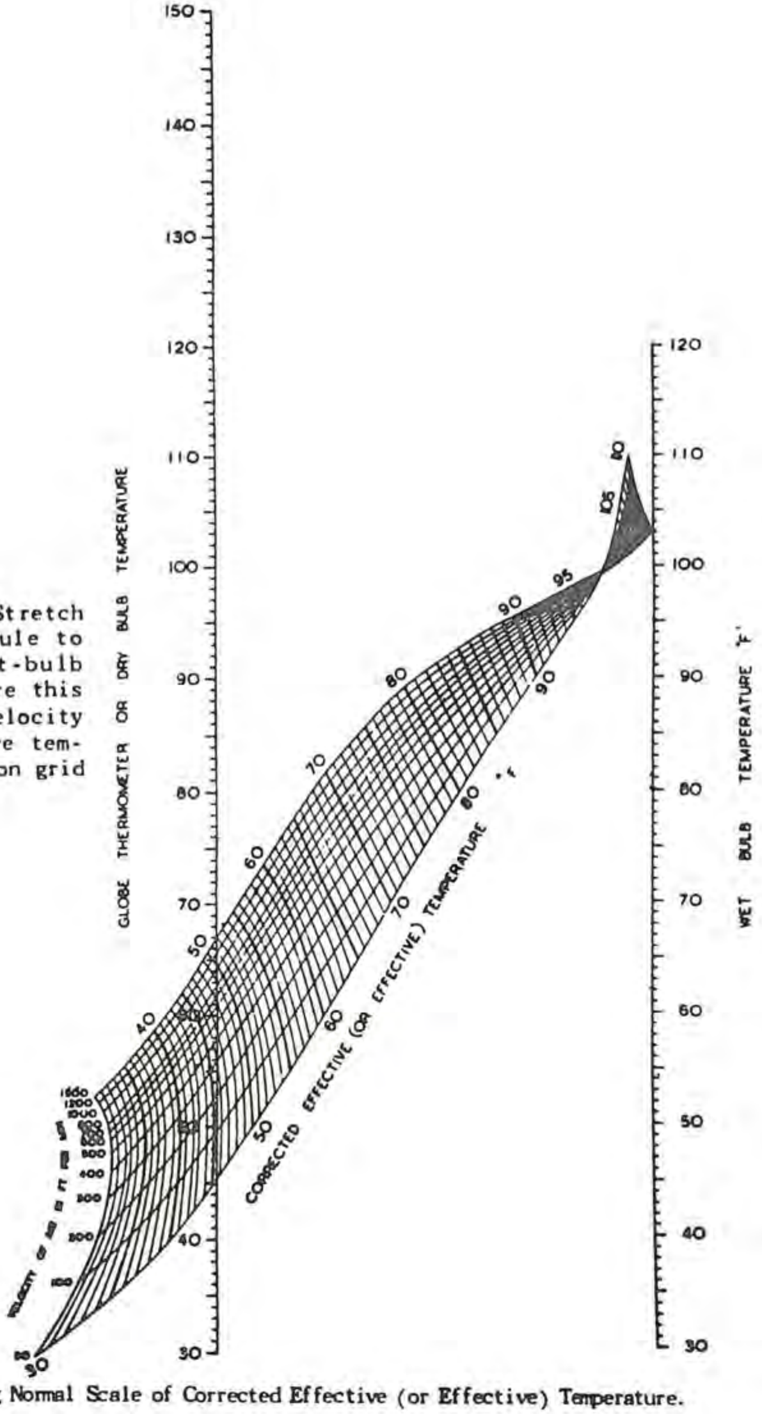
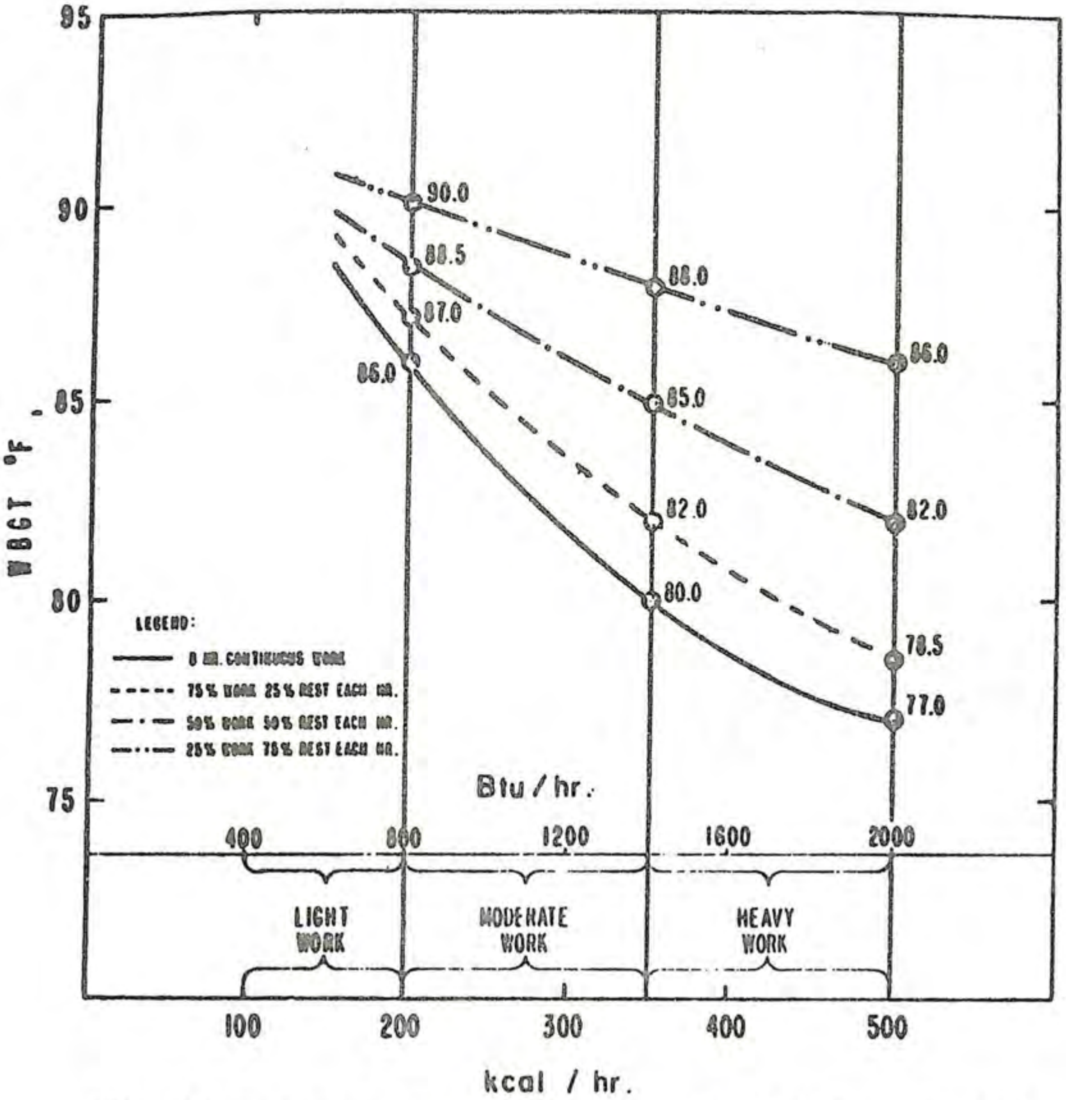


Figure 1. - Psychrometric Chart and Vapor Pressure Nomograph.

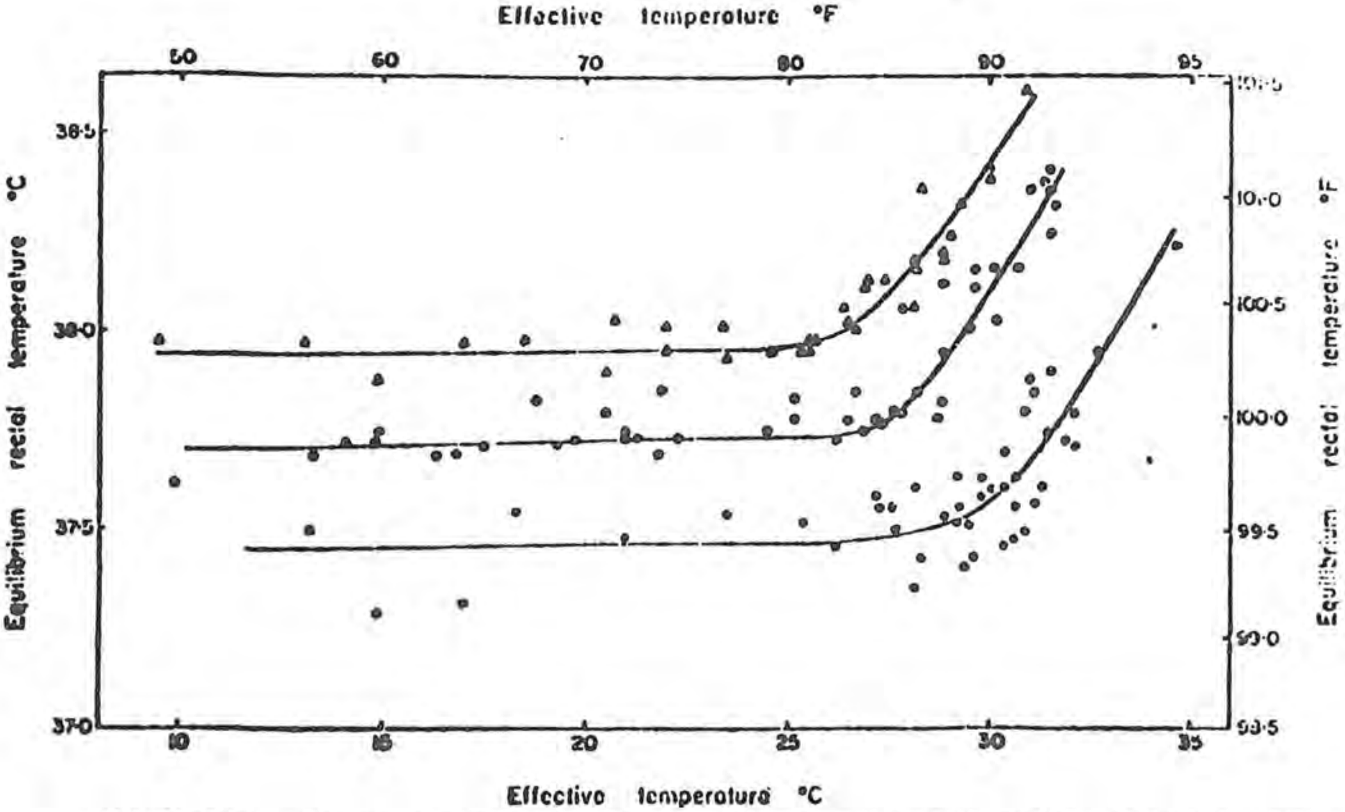


Instructions for use: Stretch a thread or place a rule to join dry-bulb and wet-bulb temperatures. Note where this cuts appropriate air velocity line and read effective temperature at this point on grid lines.

Figure 2. - Chart Showing Normal Scale of Corrected Effective (or Effective) Temperature.



PERMISSIBLE HEAT EXPOSURE LIMITS FOR WORKING IN SURFACE MINING OPERATIONS



-The levels of rectal temperature equilibrium of one subject working at 180 (○), 300 (○) and 420 (Δ) kcal./hr. in a wide range of climatic conditions.

(From: Lind (1963), *J. appl. Physiol.* 18, 51.)

Laboratory

HEAT STRESS ENVIRONMENTAL MEASUREMENTS

OBJECTIVE

To familiarize the student with the equipment and procedures used to evaluate heat stress in the working environment.

EQUIPMENT

1 Psychrometers
2 Globe thermometers
3 Natural wet bulb thermometers
3 Dry bulb thermometers
5 Botsball thermometers
6 Charts - Psychrometric, Effective temperature
7 Thermal anemometer

PROCEDURE

Using the instruments provided make the appropriate measurements and calculate the indices as indicated below:

	HOT, HUMID	NORMAL (classroom)	HOT (RADIANT)	HOT (RADIANT) with fan
TIME				
DATE				
AIR VELOCITY - FT/MIN				
MEASURED TEMP, °F				
GLOBE				
UNSHIELDED DRY BULB				
NATURAL WET BULB				
PSYCHRON DRY BULB				
PSYCHRON WET BULB				
RELATIVE HUMIDITY				
BOTSBALL, WGT				
PSEUDO WET BULB, °F				
CALCULATED INDICES, °F				
WBGT				
ET				
CET				

Prepared by William H. Perry. Revised by A. F. Schaplowsky, Public Health Advisor, Division of Training/NIOSH, 3/74.

WORK SESSION - HEAT STRESS

I Using the Psychrometric Chart

Provide the missing data:

	DB	WB	% RH	DP	SP Hum	V. Pressure
A.	75	65				
B.	75		40			
C.		65		55		
D.	100	75				
E.		60				13
F.	75				80	
G.			30	55		
H.		65	30			

II Heat Stress Measurements

1 Using the data provided complete the following table - (in calculating ET use nomogram in course manual)

	HOT DRY		RADIANT		HUMID	
LOCATION	I	II	III	IV	V	VI
Air Velocity - ft/min.	10	10	10	10	10	10
Globe Temperature	95	115°	118	143°	92	98°
Natural Wet-bulb Temp.	72	80°	80	97°	84	85°
Psychron Dry-bulb Temp.	94	113°	94	114°	91	84°
Psychron Wet-bulb Temp.	69	73°	78	80°	83	82°
WBGT						
ET						
CET						
Vapor Pressure of H_2O/mm Hg						
Pseudo Wet-bulb Temp.						
Relative Humidity						

Prepared by A. F. Schaplowsky, Public Health Advisor, Division of Training/NIOSH, 3/74. 1/76.

2 Using the data provided complete the following table:

LOCATION	I	II	III	IV	V	VI
Air Velocity - ft/min.	100	100	500	500	1000	1000
Globe Temperature	113°	95°F	113°F	95°F	113°F	95°F
Psychron Dry-bulb Temperature	90°	90°F	90°F	90°F	90°F	90°F
Psychron Wet-bulb Temperature	70°	70°F	70°F	70°F	70°F	70°F
ET						
CET						

III Time Weighted Averages

1 A worker in an industry (indoors) having a hot environment spends time each hour during the 8-hour day in four locations. The times spent each hour in these locations and the WB and GT readings were as follows:

LOCATION	TIME	GT	WB
1	15 min.	113°F	85°F
2	20 min.	95°F	70°F
3	5 min.	140°F	88°F
4	20 min.	77°F	66°F

The time-weighted average WBGT is __________.

2 A worker in an industry (outdoors) spends time each hour during the 8-hour day in 5 locations. The time spent each hour in these locations and the WB, DB and GT readings were as follows:

LOCATION	TIME	GT	DB	WB
1	10 min.	110°F	95°F	78°F
2	25 min.	100°F	90°F	85°F
3	10 min.	105°F	91°F	82°F
4	5 min.	89°F	85°F	75°F
5	10 min.	98°F	92°F	80°F

The time-weighted average WBGT is ___________.

IV Indicate in the table below the work situations in which the amount of work permitted per hour should be reduced or special practices and/or environmental controls introduced for an individual whose work level is 400 Kcal/hr.

	Protective Work Practices Should Be Introduced	Protective Work Practices Are Not Indicated
Question II 1. Location I		
II		
III		
IV		
V		
VI		
2. Location I		
II		
III		
IV		
V		
VI		
Question III 1.		
2.		

9

ILLUMINATION

Light is electromagnetic radiation. Visible energy, which is a very small portion of the electromagnetic spectrum, is the range of wavelengths between 380 and 750 manometers. It is that portion of radiant energy which, on striking the eye, produces the sensation of sight.

Light is needed for seeing. The amount required for seeing detail is considerably greater than that required for casual seeing. Four very important factors in seeing are size, contrast, brightness and time. Size is fixed while contrast and time are limiting. Brightness, on the other hand, can be varied more extensively than the other three factors. Brightness is used to compensate for deficiencies in size, contrast and time.

A quantity of light is not the total answer to lighting. A pleasant visual environment is the result of quantity and quality illumination. The most common fault of lighting systems is low illumination, glare, shadows and bad brightness ratios. Lighting installations, deficient in quality, result in loss of seeing efficiency and eye fatigue.

Glare anywhere within a field of vision causes visual discomfort. Glare associated directly with the source of light and the immediate surroundings is called direct glare. Glare associated with the visual task and its immediate surroundings is called reflected glare.

Shadows cast on the visual task reduce the brightness of the visual task, interfere with effective seeing and are also very annoying.

Proper brightness ratios between the visual task and the immediate surrounding environment is very important in creating comfortable seeing.

Quality of illumination pertains to the distribution of brightness. The factors involved are many and complex. Quality of illumination involves brightness, brightness ratios, light distribution, reflectance, diffusion and color. These contribute to visual comfort, safety and esthetics of the visual task. Visual tasks which involve fine detail and are performed over extended periods of time require considerably higher quality of lighting than when seeing is casual or of relatively short duration.

People do things best in a pleasant environment. Proper lighting adds greatly to creating pleasant working conditions. Proper lighting promotes safety, worker morale and quality and quantity production.

In order to determine whether a particular environment is well lighted, lighting survey procedures are available for evaluating a lighting system.

Light measurement is called photometry. In order to maintain reliability in photometric, it is imperative that the light measuring instruments be understood and properly calibrated and maintained.

Several types of instruments are available for photometric measurements. The most commonly used footcandle meters employ the light-sensitive barrier-layer cell. The majority of the portable photoelectric illumination meters are of this type. These meters are simple and convenient to use and although not designed to be precision instruments; they do, with careful handling and frequent checking, give reliable results.

Ideally, a light measuring instrument should uniformly respond to unit changes in light falling on it. If this condition holds, the instrument is linear. All light sensitive cells have certain inherent characteristics which limit their accuracy if they are not corrected.

Light meters are usually calibrated with light normal to the surface of the light sensitive cell. Light striking the cell at an oblique angle or diffuse light will give readings lower than the true values.

Prepared by Steven Dereniuk, Analytical Chemist, Division of Training, NIOSH, 1/73.

The illumination produced is proportional to the angle of incidence. The reading is lower because part of the light striking the cell obliquely is reflected and also because the rim of the case surrounding the cell partly shades it. Most cells are corrected so that the light striking the cell from all angles is properly evaluated. Corrected cells have diffusing covers or some other means of correction to give a nearly true cosine response.

Light sensitive cells respond to various wavelengths of the spectrum different from that of the human. The spectral characteristics of a tungsten filament lamp differ from the spectral distribution of electric discharge type lamps. With correcting filters over the cell, the response of the cell to different wavelengths of light closely matches that of the human eye.

All light sensitive cells show some instability when exposed to light. It is most noticeable at high footcandles values and also after a meter has been stored in the dark for an extended period of time. A meter should be allowed to stabilize (usually 5 to 15 minutes) before any readings are taken.

The performance of the barrier-layer cell, especially if the external resistance of the current is high, is affected by high and low temperatures. When the meter is used at temperature other than the temperature at which it was calibrated, a correction factor may have to be used. Prolonged exposure above 120°F, should be avoided as it may damage the selenium cell. The meter should be at the air temperature of the space being surveyed. A preferred working temperature range is 60°F to 90°F.

In making any lighting measurements, it must be borne in mind that the readings obtained are determined by conditions existing at the time. All pertinent information such as type of meter, ambient temperature, condition of fixtures, condition of walls, floors, and ceiling, time of day and length of time the lamps have been on should be recorded. If there are windows, weather conditions and any light coming in from the outside also should be noted.

New lamps emit light at a considerable higher level tha their initial rated output. New lamps should not be measured for light output until the lamps have seasoned. Incandescent filament lamps reach a stable output after about 20 hours of burning. Gaseous-arc sources and fluorescent lamps require at least 100 hours burning before they stabilize.

The light output of gaseous-arc sources and fluorescent lamps is significantly affected by ambient temperature. No measurements should be made until the lamp and fixture have reached equilibrium temperature which usually requires at least one half hour burning. Fluorescent lamps in enclosed fixtures may require several hours to equilibrate.

In light measurement, the candela is the international reference standard for the unit of candlepower. All other units are derived from it. Its value is determined by the light emitted from a device called a blackbody, operating at the temperature of solidification of platinum. The candela is calculated as 1/60 the intensity of a square centimeter of the blackbody radiator.

A lumen is the unit of light flow. It is defined as the rate at which light falls on a one square foot surface whose every point is one foot from a point source whose intensity is one candela.

The unit of illumination is the footcandle. The footcandle is one lumen uniformly distributed over a one square foot area. This means one footcandle equals one lumen per square foot. Area multiplied by the footcandle desired gives the number of lumens which must fall on the area.

A footlambert is the unit of brightness (luminance or photometric brightness) and is defined as one lumen uniformly emitted or reflected by an area of one square foot. A surface which reflects diffused light at a rate of one lumen per square foot has a brightness of one footlambert. However, all surfaces absorb some light. The brightness in footlamberts of a reflecting surface is footcandles of illumination times the percent of light reflected. Footlamberts are normally less than the incident lumens.

In making a lighting survey it must be understood that the visual environment is affected not only by the illumination level but also by the brightness distribution in the field of vision. The ratio of brightness between the visual task and the immediate area affects the ease of seeing. In a total appraisal of a lighting system illumination and brightness measurements are made.

The chance of making errors in lighting measurements is quite high. In order to insure acceptable measurements, methods and guidelines for lighting measurements are available from the Illumination Engineering Society.

An accurate, but tedious method in making a lighting survey is to divide the area under survey into two-foot squares, read the footcandles in each square and then average the readings.

In another method, which requires much less work, involves, depending on the geometry of the area and the lighting installations selecting certain areas, reading the footcandles in these areas and then calculating the average footcandles.

Probably the most common method for measuring illumination is the spot method where the measurement is made at the work location.

In making any illumination measurements, the proper instrument must be selected and its operation must be understood. It is imperative that the instrument is properly used and maintained. The selection, use, and care of the instrument should be as follows:

1 The instrument should be color and cosine corrected.

2 It should be accurate.

3 It should have a temperature correction factor if its sensitivity is affected by changes in temperature.

4 The meter should be at the air temperature of the area being surveyed and should preferably be used at a temperature of 60° to 90°F.

5 The meter should be allowed to stabilize (usually 5 - 15 minutes) before any readings are taken.

6 In taking readings, the meter may be positioned with the scale in the vertical or horizontal position, but never on its side.

7 In spot illumination measurements, the readings should be made at the work area.

8 The readings should be taken under general lighting only and then with supplementary lighting added.

9 The readings should be made with the worker in his normal working position.

10 The readings should be made at the working plane whether horizontal, vertical or oblique.

11 If the worker casts a shadow over the visual task, the readings should be made under this condition.

12 The readings should be taken at night or with windows and skylights covered.

13 The investigator should wear clothing similar to those worn by the worker.

14 New lamps should not be measured for light output until the lamps have been seasoned. Incandescent filament lights require at least 20 hours burning to reach a stabile light output while gaseous discharge sources and fluorescent lights require somewhat in excess of 100 hours burning to stabilize.

15 Seasoned fluorescent lights should not be measured until they have been burning for at least one half hour.

16 Luminance or brightness measurements should be made under actual working conditions. Brightness measurements usually are not made unless there is a discomfort problem or one is anticipated.

17 The readings should be taken from a specified work point location with a brightness meter aimed at various surfaces. Brightness measurements are made of the visual task, the area

immediate to the visual task and the major surfaces in the visual environment. The areas are the work plane, machinery, floors, ceilings, walls, windows, light fixtures and the outside.

18 The general and supplementary lighting should be in normal use.

19 Consideration should be given to sun position and weather conditions.

20 Work areas used in the daytime should be surveyed in the daytime. The shades should be adjusted for best control of daylight.

21 Work areas used at night should be surveyed during the nighttime. The shades should be drawn.

22 All readings should be recorded and factors that may affect the readings should be noted.

23 Instruments should be handled carefully and should be properly stored when not in use.

24 The instruments should be stored in cases or cabinets free from dust, excessive heat, moisture, and vibration and corrosive fumes.

It is only when the proper instrument is selected and is understood and attention is paid to detail that reliability in illumination measurements is attained.

REFERENCES

IES Lighting Handbook, 4th Edition. Illuminating Engineering Society, New York, (1966).

LIGHTMETER CALIBRATION

OBJECT

Calibration of Lightmeters (color corrected) in the range of 5 to 200 ft. candles.

THEORY

A calibrated light-bulb can be used to calibrate lightmeters.

EQUIPMENT

1 Regulated current source which will deliver voltage and current compatible with the calibrated lamp.

2 Calibrated lamps 3 ea. 500 watts.

3 Current monitor -- .5% accuracy or better.

4 Long black box 10' x 1-1/2'

5 Start-up/shut-down pot.

EQUIPMENT SET UP

COMMENTS

1 Three calibrated lumps are necessary so the working lamp may be cross checked with the seldom used "Standards".

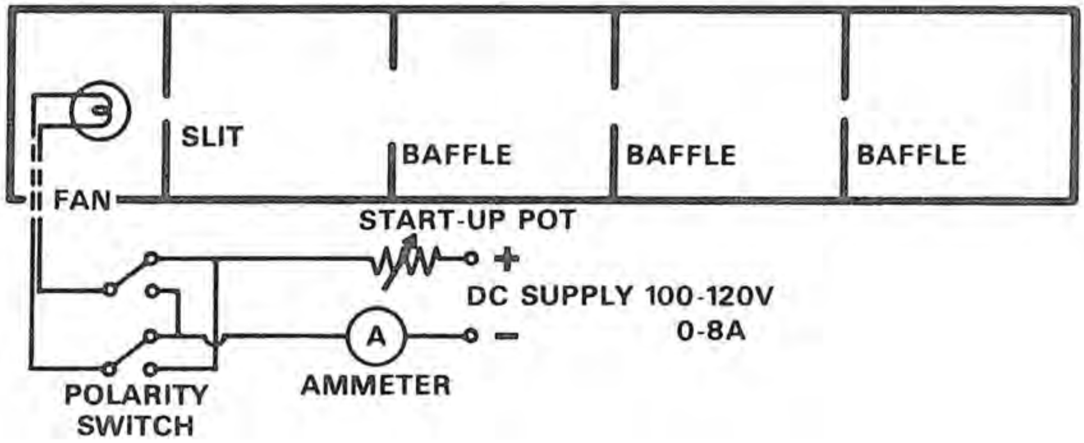
2 The purpose of the start-up, shut-down pot is to prevent rapid heating or cooling and to prevent current surges when the lamp filament is cold.

3 Baffles in the black box are necessary to prevent reflected light from the side of the box from reaching the sensor.

4 The polarity reversing switch is used if D. C. lamps are chosen as the standards. The direction of current flow should be reversed before each start-up.

5 It is not possible to convert from foot candles to watts/cm^2 unless the bulb's spectrum is known.

6 Distance from source to sensor is measured from the lamp filament to the sensor.



7 The minimum distance from the bulb for which meaningful calibration can be accomplished is 10 times the maximum filament dimension (for a clear bulb) or 10 times the maximum sensor dimension (whichever distance is greater.

8 Bulb orientation and other calibration information is generally supplied by the manufacturer.

9 The sensor center should be at the same altitude as the filament center.

PROCEDURE

1 Turn on power and bring bulb slowly up to rated current. This should take 15 to 30 seconds.

2 Check the current monitor and adjust controls to obtain exactly the specified calibration current.

3 Place the lightmeter in the box at a known distance with sensing element facing the lamp.

4 Calculate the number of foot-candles.

$$\text{No. of Footcandles} = \frac{\text{No. of Candles of Lamp}}{D^2}$$

$$D = \text{ft}$$

<u>Example</u>

A 500 watt bulb produces 805 candelas, find the number of ft-candles at 2 ft and 10 ft.

a 2 ft

$$\frac{805 \text{ candelas}}{(2 \text{ ft})^2} = 201.3 \text{ ft - candelas}$$

b 10 ft

$$\frac{805}{(10)^2} = 8.05 \text{ ft-candles}$$

Laboratory VI

19. ILLUMINATION MEASUREMENT

PRINCIPLES OF RADIATION

I INTRODUCTION

A Objectives

1 Identify radiation source.

2 Cite the regulations or standard pertaining to that source.

B Scope

1 Ionizing radiation

2 Nonionizing radiation

II ELECTROMAGNETIC RADIATION

A Definition

B Characteristics

1 Wavelength

2 Frequency

3 Energy

C Electromagnetic Spectrum

III IONIZING RADIATION

A Types and Characteristics

B Common Sources

C Hazards

1 External

2 Internal

D Regulations

IV NONIONIZING RADIATION

A Ultraviolet (UV)

1 Sources and characteristics

2 Standards

B Microwaves

1 Sources and characteristics

2 Regulations

C Lasers

1 Characteristics

2 Regulations

3 ANSI Z-136 Laser Safety Standard

D Other Types of Nonionizing Radiation

1 Infrared (IR)

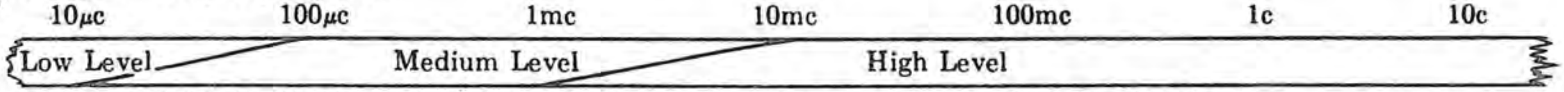
2 Visible

3 Radiofrequency

Prepared by William E. Murray, Health Physicist, Division of Training, NIOSH, 3/74.

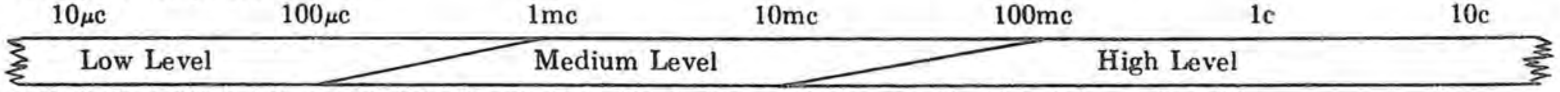
Table 2. ***Hazard from absorption into the body***

Group 1. Very High Hazard.



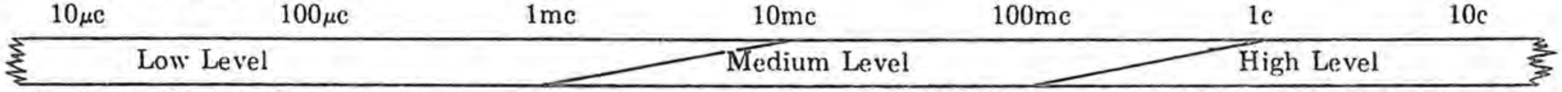
*Pb^{210}, Po^{210}, *Ra^{226}, *RA^{228}, Ac^{227}, Th^{228}, Th^{230}, Np^{237}, Pu^{238}, Pu^{239}, Pu^{240}, Pu^{241}, Pu^{242}, *Am^{241}, Cm^{242}

Group 2. High Hazard.



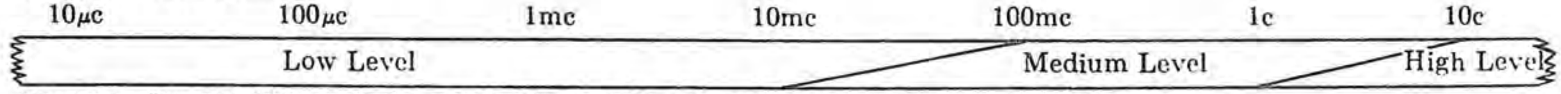
*Na^{22}, Ca^{45}, *Sc^{46}, *Co^{60}, Sr^{90}, *Ru^{106}, I^{129}, *I^{131}, *Cs^{137}, *Ce^{144}, *Eu^{154}, *Ta^{182}, Bi^{210}, At^{211}, Ra^{224}, U^{233}

Group 3. Medium Hazard.



C^{14}, *Na^{24}, Si^{31}, P^{32}, S^{35}, Cl^{36}, *K^{42}, Sc^{47}, *V^{48}, *Cr^{51}, *Mn^{54}, *Mn^{56}, Fe^{55}, *Fe^{59}, *Cu^{64}, *Zn^{65}, *Ga^{72}, *As^{76}, *Rb^{86}, Sr^{89}, Y^{90}, Y^{91}, *Zr^{93}, *Nb^{95}, *Mo^{99}, *Ru^{103}, *Rh^{105}, Pd^{103}, Ag^{105}, Ag^{111}, *Cd^{109}, *Sn^{113}, *Te^{127}, *Te^{129M}, *Ba^{140}, *La^{140}, Pr^{143}, Pm^{147}, Sm^{151}, *Ho^{166}, *Tm^{170}, *Lu^{177}. *Re^{183}, *Ir^{190}, Ir^{192}, *Pt^{191}, *Pt^{193}, *Au^{196}, *Au^{198}, *Au^{199}, *Tl^{200}, *Tl^{201}, Tl^{202}, Tl^{204}, *Pb^{203}, Rn^{220}, *Rn^{222}, U^{235}

Group 4. Low Hazard.



H^{3}, *Be^{7}, C^{14}, F^{18}, Ni^{59}, Zn^{69}, Ge^{71}, U^{238}, Natural Thorium, Natural Uranium, Noble Gases.

*Emits gamma radiation in significant amounts.

Safe Handling of Radioactive Materials, Handbook 92,
National Bureau of Standards, March 9, 1964, Page 12.

X-RAY SURVEY BRIEFING SHEET

I REGULATIONS

The following regulations promulgated by OSHA and the AEC are pertinent to the survey of an industrial x-ray and/or sealed gamma-ray installation inspection.

A Maximum Permissible Dose (MPD) for Radiation Workers

1 Annual - 5 rems

2 Quarterly - 1.25 rems

3 Weekly average - 0.1 rems = 100 mrems

B Definitions

1 Restricted area - Any area where access is controlled for radiation protection purposes

  a Dose to individuals may not exceed the MPD

2 Unrestricted area - Any area where access is not controlled (not defined by OSHA)

  a Dose to individuals may not exceed:

    1) 2 mrem in any hour

    2) 100 mrem in any seven consecutive days

    3) 0.5 rem in a calendar year

C Posting Requirements

1 Radiation area - Any area where in individual could receive a dose exceeding 5 mrem in any hour of or 100 mrem in any week. Area must be posted as such.

2 High radiation area - Any area where an individual could receive a dose exceeding 100 mrem in any hour. Area must be posted as such.

D Personnel Monitoring - Required under the following circumstances:

1 Employee likely to receive dose exceeding 25% of the MPD.

2 Minor (under 18 years old) employee likely to receive dose exceeding 5% of the MPD.

3 Each employee entering a high radiation area.

II SURVEY PROTOCOL

A Installation Inspection

The installation shall be inspected to determine the present and expected occupancy of adjacent areas; all radiation shields and barriers; the operation of audible or visible warning signals, interlocks, etc., and other devices that have a bearing on radiation protection.

B Radiation Measurements

Radiation exposure shall be measured in all adjacent areas that can be occupied. The measurements shall be made under practical conditions of operation that will result in the greatest exposure at the point of interest. X-ray apparatus should be operated at its maximum kilovoltage and milliamperage for continuous operation.

C Survey Report

The report shall include the following information:

1 Identification of the radiation source and its location

2 The operating parameters of the x-ray tube during measurement

3 The source location and beam orientation during measurement

4 The measured exposure rates in all adjacent occupied areas

5 A description of any devices used to restrict source location and beam orientation

6 A statement of compliance or non-compliance. In case of the latter, specific recommendations should be made to ensure compliance. Resurvey where necessary.

RADIATION DETECTION INSTRUMENTATION

I IONIZING RADIATION DETECTION

A Basic Principles of Radiation Detection Instruments

B Survey Instruments

C Personnel Instruments

II NONIONIZING RADIATION DETECTION INSTRUMENTATION

A Laser Radiation Detection

B A Comparison of Microwave Detection Instruments

C Microwave Oven Leakage Meters

III REFERENCES

1 "Instrumentation for Environmental Monitoring: Radiation," LBL-1, Vol. 3. Environmental Instrumentation Group, Lawrence Berkeley Laboratory, University of California, Berkeley, Calif. 94720. ($7.00)

2 Brannigan, Francis L., "Living with Radiation. 1. Fundamentals," Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. ($0.70)

3 "Safe Handling of Radioactive Materials," National Bureau of Standards Handbook #92, U.S. GPO. ($0.40)

4 "Safety Standards for Non-Medical X-Ray and Sealed Gamma-Ray Sources," NBS Handbook #93, U.S. GPO. (#0.30)

5 "Basic Radiation Protection Criteria," NCRP Report No. 39, National Commission on Radiation Protection and Measurements, 4201 Connecticut Avenue N.W., Washington, D.C. 10008. ($2.00)

6 "Radiation Protection Measurement and Its Application," ICRU Report 20, ICRU Publications, P.O. Box 30165, Washington, D.C. 20014. ($3.50)

7 Michaelson, Sol M., "Human Exposure to Non-Ionizing Radiant Energy - Potential Hazards and Standards," Proceedings of IEEE <u>60</u>: #4, 389-421, April, 1972.

Prepared by William E. Murray, Health Physicist, Division of Training, NIOSH, 2/73.

Basic Principles of Radiation Detection Instruments

I. INTRODUCTION

Since man can neither sense nor measure the presence of radiation, instruments must be used for its detection. Such instruments measure or respond to the charged particles which are produced as radiation interacts with matter. The basic difference between the various instruments is the medium in which the ionizing events occur.

The principal means of detection are: gas ionization, photographic emulsions, scintillation media, semiconductors, chemical decomposition media, radiophotoluminescence and optical density, thermoluminescence, and calorimetry. They will be discussed in the paragraphs that follow.

II. GAS IONIZATION

Radiation detection devices, based on the principle of collecting ions formed by the interaction of ionizing radiation in the chamber wall and enclosed gas, comprise a large segment of all radiation detection instruments now in use. The gases usually used are air or tissue-equivalent gas mixtures, or a mixture of a noble gas and a small amount of a polyatomic gas such as methane or isobutane. The content, concentration, and pressure will vary with the specific function of the instrument.

A. Regions of Response

The relationship of the several types of gas ionization instruments can best be illustrated by a hypothetical experiment which utilizes a detection chamber, a variable voltage supply, and a current indicator of high sensitivity and wide range.

In this experiment, if we expose the detection chamber to a constant source of radiation and apply an increasing voltage across the chamber, the measured current output produced by ionization within the chamber will yield five regions of response, as illustrated in Figure 1.

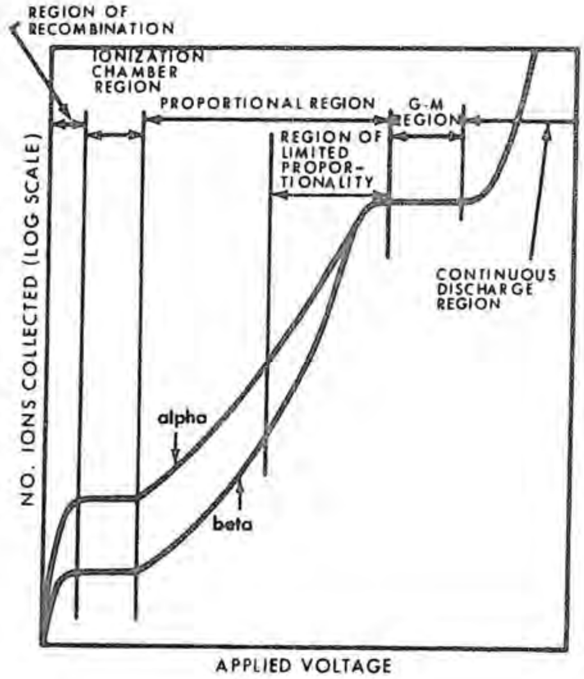


Figure 1.--Regions of Instrument Response

1. RECOMBINATION REGION

In the first region, the ions produced by the radiation will be under very low voltage gradients and will tend to recombine with each other rather than migrate to the electrodes and be collected. This recombination of ion pairs decreases as the applied voltage is increased and finally becomes negligible. At some voltage the field strength will be sufficient to collect essentially all of the ion pairs that are formed. This first region is known as the region of recombination and is usually not useful for the operation of radiation detection instruments.

2. SATURATION OR IONIZATION CHAMBER REGION

This region begins at the voltage at which all ions formed are collected. These are the primary ions resulting from the action of the radiation, and are comprised of ion pairs. The negative portion of the ion pair (electron) is accelerated toward the anode or positive electrode of the chamber, while the positive ion (residue of the atom) is drawn more slowly toward the cathode or negative electrode. For some large increment of voltage above the region of recombination, all ions produced in the gas by radiation are collected by the electrodes. As the voltage is increased within this region, the ions are given more energy and move faster toward the electrodes. However, they do not become energetic enough to produce additional ionization. This second region provides the first of the three operating regions for gas ionization instruments.

3. PROPORTIONAL REGION

If the voltage is increased above the ionization chamber region, the number of ions collected by the electrodes is greater than the number produced by the radiation. Under the voltage gradient, the primary electrons achieve a high enough velocity to cause secondary ionization in the filling gas. This secondary ionization results in an amplification of the number of ion pairs produced by the radiation. Hence, each primary ion pair produces several additional ions which are collected and measured on the instrument.

The number of secondary ions produced for each primary ion pair formed by the radiation is called the "gas amplification factor." As the voltage is raised, the gas amplification factor is increased. Gas amplification factors are normally about 10^3; factors as high as 10^5 or 10^6 are sometimes attained in this region. The number of ions collected is related to the applied voltage, and is proportional to the number of primary ion pairs formed. Thus, an alpha particle with its high specific ionization will produce a much larger pulse of current than will beta radiation with its correspondingly lower energy and lower specific ionization, illustrated by the alpha and beta curves respectively in Figure 1. This fact makes possible pulse height discrimination between alpha and beta which differ in the amount of primary ionization produced.

This proportionality (of the number of ions collected to the primary ionization) is the reason for naming the third region of instrument operation "the proportional region." The upper part of this region, where the two curves begin to approach each other (see Figure 1), is referred to as the "region of limited proportionality" and is not generally used in radiation instrumentation. This limit is controlled by the physical dimensions of the counter and the number of gas atoms present. The true proportional relationship no longer exists in this upper region.

4. GEIGER-MUELLER REGION

In the G-M region the increased voltage accelerates the primary electrons. These latter interact with gas molecules, producing a sequence of ionizing events during their travel to the anode. When the secondary ionization does start, it builds up rapidly, since the secondary ionizing events can also produce more ionization. The buildup of ionization, referred to as a "Townsend avalanche," then collects on the central electrode.

Since a single ionizing event can produce a very large number of ions, the number of ions collected is relatively independent of the applied voltage and the specific ionization of the incident radiation. G-M counters operating in the G-M region provide a gas amplification factor as high as 10^{10} and are extremely sensitive to any radiation which produces even one ion pair. Consequently, individual ionizing events may be detected.

The positive ions (often argon) produced during this avalanche of electrons migrate to the cathode, where their electron deficiency is satisfied by the excess negative charge at the cathode. When the vacant orbits of the gas atoms are filled, electromagnetic radiation is emitted. This radiation, which may be either ultraviolet or x radiation, tends to continue the discharge action, and so sustain the period during which the gas is essentially a conducting medium.

5. CONTINUOUS DISCHARGE REGION

If the voltage is increased above the G-M region the gas arcs, thereby producing a state of continuous discharge.

The experiment described (utilizing a detection chamber, a variable voltage supply, and a current indicator of high sensitivity and wide range) is theoretically possible. But in practice one does not convert an ionization chamber to a proportional counter or G-M counter by merely raising the voltage. For practical reasons these instrument types differ from each other not only in voltage but in configuration and composition of the contained gas.

B. Operational and Practical Considerations

The operational characteristics of detection instruments occur primarily in three of the five regions of instrument response. The first--the ionization chamber region--provides low sensitivity but high range, since it measures only the primary ionization produced. Discrimination between the several types of radiation is not possible except by use of external absorbers. The operating voltage for ionization chamber instruments will usually be between 60 and 600 volts, depending upon the filling gas (usually air at atmospheric pressure) and the physical size and shape of the chamber.

Proportional instruments provide a high sensitivity due to their gas amplification and a (relatively) high range, since the secondary ionization takes place over only a portion of the chamber volume. Due to the proportionality factor which exists in this region, the instrument is inherently capable of discriminating between different types of radiation. Proportional counters are usually filled with a mixture of argon and methane, although air is sometimes used. Operating voltages range from 500 to 5000 volts, depending upon chamber design and filling gas.

The G-M region provides high sensitivity, since any ionizing event occurring within the G-M tube can be counted. It has a low range due to the discharge dead time (the time during which the gas is conducting and therefore insensitive to any further ionizing events). Because of the nature of the discharge, it is impossible to discriminate between the various types of radiation in this region. Geiger-Mueller chambers are usually filled with argon or helium (and in most cases, a quenching vapor) at lower than atmospheric pressure. They operate in the range of 600 to 3000 volts.

To suppress the secondary emission of electrons from the cathode, a quenching agent is used. Organic quenching agents, usually polyatomic molecules such as ethyl alcohol, absorb the energy from the positively charged ion and dissociate into smaller particles which do not emit ultraviolet light and hence cannot eject electrons from the cathode. The useful life of the organically quenched tube is limited by the number of quenching molecules present. Organically quenched tubes have a reasonably flat plateau. The use of halogen gases will produce the same quenching effect; however, the halogen ions apparently recombine after dissociation and therefore do not limit the life of the tube.

The G-M region is illustrated in Figure 2. The threshold voltage is that applied voltage where the pulses are first detected and the avalanche effect results with further voltage increase. Normal operating voltage is selected at approximately one-third the plateau distance to obtain the greatest stability and life of the tube. Sustained operation in the continuous discharge region will result in permanent damage to the G-M tube.

Each of the regions provides certain operating characteristics described above

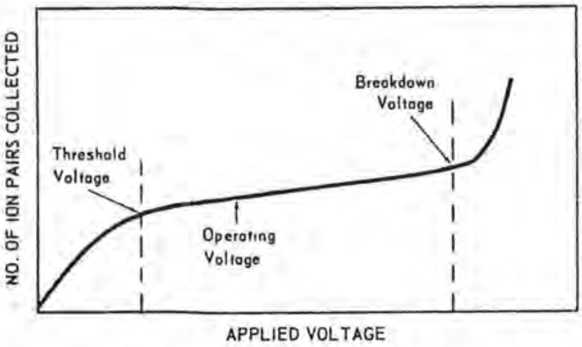


Figure 2.--G-M Response Curve

which makes it useful for one purpose or another: The ionization chamber region, providing a direct indication of the number of ions produced by a given radiation, is eminently suitable for indicating cumulative exposure or radiation exposure rate. Ion chambers are not sensitive to low radiation intensities, but complementary to their low sensitivity is their ability to measure large doses or high radiation intensities. Proportional instruments find their best use in the discrimination between alpha and beta radiation, while G-M instruments are extremely sensitive indicating devices for measuring low intensities of radiation. Both the proportional and the G-M instruments are counters; that is, they provide a pulse of current for every particle or photon which interacts within the chamber. These two types are useful in the measurement of radioactivity.

III. PHOTOGRAPHIC EMULSIONS

The first method used to detect nuclear radiation was the exposure of photographic plates. Becquerel thus discovered radioactivity. Radiation interaction with the silver halide in the photographic emulsion results in ionization. The silver ions produced are attracted to the negatively charged sensitivity center in the crystal, where the silver ions are reduced to free silver. This concentration of silver ions is known as the "latent image" and is proportional to the incident ionizing radiation. The latent image acts as a catalyst during the developing process to convert the grain to free silver. This results in an image amplification factor of approximately 10^{10}. The fixing process dissolves the non-reduced silver halide in the emulsion, leaving the final radiograph.

Photographic emulsions are used extensively in research, autoradiography, quality control, and personnel monitoring.

With the proper selection of film, filters, etc., the film exposure may be related to the type, energy, and quantity of radiation received by the film.

IV. SCINTILLATION MEDIA

Scintillation detectors were in use as early as 1908, and played an important part in the experiments of Rutherford and his collaborators. However, scintillation counting was not widely used until 1947, when the newly developed photomultiplier tube eliminated the tedium of counting scintillations under the microscope. The theory of scintillators is based on the luminescent property of certain materials. The interaction of radiation in a scintillation media results in absorption of energy. This energy raises a molecule or an ion to an excited or elevated energy state. The return to lower energy or metastable state levels, and finally decay to the ground state, results in the emission of energy as visible or near-visible light. The magnitude of each light pulse is proportional to the energy deposited in the medium. The energy deposited in the medium more closely approaches the total energy of the incident radiation as the volume of the scintillating medium increases. The combination of the phototube and suitable electronic circuits has resulted in a very effective counting system.

The sequence of transforming the energy of ionizing radiation into measurable electrical signals is illustrated in Figure 3. The advantages of the scintillation detector are the high efficiency in gamma ray detection compared to gas flow detectors, the capacity

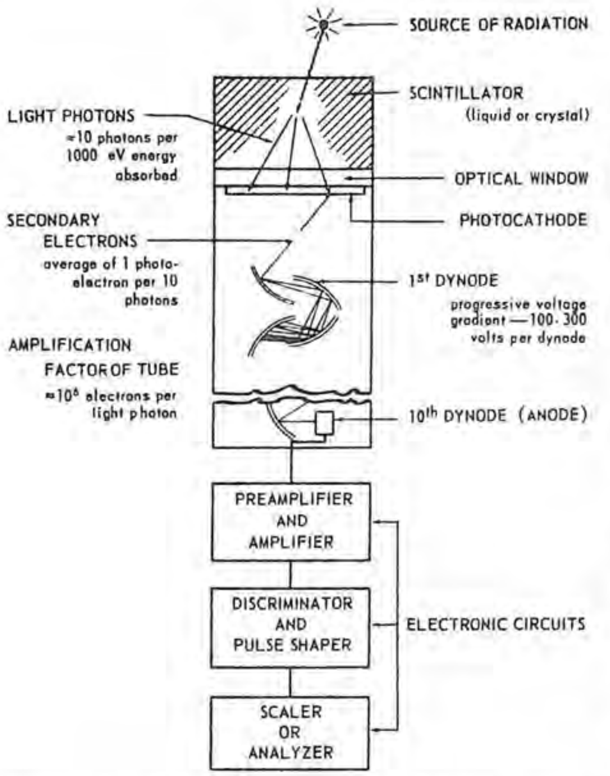


Figure 3.--Schematic Diagram of Scintillator-Photomultiplier Counting System

to handle high counting rates because of the very short resolving time, and the ability to detect different types and energies of radiation. Perhaps the greatest use of scintillation counters is in measuring the energy spectrum of gamma emitters. Liquid scintillation systems have the advantage of high sensitivity, accuracy, reasonable stability and reproducible geometry. They have the disadvantage of poor resolution. Solid scintillation systems have high sensitivity and high resolution, but reproducible geometry is more difficult to attain.

Some of the most common scintillation media are: silver-activated zinc sulfide for the detection of alpha radiation, anthracene, naphthalene, stilbene, and liquid scintillators such as 2, 5-diphenyloxazole (PPO) and 2, 2-p-phenylenebis (5-phenyloxazole) (POPOP) for measuring beta radiation; and thallium-activated sodium iodide crystals for gamma detection.

V. SEMICONDUCTORS

Semiconductors use a dense ionizing medium, so photons of higher energy can be stopped completely within the medium. The ionizing events produce an electric field at the junction surface of two semiconductor materials. The most widely used types of semiconductor devices are diffused p-n junction, surface barrier, and lithium drift detectors.

A. Diffused p-n Junction

The diffused p-n junction detector obtains its name from its manufacturing process. A slice of p-type silicon or germanium crystal with a layer of n-type impurity (usually phosphorus) deposited on the surface is heated to form a p-n junction just below the surface. The phosphorus may also be painted onto the silicon and made to diffuse into it by applying heat. Since the n-type crystal has an excess of electrons and the p-type has an excess of "holes" (holes may be thought of as unit positive charges), the natural action of the crystal tends to align the electrons on one side of the junction and the holes on the other. Thus, a difference of potential is built up across the junction.

By applying an external voltage to the crystal of such polarity as to oppose the natural movement of electrons and holes (reverse bias) the potential barrier across the junction is increased and a "depletion region" produced. (See Figure 4.) This

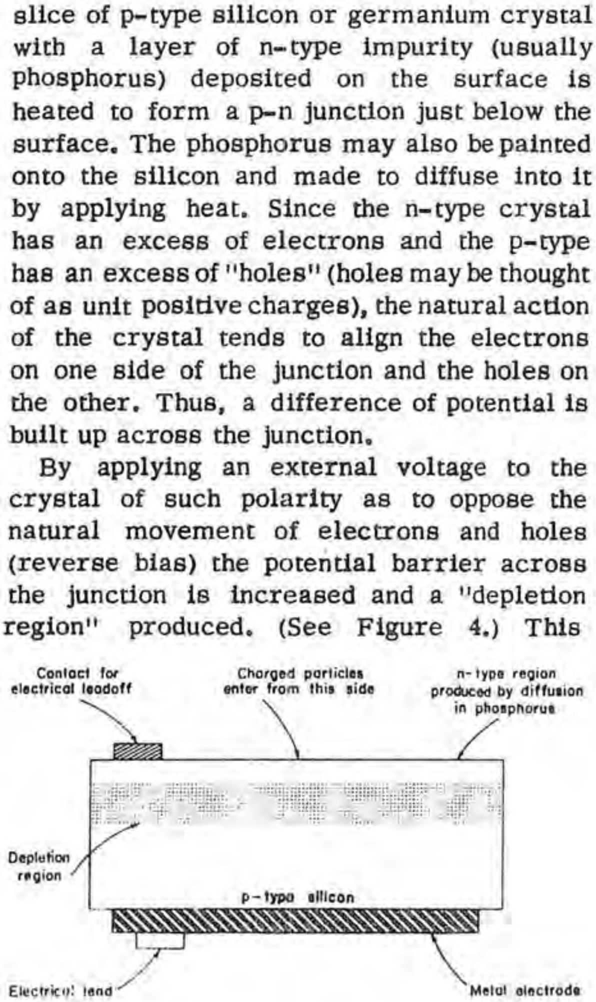


Figure 4.--Schematic Representative of a Diffused p-n Junction Detector

depletion region is the sensitive volume of the detector, and is analogous to the gas volume in a gas ionization detector. Charged particles entering the depletion region produce electron-hole pairs analogous to ion pairs produced in gas ionization chambers. Since an electric field exists in this region, the charge produced by the ionizing particle is collected, producing a pulse of current. The size of the pulse is proportional to the energy expended by the particle.

B. Surface Barrier Detectors

The operating principle of the surface barrier and lithium drift detectors is the same as for the p-n junction, in that a depletion region exists when an electric field is produced. The method of producing the depletion region, as well as its dimensions and location within the crystal, vary from one type to another.

The surface barrier detector depends for its operation upon the surface states of the silicon or germanium. At the surface of a piece of pure crystal, an electric field exists such that both holes and electrons are excluded from a thin region near the surface. For n-type crystals, the field is such as to repel the free electrons from this region. If a metal is joined to the crystal the free electrons are still repelled, but a concentration of holes is produced directly under the surface. If a reverse bias is then applied, a depletion region is produced. (See Figure 5.)

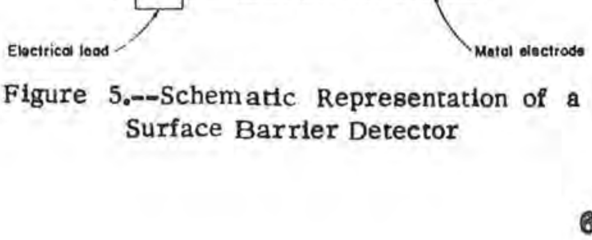


Figure 5.--Schematic Representation of a Surface Barrier Detector

Surface barrier detectors give better resolutions for particle spectroscopy than p-n junctions, but deeper depletion regions are possible with the latter. (The deeper the depletion region, the higher the energy of particles which can be analyzed, since the particle must expend all its energy in the depletion region.)

C. Lithium Drift Detectors

The lithium drift detector is produced by diffusing lithium into low resistivity p-type silicon. When heated to about 150° C under reverse bias, the lithium ions drift into the junction in such a way that the impurities are compensated to form a depletion region of high resistivity intrinsic silicon. Wide depletion regions may be obtained at low bias voltages in this manner.

Semiconductor detectors have been popular mostly in the area of charged particle spectroscopy. Much better resolution can be obtained in these devices than with scintillators or grid-type ionization chambers.

VI. CHEMICAL DECOMPOSITION INDICATORS

Since radiation can cause ionization, it is possible to use the ionization produced in a chemical system as an indication of the amount of radiation received. This is done in the case of chemical decomposition indicators: Ions produced by radiation combine chemically to form new compounds or change chemical characteristics from those existing in the pre-irradiation stage.

A typical chemical decomposition indicator is a chloroform-water mixture. When exposed to radiation, it produces hydrochloric acid in proportion to the radiation absorbed. This formation of acid decreases the pH. By the use of a suitable indicator, it is possible to ascertain when a predetermined dose has been received by the chemical system. An indicator frequently used in this system is bromcresol-purple.

An inherent drawback of chemical decomposition systems is the fact that the sensitivity to radiation is quite low. While these systems require higher exposure rates for detectable chemical change, newer systems are being developed to respond to lower exposures.

VII. RADIOPHOTOLUMINESCENCE AND OPTICAL ABSORPTION

Radiophotoluminescence is the phenomenon by which certain materials undergo changes in their photoluminescent properties after irradiation. Irradiated material will fluoresce when activated by light of the proper wavelength (ultraviolet or near-ultraviolet), while unirradiated glass will not fluoresce under the same conditions.

Silver-activated phosphate glass has proved a useful radiation detecting medium, exhibiting the photoluminescence property. The ionizing radiation liberates electrons within the glass. These are trapped by the Ag^+ ions of the glass. The resulting metallic silver centers serve as the origin of the photoluminescence. After radiation exposure of the glass, it is subjected to ultraviolet light and the resulting fluorescence detected by a photomultiplier tube. The intensity of the light emitted is proportional to the dose. Personnel dosimeters of this type have been developed which cover the range from 10 mR to 10^4 R.

Higher radiation doses may be determined by measuring the increased optical density of the glass after irradiation. This is done by making optical transmission measurements using light of the proper wavelength for the dose range of interest. This principle is useful from 10^3 to 10^6 rads.

VIII. THERMOLUMINESCENCE

Thermoluminescence is the phenomenon whereby certain materials can absorb and store energy from ionizing radiation, and release this energy as light in the visible or near-visible region of the spectrum when the material is heated. Irradiation of a luminescent material results in the excitation of electrons (see Figure 6) from the ground state to the conduction band of the material (a). The electrons are then trapped in a metastable state, present as imperfections in the crystal lattice of the material (b).

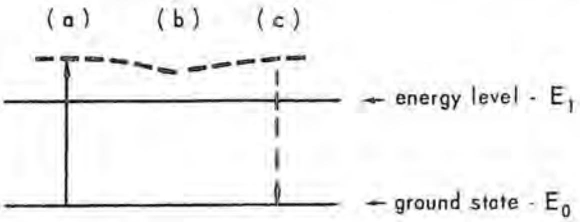


Figure 6.--Schematic of Electron Energy Bands

The electrons stored in the metastable state are activated by the addition of energy in the form of heat. The electron is then able to return to the ground state, and the energy released as light (c). The light intensity is proportional to the energy absorbed in the material from the original ionizing radiation. The TLD (thermoluminescent dosimetry) system requires a separate readout system which can measure either the integrated light output during, or the peak light output after, a constant heating cycle.

TLD is most widely used in personnel dosimetry and special research projects.

IX. CALORIMETRY

Calorimeters take advantage of radiation's heating effect to detect its presence. A calorimeter is a device for the measurement of quantities of heat. Calorimeters have received greatest application in the determination of the radiation-energy absorption in material, since ultimately the absorbed energy is degraded into heat. Calorimetry can also be used to determine the activity of a sample of radioactive material. The main advantage of the calorimetric method for measuring absorbed energy or activity is its inherent accuracy. For dosimetry purposes a direct reading of energy absorption can be obtained. However, the rate of heat input is so small that only very high intensities of radiation can be measured. For this reason, calorimetry is not used for routine monitoring purposes. Applications include the measurement of the activity of curie amounts of alpha emitters, the measurement of the energy of particles produced by particle accelerators, the dose from high intensity x-ray machines, etc. Calorimetry provides the only fundamental method for measuring absorbed dose.

X. SUMMARY

Radiation detection instrument design has been dictated by the exposure rate or activity to be measured, the type and energy of the radiation, accuracy desired, and the area of interest in which the data are to be used. Each of the primary means of detection discussed has inherent advantages and disadvantages. Laboratory and research studies should utilize all types of media for specific applications. Survey instruments use predominately gas ionization and scintillation media. Personnel monitoring instruments rely on gas ionization, photographic emulsions, and thermoluminescent media for detection of radiation.

As a result of these considerations, radiation detection instruments may be divided into three groups:

1. Personnel monitoring instruments, which measure accumulated exposure that can be related to the dose equivalent.
2. Survey instruments designed to measure exposure rate in milliroentgens per hour (mR/hr) or activity in counts per minute (cpm).
3. Laboratory instruments designed primarily to relate the ionizing events in terms of units of activity (curie).

BIBLIOGRAPHY

A Manual of Radioactivity Procedures (National Bureau of Standards Handbook No. 80 [Washington, D.C.: Supt. of Documents, U.S. Government Printing Office, Nov. 1961]).

Attix, F. H., and Roesch, W. C., Radiation Dosimetry (Vol. II Instrumentation) (2nd ed.; New York: Academic Press, Inc., 1966).

Becker, K., "Photographic, Glass or Thermoluminescence Dosimetry," Health Physics, Vol. 12, No. 7 (1966).

Blatz, H., Introduction to Radiological Health (New York: McGraw-Hill Book Co., Inc., 1964).

Brown, W. L., "Introduction to Semiconductor Particle Detectors," IRE Transactions on Nuclear Science, Vol. NS-8, No. 1, 1961.

Chase, C. D. and Rabinowitz, J. L., Principles of Radioisotope Methodology (2nd ed.; Minneapolis: Burgess Publ. Co., 1962).

Choppin, G. R., Experimental Nuclear Chemistry (2nd printing; Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1963).

Friedlander, G., Kennedy, J. W., Miller, J. W., Nuclear and Radiochemistry (2nd ed.; New York: John Wiley & Sons, Inc., 1964).

Price, William J., Nuclear Radiation Detection (2nd ed.; New York: McGraw-Hill Book Co., Inc., 1964).

Survey Instruments

I. INTRODUCTION

None of the ionizing radiations is detectable by any of man's five senses, therefore all indications of their presence and intensity must be obtained by instruments. Radiation detection devices, like other measuring instruments, operate because of some effect the phenomenon being measured has on matter. In the case of radiation, this effect is ionization. Survey meters are similar to other radiation detection instruments in their operational characteristics. A good survey meter should be portable, rugged, sensitive, simple in construction, and reliable. Portability implies lightness and compactness with a suitable handle or strap for carrying. Ruggedness requires that an instrument be capable of withstanding mild shock without damage. Sensitivity demands an instrument which will respond to the type and energy of radiation being measured. Rarely does one find an instrument capable of measuring all types and energies of radiation that are encountered in practice. Simplicity in construction necessitates convenient arrangement of components and simple circuitry comprised of parts which may be replaced easily. Reliability is that attribute which implies ability to duplicate response under similar circumstances. All these conditions are not met in any one instrument, but they are approached in many. In any monitoring operation, one must select the proper instrument, use it intelligently, and then be able to interpret the results of the meter readings.

II. IONIZATION CHAMBERS

A. Theory

Ionization chambers are instruments in which the ionization initially produced within the chamber by radiation is measured without further gas-amplification. Primary ions formed in the chamber are attracted to the respective electrodes, and the current pulses are amplified externally to a measurable current. The gas-amplification factor is thus one.

B. Physical Description

Ionization chamber survey meters have three principal components: (1) the ionization chamber; (2) the electronic circuit; and (3) the dial or indicating meter.

(1) Ionization Chambers are usually about 30 to 50 cu. in. in volume and are filled with air at atmospheric pressure. The chamber wall design and type of material used in its construction determine the types of radiation to which it is sensitive. The larger the chamber the more sensitive the instrument and the greater the voltage required for proper operation. Practically all chambers have walls that conduct electricity and serve as the cathode, while wires mounted in the center of the chambers constitute the anode. Operating voltage is supplied by batteries and has a magnitude of about 100 volts. The current which flows is directly related to the type, energy, and quantity of radiation penetrating the chamber. With movable shields, as in the "Juno," it is possible to discriminate between types of

radiation. In general, ionization chamber survey meters are used to measure relatively high level intensities. Their low sensitivity enhances their capacity to measure radiation at higher dosages or exposure rates.

(2) The electronic circuit is actually a precision amplifier. Vacuum tube or transistor circuits are used to build up the feeble ionization current so that it may be measured directly by a microammeter. Most survey meters incorporate a system whereby the amplification characteristics of the circuit may be changed by factors of ten. This enables the operator to change the instruments' range and sensitivity.

Since there is a gas amplification factor of unity, circuit amplification becomes a problem which one does not necessarily have in a GM instrument. On the other hand, there is no problem of quenching the discharge or of losses due to coincidence.

(3) The indicating meter is usually a microammeter that registers the amplified current. The dial is generally calibrated in milliroentgens/hour or, in the case of contamination monitors such as the "Samson," in counts per minute.

C. Operation

Most ionization chamber survey instruments have a selector switch marked "off," "wait," and x1, x10, x100. When the switch is off, the batteries are disconnected and the meter is short-circuited making the instrument inoperative. With the switch in the wait position, the batteries are connected, permitting the circuit to warm up and the instrument to be zeroed after a warmup period of from 1 - 5 minutes. The meter is connected while the ionization chamber is disconnected making it possible to adjust the meter accurately to zero even in the presence of radiation.

The ionization chamber does not wear out or suffer changes in characteristics as GM tubes do; however, the circuit of the ionization chamber survey meter has more elements that can get out of adjustment if not properly handled. Loose leads and weak batteries are a source of trouble which can be readily serviced. Other difficulties are usually caused by faulty circuits which cannot generally be fixed without the aid of a competent service man.

No aural indication is used in IC instruments and thus the operator must constantly watch the meter to ascertain the field intensity. There is a lag between the instant radiation enters the chamber and the time when the meter reaches its maximum reading; therefore, one must allow time for the meter to reach its maximum before taking a reading. This is on the order of a few seconds.

D. Calibration

Instruments are designed by manufacturers to read directly in radiation intensity units, generally mr/hr or r/hr; however, there is considerable error in a direct reading, since the characteristics of individual components causes variations in instrument response. Each instrument must be calibrated for accurate interpretation. Instrument response intended by the manufacturer is related to one type of radiation, usually of a definite energy range. If radiation of a different energy or type is measured, the results will be incorrect and the instrument must be recalibrated with radiation of the same type and energy that is to be measured.

For gamma ray calibration an ionization chamber instrument can be checked by placing it in a known field of radiation. Radium and Co^{60} are the most frequently used sources for gamma calibration. A plot of scale readings versus true radiation intensity can be made by comparing scale readings at known distances from the source against the true intensities at these distances, employing the formulae given below.

$$I = \frac{\text{milligrams of Ra}}{D^2}\text{, or } I$$

$$= \frac{1.59 \times \text{millicuries of Co}^{60}}{D^2}$$

where: I = Intensity, mr/hr

D = Distance from source to detector, yards

From five to ten equally spaced scale readings should be taken and a graph of these values versus the calculated intensities at the corresponding points should be plotted on linear graph paper. A typical calibration curve would plot meter readings on the ordinate and corresponding "true" intensities on the abscissa.

When calibrating an instrument, the reference point of the instrument is generally considered as the center of the sensitive volume. It should be pointed out that the ionization chamber type survey instrument, when properly calibrated, will give a good measurement of x- or gamma radiation intensity, but for alpha and beta radiation, only qualitative measurements can be made.

E. Uses

In x-ray survey work, calibrated ionization chamber instruments are very useful for measuring dose rate. Ion chambers are used extensively for beta and gamma survey work, and if properly modified, they may be used for neutron monitoring.

F. Typical Instruments

Cutie Pie: Perhaps the most widely used and one of the most versatile ionization chamber instruments available for radiological survey work is the Cutie Pie. These are available with maximum scale readings up to 50 roentgens/hour.

Condenser r-meters: A very reliable and accurate instrument for x-ray calibration is the condenser r-meter. By nature, the condenser r-meter measures cumulative dose. It consists of a charger-reader mechanism and several detachable ion-chambers. These chambers are charged and then left in a radiation field for a known time. When read on the charger-reader, they show the total dose received during the time of exposure. Ionization chambers for condenser r-meters are available in ranges from 0.025 roentgens full scale to 250 roentgens full scale and are nearly energy independent (- 2%) for x-ray energies of 30 Kev effective to 400 Kev effective.

III. GEIGER-MUELLER INSTRUMENTS

A. Theory

Essentially, the theory of ion collection in the GM type detector is the same as for the IC instrument except that there is the formation of secondary electrons; that is, primary ions, formed by the incident radiations, are accelerated (given energy) by the high voltage potential and this added energy enables them to produce secondary ion-pairs. The ratio of the total number of secondary ion-pairs produced to the primary ion-pair (Gas Amplification Factor) may be as high as 10^9. For control of the amplification, a quenching gas is introduced. The avalanche, caused by radiation entering the Geiger-Mueller tube, sends a pulse to the indicating unit of the survey instrument. The quenching gas functions to stop the avalanche and makes the GM tube ready for another ionization event. The amplification, inherent in the detector tube, allows a single beta particle or gamma photon to be detected.

B. Physical Description

The principal elements of the portable Geiger counter are: (1) the GM tube with its housing; (2) the electronic circuit; and (3) the meter.

(1) The GM Tube is essentially a glass tube filled with an inert gas at less than atmospheric pressure. The filling gas, usually argon, yields ion pairs (when irradiated). Generally, the tube wall is the cathode and the wire traversing the axis of the tube is the anode. Some tubes have a thin window which admits alpha particles, but these are not used in survey meters to any extent.

Each GM tube has its own characteristic curve of counts/minute versus voltage, which will vary with usage of the tube. The operating voltage must be well up on the Geiger plateau for the proper operation, and it is generally in the range of 1 to 2 thousand volts.

To count efficiently, Geiger tubes must have adequate means for quenching the ionization avalanche started by a particle entering the tube. In survey Geiger counters the tubes are invariably self-quenching; that is, the gas within the tube contains from 10 to 25 per cent vapor of a substance such as ethylene or iso-butane. Quenching gas is decomposed by radiation, therefore a self-quenching tube has a limited lifetime. It is thus obvious, that a Geiger counter should not be left turned on when not in use, especially near a source of radiation.

With a self-quenching tube there is a brief lapse of time from the moment one particle enters the tube until the tube is ready to count the pulse produced by another particle. The initial ionization, the avalanche, the registration of the pulse, and the quenching, all take place in the matter of a few microseconds; then the tube must be cleared in the residual ions. This clearing requires a few hundred microseconds. Dead time becomes important when measuring intense radiation fields.

Most Geiger tube walls are designed so that all but the weakest beta particles may enter. Allowing for the errors due to simultaneous entry, each and every beta particle entering the tube will be counted. Gamma ray counting is not nearly so efficient.

Since one measures each beta particle and each gamma ray that produces ionization within the sensitive tube volume, the instrument is extremely sensitive to radiation, and on the most sensitive scales background levels can be read.

A discriminating shield is provided for the GM tube or probe which when open admits both beta and gamma. With the shield closed only gamma is admitted.

(2) The Electronic Circuit provides the desired voltage to the GM tube, assists in quenching the discharge and receives, amplifies and transforms pulses from the tube to the type of impulse that can be heard in an earphone and registered on a microammeter.

(3) The Indicating Mechanism on most Geiger counters is usually twofold; that is, earphones for aural indication and a meter for visual indication. The meters are in reality microammeters that indicate radiation intensity by a pointer on a scale. The pointer or needle will waver slightly and an average reading should be used. In general, the dial is calibrated either in counts/minute or in milliroentgens/hour, or both. Also, the instrument has a switch for selecting different ranges of sensitivity. For the mr/hr scale, the sensitivities are usually indexed indicating full scale values at a particular switch position, whereas the counts/minute scale is usually marked by x1, x10, x100, or x1,000 of full scale as read on the face of the dial.

Equipment failure is generally due to batteries (some instruments have a battery check in the "on" position), loose connections or faulty GM tube.

C. Operation

The operation of the GM Survey Instrument is essentially the same as that of the IC Survey Instrument. The warmup period is much less critical, and usually 5 to 10 seconds is ample. Care should be taken not to exceed the maximum capacity of the instrument; such excessive exposure will likely damage the GM detecting tube. The GM tube is in operation when in the "on" position and no zero adjustment is possible. It is important to remember that GM survey meters are sensitive instruments and in general do not read high levels of radiation intensity.

D. Calibration

The calibration of GM instruments is the same as for the IC type. The only change that might be noted is that a smaller source of radiation might be used for calibration, since the sensitivity of the GM is much greater than that of the IC instrument.

E. Uses

Survey Geiger-Mueller instruments are useful for low level beta, and gamma ray survey work; with proper modification, they may also be used to monitor for neutrons. Portable GM instruments are available in a variety of types and full scale ranges from .2 mr/hr to 50 mr/hr.

IV. PROPORTIONAL SURVEY INSTRUMENTS

A. Theory

This type instrument derives its name from the fact that it operates in the proportional region of the typical instrument response curve. The probe has an extremely thin window which admits alpha particles to the ionization chamber. The operating voltage is quite high, in the order of 1,500 to 4,000 volts. Gas amplification factors are in the order of 10^5 to 10^6. This instrument can be made to respond only to alpha particles, by choosing the proper operating point in the proportional region, and by circuit adjustment. Alpha particles, since they have the highest specific ionization, give greater pulses than do beta and gamma; thus, by properly adjusting the input sensitivity of the main instrument circuit, we can eliminate all indications from the detecting element except those produced by alpha particles.

B. Physical Description

Proportional survey instruments have three principal components: (1) the ionization chamber; (2) the electronic circuit; (3) the meter.

(1) The Ionization Chamber has walls which serve as one electrode, and wires transversing the chamber which function as the opposite electrode. Such a chamber contains air or gas at normal pressure. A thin window of nylon, etc., allows alpha particles to enter, and the ionization they produce causes secondary ionization proportional to the production of primary ion pairs.

(2) The Electronic Circuit is more complex than that used in other type instruments. It is necessary to control the chamber voltage within fairly narrow limits.

(3) The Meter is marked in counts/minute with several sensitivity scales. The dial is used in a manner already discussed.

C. Operation

The operation of the proportional radiation survey instrument is similar to other instruments. A warmup period of several minutes is usually required to allow the circuit to become properly energized.

D. Calibration

Calibration of proportional meters for alpha contamination is accomplished by means of known quantities of the alpha emitter in question deposited on planchets.

E. Uses

Proportional survey instruments find their greatest application in alpha survey work. In making any alpha survey, the instrument probe must be extremely close to the surface being monitored.

V. SCINTILLATION SURVEY INSTRUMENTS

A. Theory

Scintillation counters depend upon the light produced when ionizing radiation interacts with a phosphor or crystal of certain substances capable of producing this light. The scintillations produced in the phosphor or crystal are then permitted to fall on a photomultiplier tube which converts the light pulses to electrical impulses. These electrical impulses may then be amplified and caused to register on a microammeter.

B. Physical Description

Scintillation type survey instruments have four principal components: (1) the scintillating phosphor or crystal; (2) the photomultiplier tube; (3) the electronic circuit; and (4) the meter.

(1) Scintillating Phosphors may be liquid or crystalline, but for survey work, the crystalline type is, at present, preferable. If one is interested in detecting alpha radiation, a silver activated zinc sulfide screen (similar to the sensitive screen of a television picture tube) is generally used.

For the detection of beta radiation, an anthracene crystal, covered with a thin metal foil to shield out alpha radiation, is preferable; for x- or gamma radiation a sodium iodide crystal is generally employed. When it is desirable to detect neutrons, a secondary reaction must be employed such as the reaction of thermal neutrons with boron in which an alpha particle is released. The alpha particle may then be detected with a ZnS phosphor.

(2) The Photomultiplier Tube picks up light flashes from the phosphor which is in contact with it, and converts these light flashes to electrical impulses. It consists of a photosensitive screen, which emits electrons when light falls on it, and a series of dynodes at a positive potential with respect to the photocathode and with respect to each other. An electron liberated in the photocathode is accelerated to the first dynode, which is about 100 volts positive to the photocathode, where it knocks out additional electrons that are accelerated toward the second dynode. The second dynode is 90 to 100 volts positive to the first dynode and the electrons striking the second dynode produce still more electrons. This multiplication process proceeds through each successive dynode until the electrons reach the anode. From this process, the current amplification is in the neighborhood of 10^9 - 10^{10}.

(3) The Electronic Circuit serves to maintain the voltage across the elements of the photomultiplier tube and to amplify the current impulses from the photomultiplier tube to a magnitude great enough to read on a meter.

C. Operation

Operation of scintillation survey instruments is similar to that of ion chambers and GM instruments. It should be pointed out that the photomultiplier tube of a scintillation instrument will be ruined if exposed to light without first removing the voltage applied to the tube.

D. Calibration

Scintillation instruments may be calibrated in the same manner as is used for a GM or an ion chamber instrument.

E. Uses

As previously pointed out, scintillation devices may be used to detect either alpha, beta, gamma, or x-rays or neutrons simply by placing the proper phosphor in contact with the photomultiplier tube. Scintillation detectors are very sensitive, more sensitive and efficient than GM counters, particularly to gamma radiation. They may be used to detect extremely low levels of activity, as the noise background may be kept much lower than that encountered in the circuiting of a GM or ion chamber instrument. Losses due to dead time in a scintillator are very slight, as light flashes may be produced in many portions of the phosphor at the same time, and the decay time of these flashes is very short; consequently, scintillators are useful for measuring very high radiation intensities.

GPO 906-071

Personnel Instruments

I. INTRODUCTION

A. It is extremely difficult to measure the absorbed dose or energy deposition in tissues from varieties of radiations. The conditions under which one must work are generally complex, ill defined and irregular. Normally, the best one can hope for is an estimate of the exposure dose to x and γ radiation. To do this requires, usually, not one instrument or method but several. Perhaps the most practical, although less accurate, is the film dosimeter. With adequate definition of radiation conditions and proper control and interpretations, it is possible to evaluate radiation exposures under which personnel must work. This usually gives one enough material from which the absorbed dose might be inferred. Then if such inferences are further substantiated with dosimeter or pocket chamber data and dose rate information from survey instruments one could finally arrive at a rather reliable dose estimate. Therefore the devices of most general importance and which will be discussed below are: (1) film badges, (2) pocket dosimeter, and (3) pocket chambers. Survey meters are covered elsewhere in this manual. Due to the increasing interest in chemical dosimeters, rather than their importance as a personnel monitoring instrument, certain fundamental properties of this device are also mentioned.

II. FILM DOSIMETRY

A. Emulsion

There are a variety of different types of emulsions but the feature in common is a gelatin base with silver halide which is spread on film (cellulose) or glass. The thickness ranges from a few microns to several hundred microns. The most common thickness for nuclear emulsions is from 10 to 25 microns. This corresponds to a mass of about 2 to 5 mg/cm^2. Over the emulsion there is usually a thin protective coating of gelatin sometimes referred to as a T coat (about 0.5 microns). The silver halide grains in most emulsions are silver bromide. The grain size is quite important in determining sensitivity. Of course other constituents of the emulsion as well as developing techniques may modify sensitivity. The constituents or type of the emulsion may be varied depending on the type radiation and the levels to be encountered. For example, if one is concerned with recording the tracks of heavy particles, the grain abundance is adjusted to about 3 times that used in ordinary optical emulsions. Also, certain sensitizers may be added, for example, Boron-10, to greatly increase the sensitivity for thermal neutrons.

B. Theory of Latent Image Formation

The radiation loses energy by setting free or raising the energy of one or more electrons into the conduction energy band of the crystal. Probably more than one ionization event is required. The electrons migrate about the crystal, eventually being trapped in "sensitivity centers" which might consist of impurities or deformities in the crystal lattice. The electrostatic potential set up about the centers results in the accumulation of some silver ions which tend to move freely in the crystal. The number of ions which take part in such migration depends primarily on the temperature. These ions collect around the sensitivity centers due to the attraction for the negative electrons. Ultimately, the ions are neutralized to form the silver atoms. These atoms constitute the latent image of the emulsion and act as a catalyst during the development process to completely convert the grain to silver. Thus, the development process is merely an amplification (of about 10^{12}) of what has already transpired. The probability of a latent image being established increases with an increase in the number of electrons in the sensitivity centers; and this number is proportional to the energy absorbed by the emulsion from the radiation.

C. Limitations

1. ENERGY DEPENDENCE

Figure 1 demonstrates the sensitivity of Ilford Line film to x-rays as a function of their effective energy. The gradual rise in sensitivity as the energy decreases is due primarily to the photoelectric interaction with silver at the lower energies. The decrease in sensitivity below 50 Kev is due to absorption within the outer film covering. Although not shown in Figure 1, the sensitivity would tend to decrease slowly as the energy of the photons is increased above 1 Mev. If the film is used to measure dose from photons of known energy and is calibrated for this energy, the measurements would be reliable. On the other hand, if a wide range of energies are to be encountered, the energy dependence should be reduced such that the response is essentially flat from above 50 Kev to 3 Mev (energies outside of these limits should not be measured in units of roentgens[1]). There are several methods which have been used to reduce the energy dependence. A lower silver bromide content would be of some value but this may affect resolution as well as sensitivity.

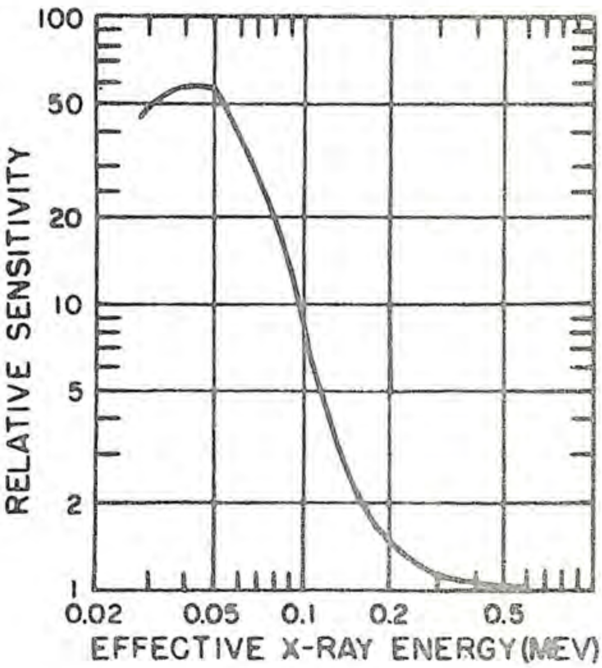


Figure 1

(Reprinted from Hine and Brownell)

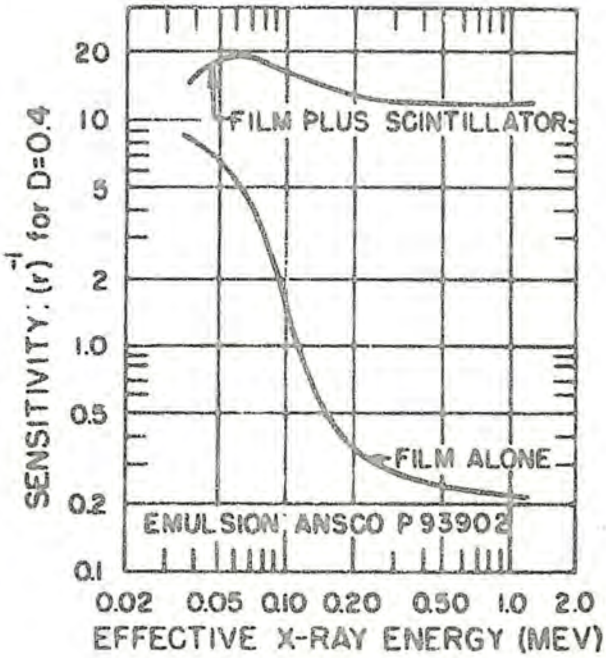


Figure 2

(Reprinted from Hine and Brownell)

Organic scintillators have been used with some success.[2]

The ultra violet fluorescence effectively increases sensitivity as well as improves the energy response. The most common approach has been to utilize a system of filters calibrated to yield information as to the energy of the unknown photons.[3] Such information may then permit an evaluation of the exposure dose.

2. ANGULAR DEPENDENCE

Actually, the dose to material (tissue or emulsion) is independent of the angle of incidence since dose is computed first to an infinitesimal slab then integrated over the entire volume. But film darkening is dependent on angle of incidence. Table 1 illustrates this dependence.

Table 1. Relative Film Badge Sensitivity for γ-Rays Incident at Various Angles

Angle of Incidence	0.11 Mev	0.20 Mev	1.2 Mev
0° (perpendicular incidence)	1.00	1.00	1.00
22.5°	0.87	0.92	0.97
45°	0.46	0.73	0.91
67.5°	0.33	0.45	0.92
90°	0.16	0.41	0.94

3. RATE OF EXPOSURE

The bulk of evidence indicates that the photographic effect is independent of the rate at which that exposure is produced. It is certainly true for intensity ratios of at least 1 to 10,000. There is little knowledge of the effect of microsecond exposures but due to the phenomenon of multi hits (one grain hit by more than 1 particle), it is probably of some significance. On exposures of several days, there is some fading of the film. The fading is influenced by both temperature and humidity. By selection of films of different sensitivity, film dosimeters of wide ranges can be devised. For example, DuPont 502 film can be used from 100 mr to 10 r, while Eastman 548-0 double coat is suitable from 500 to 10,000 r.

4. DEVELOPING TECHNIQUES

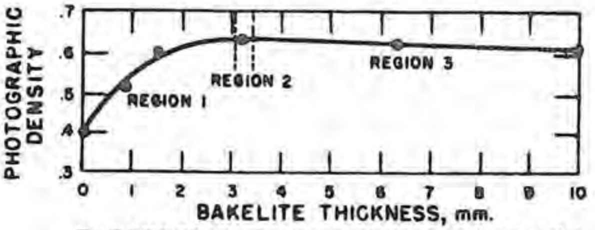
Even slight deviations in the developing time, type, quality and temperature of developer may affect the density in film dosimetry. Therefore, the usual procedure is to develop a set of known standards with each batch of unknown films.

5. MATERIAL SURROUNDING FILM PACKET

Normally, tissue equivalent or air equivalent material is used (lucite, bakelite) having an open window for the detection of beta particles. The thickness of the material must be sufficient to permit electronic equilibrium for the particular energy to be measured. Obviously, in a mixed radiation field, this ideal is difficult and sometimes impossible to achieve. This effect is demonstrated in Figure 3 where the equilibrium thickness is indicated by the dotted line.

D. Neutron Film Dosimetry

1. The measurement of thermal neutron dosage may be accomplished through the



ELECTRONIC EQUILIBRIUM IN BAKELITE, OBTAINED WITH CO^{60} RADIATION

Figure 3

comparison of film densities under cadmium and brass filters. These two filters are designed to attenuate gamma radiation by the same amount. However, because of the (n, γ) reaction induced in the cadmium by the thermal neutrons, the exposure behind the brass when thermal neutrons are present is lower than behind the cadmium. If a wide spectrum of gamma energies are present, a modification of this approach could be used. As an alternative method of measuring neutron dosage, track plates may be used. The fast neutrons interact by (n, p) reactions and the proton recoil tracks are counted and their range is measured. The thermal neutrons interact with the emulsion by N^{14} (n, p) C^{14}; a cadmium filter is usually employed to distinguish between the slow and fast neutrons. The sensitivity for slow neutrons may be increased by adding B^{10} to the emulsion since boron has a very high absorption cross section for thermal neutrons.

III. CHEMICAL DOSIMETRY

Due to the increased use of kilocurie strength sources, there is a growing need for higher range dosimeters. A considerable amount of research is presently underway in this field in an attempt to develop both solid and liquid dosimeters which by color change, photoluminescence, or other alteration, the radiation dose may be estimated.

The principle of such dosimetry is based on the Bragg-Gray Theory which states that the energy absorbed for unit mass of a substance (dE/dm) is related to the degree of ionization (J_m) per unit mass produced in a small air cavity within the material.

$$\frac{dE}{dm} = (W)\,(s_m)\,(J_m)$$

W is the energy absorbed per ion pair in the gas; s_m is the relative mass stopping power in the material to that in the gas. If this principle is used to calibrate the material to be used for a dosimeter, a very high degree of accuracy is possible for a variety of different types of dosimeters.

The effect produced in most liquid dosimeters is due primarily to the radiation effect in water. The primary phenomenon in the irradiation of water is the formation of the free radicals H and OH. These may react to form the products, hydrogen, H_2 and hydrogen peroxide, H_2O_2, as well as to re-combine to form water. Hydrogen may then act as a reducing agent on any chemical present capable of being reduced; and H_2O_2 may act as an oxidizing agent on any chemical capable of being oxidized. One of the more useful chemical dosimeters consists of a mixture of water and a chlorinated hydrocarbon such as chloroform, trichloroethylene, or tetrachloroethylene. In such indicators, hydrochloric acid is produced which may be indicated by means of organic dyes which change color depending on the hydrogen ion concentration.

Silver activated phosphate glass is a particularly useful material for a solid chemical dosimeter. The primary phenomenon of radiation interaction is through a process of radiophotoluminescence. As a result of ionizing radiation, new stable photoluminescent centers are created in certain materials. After irradiation, the materials will fluoresce under light of the proper wave length (usually in the ultra-violet), while unirradiated glass will not fluoresce under the same conditions.

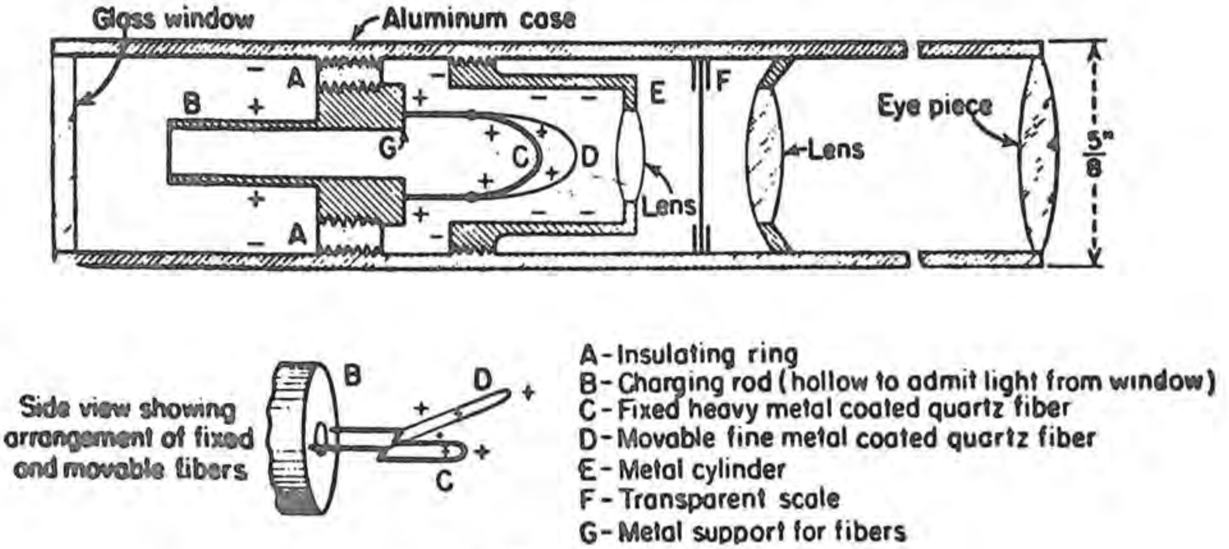
As a final point which should be emphasized, at the present time chemical dosimeters are not very useful in the dose ranges of interest in personnel monitoring. Most chemical dosimeters do not measure exposure doses below about 10 r.

IV. DOSIMETERS AND POCKET CHAMBERS

A. Dosimeters

A pocket dosimeter (Fig. 4) is a chamber containing two electrodes, one of which is quartz fiber loop free to move with respect to its mounting. Like charges are placed on the loop and its moutning, which forces the loop outward from the mount due to the repulsion of like charges. Ionization in the chamber reduces the charge and allows the fiber to move toward its normal position.

An optical system and a transparent scale are all enclosed in the instrument which is about the size and shape of a large fountain pen. The fiber is fused to a metal frame and the microscope is focused on a portion of this fiber. Radiation entering the chamber causes ionization within the sensitive volume. This ionization discharges the electroscope; the distance the fiber moves being proportional to the dose received in the chamber. Instruments of this type can be made sufficiently rugged to withstand the shocks of normal human activity, are small enough to be worn comfortably, and are very useful for measuring integrated exposures. Dosimeters usually are made to have a full scale deflection corresponding to 200 mr, but can also be made with other sensitivities such as 100 mr, 1 r, 10 r, 100 r, etc. The great advantage of this type of instrument is that it can be read at any time without the aid of a supplementary charger-reader by simply holding it up to a source of light and looking into it.



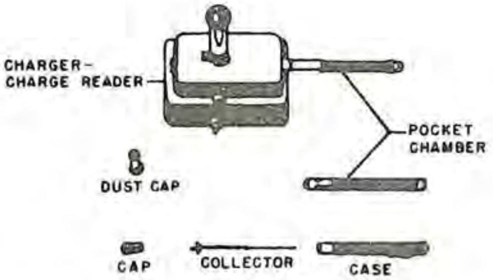
Pocket-dosimeter electroscope.

Figure 4

Reprinted from Ralph E. Lapp and Howard L. Andrews, "Nuclear Radiation Physics", p 199, Prentice-Hall, Inc., 1948.

B. Pocket Chamber

A pocket chamber (Figure 5) has a cylindrical electrode with a coaxial collecting rod well insulated from the rest of the instrument. A charge is placed on this rod. Ions formed in the chamber collect on the rod and reduce the previously placed charge. A pocket chamber differs from the dosimeter mainly in that the electroscope portion (the quartz fiber mechanism and optical system) is in an external unit. This means that the chamber must be charged and read with a separate unit called a "charger-reader". The pocket chamber is similar in size and shape to a fountain pen. The change in charge is measured on a scale that may be calibrated in milli-roentgens. The advantage of this unit is its low cost when compared to a self-reading dosimeter.



POCKET CHAMBER AND CHARGER-CHARGE READER

Figure 5

C. Operation Characteristics

A small amount of dust or lint on an insulator of one of these instruments can be enough to discharge it completely. Therefore, they must be kept clean. Dropping or sudden jarring will also sometimes discharge the instrument.

Insulator "soak-in" is a phenomenon regularly encountered in the operation of these chambers. When an instrument has been out of use for some time and is charged, a rather rapid discharge may be noted. This is due to the penetration of part of the charge into the insulator. It is not leakage in the ordinary sense because it practically disappears if the instrument is kept charged for a day or so. To eliminate this, the instrument should be charged a day or more before it is used. Generally these instruments are designed to respond to x- or gamma radiation, as the walls are too thick to admit beta or alpha radiation.

The chambers are calibrated by the manufacturer to read exposure in milli-roentgens, or roentgens, but they show some energy dependence in their sensitivity and may, therefore, read erroneously. They are relatively energy independent at high energies (greater than 200 Kev) but it is best to know what energy radiation is involved for correct interpretation. Calibration curves can and often should be made for pencil chambers.

V. SUMMARY

Film badges, dosimeters, and pocket chambers are the principal personnel monitoring instruments. Each has specific advantages. Film badges provide a permanent record of exposure, but require more work to obtain readings than the ionization instruments. Dosimeters are especially useful to determine exposure at any time while continuing to act as a monitor without further attention. Pocket chambers are quite simple and therefore represent an inexpensive means of measuring exposure.

There are other personnel monitoring instruments which have limited usefulness in this field. Hand and foot counters are only applicable in permanent locations such as laboratories. Pocket alarms are impractical due to their size and weight, when carried on the person. At the present time, chemical dosimeters are too insensitive for measuring low-level, chronic type of personnel exposures; however they offer a valuable adjunct in estimating dose intensities during radiation accidents and of course there are a variety of research and industrial applications.

REFERENCES

1. "Report of the International Commission on Radiological Units in Measurements (ICRU) 1959", Handbook 78, published by National Bureau of Standards, January 16, 1961. Available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402 Price 65¢.

2. Hoerlin, H., "Development of a Wavelength Independant Radiation Monitoring Film", ANL 5168, 1953.

3. Tochilin, E., Davis, I. H., Clifford, J., "A Calibrated Roentgen Ray Film Badge Dosimeter" American Journal of Roentgenological Radium Therapy, Vol. 64, page 475, 1950.

4. Hine, G. J., and Brownell, G. L., "Radiation Dosimetry", Academic Press Inc., 1956.

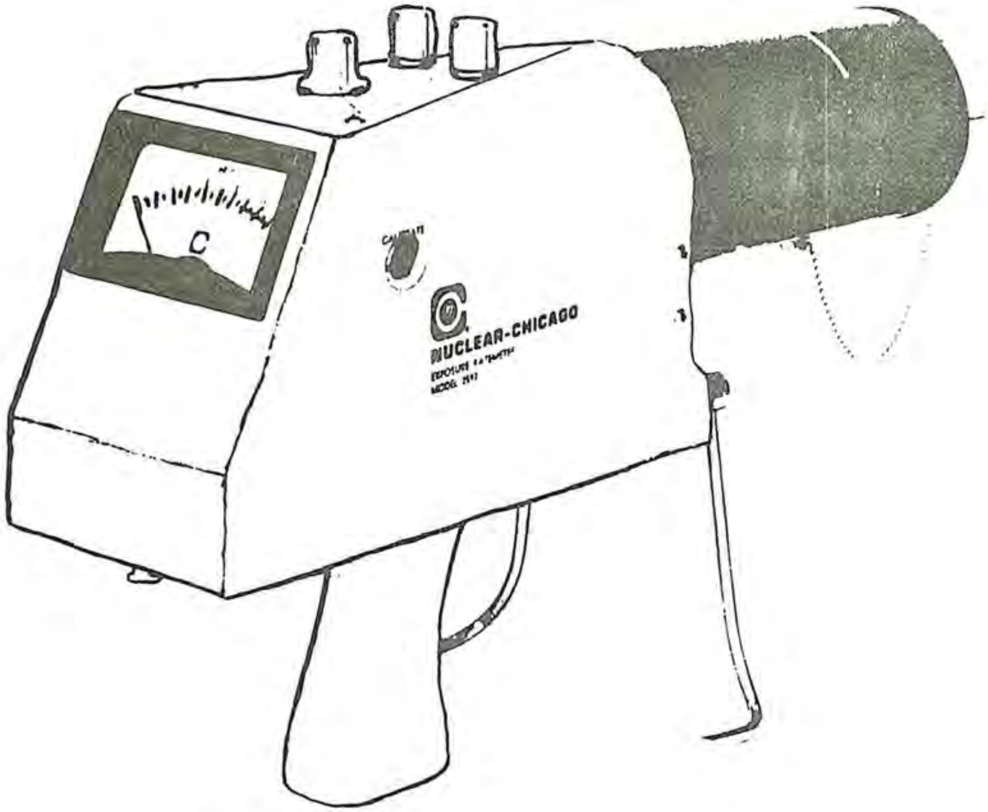
5. Price, W. J., "Nuclear Radiation Detection", McGraw-Hill Book Co., Inc., 1958.

6. "Photographic Dosimetry of X- and Gamma Rays", Handbook 57, Available from Superintendent of Documents, Government Printing Office, Washington, D.C. 20402 Price 15¢.

GPO 900.862

RAD-GAM, XRA
Survey
Nuclear Chicago
Mar. 1972

Radiation Survey Meter
Nuclear Chicago Model 2590



Class	Portable
Principle of Operation	Ionization chamber, amplifier, and meter read-out
Sensitivity and Range	Minimum calculated alpha energy 1.7 MeV Minimum calculated beta energy 0.025 MeV

	Model 2595 (low range)	Model 2596 (high range)
Exposure Rate	0 to 10 mR/h	0 to 10 R/h
	0 to 100 mR/h	0 to 100 R/h
	0 to 1000 mR/h	0 to 1000 R/h
Accumulated Exposure	0 to 0.1 mR	0 to 0.1 R
	0 to 1.0 mR	0 to 1.0 R
	0 to 10 mR	0 to 10 R

Sampling	Continuous
Performance	Accuracy: ±10%, calibration from 1.25 MeV X-ray, ^{60}Co Warm-up Time: 30 sec maximum Response Time: Maximum (0 to 90%) for Model 2595 is 3 sec.; for Model 2596 is 0.5 sec

Requirements	Power: Three 1.5 V "D" cells, 480 hrs continuous Size: 37.4 cm x 10 cm x 21.6 cm (14.75" L, 4" W, 8.5" H) Weight: 2 Kg (4.5 lbs)
Features	Accumulated exposure mode
Cost	
Address	Nuclear Chicago Corp. 333 Howard Avenue Des Plaines, Illinois 60018 (312) 827-4456

Radiation Survey Meters

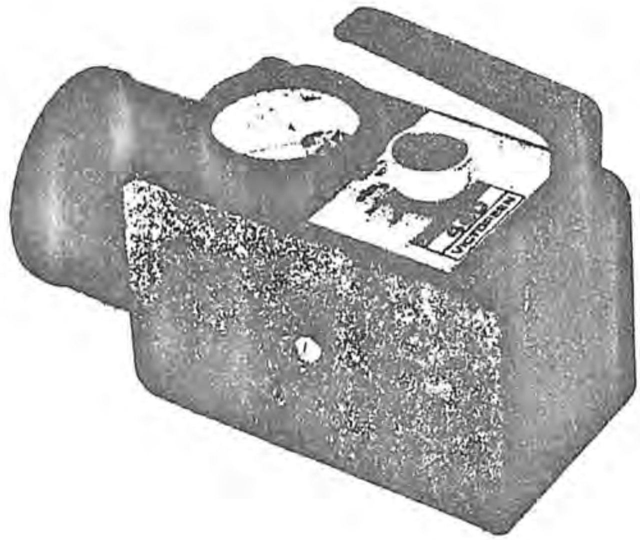
Nucor Models

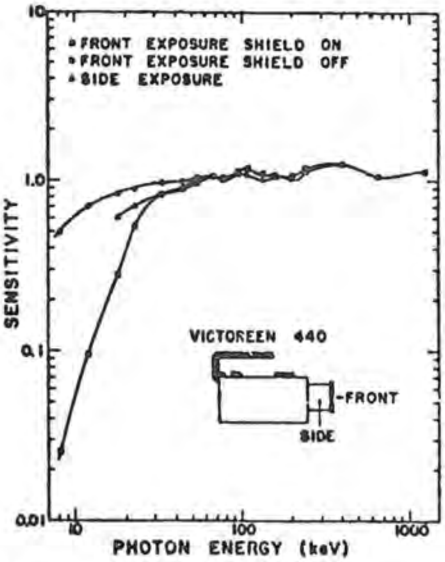
MODEL	CS-40	CS-30	D-6	D-1A
RADIATION DETECTED	Gamma X-Ray	Alpha, Beta Gamma	Alphas Gammas	Beta Gamma
DETECTOR	Ion Chamber	GM Tube	Ion Chamber	Ion Chamber
RANGES	(5) Ranges: 0-5 mR/hr to 0-50 R/hr	3 probes 0.1 to 60 mR/hr	0-500/2500/12,500 c/s (alphas) 0.07/ 3.5/17.5 mR/hr (Gammas)	(3) Ranges 0-50 to 0-5000 mR/hr
SCALE	Linear	Linear	Linear	Linear
ACCURACY Energy Response	±15% from 30 kev to 2 mev	Unavailable	Unavailable	Unavailable
POWER	(1) 1.3v mercury cell	(3) "D" cells 300 hours	Mercury batteries 300 hours	(4) 22.5v and (1) 1 1/2v battery
WEIGHT	5 pounds	5 pounds	7 1/2 pounds	2.5 pounds
SIZE	14 1/4" x 4 1/2" x 4 3/4"	10" x 4 3/4" x 5"	6 1/8" x 8 1/2" x 7 5/8"	11" x 3" x 8"
FEATURES	Sealed moisure proof case	Sealed moisture proof case	Sealed moisure proof case	Sealed moisture proof case
COST	$395	$395	$595	$395

Class	Portable, hand-held
Address	Nuclear Corporation of America 2 Richwood Place Denville, New Jersey 07834 (201) 627-4200

Radiation Survey Meter

Victoreen Model 440





Victoreen Instrument Company survey meter Model 440, Serial No. 521.*

Class	Portable, hand-held
Principle of Operation	Ionization chamber, meter read-out
Sensitivity and Range	Range: 0-3, 0-10, 0-30, 0-100 and 0-300 mR/hr. Energy dependence: ±15% from 6.5 keV to 1.2 MeV
Sampling	Continuous
Performance	Accuracy: ± 10% F/S (linear) Time constant: 8 seconds on most sensitive range 5 seconds on all other ranges
Requirements	Power: (4) "D" cells Size: 25 cm L, 10 cm W, 19 cm H (10" L, 4" W, 7.5" H) Weight: 2.2 Kg (5 lbs.)
Cost	$795
Address	Victoreen Instrument Division 10101 Woodland Avenue Cleveland, Ohio 44104 (216) 795-8200

---

* "The Photon Energy Response of Several Commercial Ionization Chamber, Geiger Counters, and Thermoluminescent Detectors", Los Alamos Scientific Laboratory Report LA-4052, UC-37, Instruments TID-4500 dated February 1969.

Alpha Survey Meters

Eberline Portable Models

PAC-4S

PAC-15AGA

PAC-4G

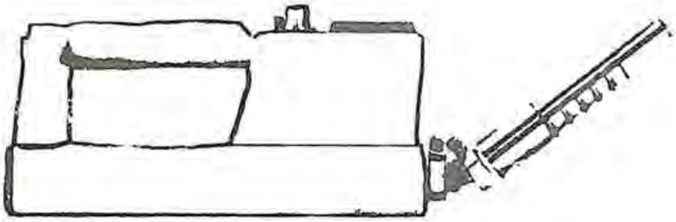
Class	Portable, hand-held
Sampling	Continuous
Features	Some models have earphone and speaker outputs, regulated power supply, individual calibration controls for each range.
Address	Eberline Instrument Corporation P.O. Box 2108 Santa Fe, NM 87501 (505) 982-1881

MODEL	PAC-4S	PAC-1SAGA	PAC 4G
RADIATION MEASURED	Alpha	Alpha Gamma	Alpha
DETECTOR	Alpha scintillation probe	Alpha scintillation det. and GM tube	Gas proportional alpha probe
RANGE	$0 - 2 \times 10^6$ counts/min.	$0\text{-}2 \times 10^6$ c/m for alphas. 0-2 R/hr for gammas	$0\text{-}5 \times 10^5$ counts/min
SCALE	Linear	Linear	Linear
ACCURACY	±10% F/S	±10%	±10% F/S
TEMPERATURE	-40°F - +140°F	-40°F - +130°F	-40°F - +140°F
POWER	5 "D" cells 200 hours		5 "D" cells 200 hours
WEIGHT	7 pounds	8 pounds	9 pounds, 6 oz.
SIZE	7 1/4" H x 4" W x 9" Long	7 1/4" H x 3 7/8" W x 9" Long	9" x 4" x 10"
FEATURES	Linear-Log presentation	Aural readout with optional headset or speaker	Adjustable high voltage control
REMARKS	Waterproof construction	High level plutonium probe optional	High voltage selector option
COST	$650	$720	$600

RAD-ALP, BET, GAM
Survey
Nuclear Chicago
Mar. 1972

Radiation Survey Meter

Nuclear Chicago Models 2651, 2652



2651

2652

Class	Portable, hand-held alpha, beta, gamma survey meter
Principle of Operation	Model 2651 uses a Model 2660 side window halogen quenched GM tube probe for hard beta and gamma measurements. Model 2652 uses a Model 2661 end window halogen quenched GM tube probe for alpha, soft beta, and gamma measurements. Both are factory calibrated in terms of gamma rays from Cesium-137 source which is radium equivalent for these instruments, oscillator, meter read-out.
Sensitivity and Range	Minimum Sensitivity: 40 keV Ranges: 0.1, 0.2, 1.0, 3.0, 10, 30, and 100 mR/nn. Also 150, 1500, 15,000, and 150,000 counts/min full scale
Sampling	Continuous
Performance	Accuracy: ±10% of full scale on all ranges Temperature: 0°C to 50°C Time Constants: Selectable 4 or 8 secs. on the 0.1, 0.3, and 1.0 mR/nn ranges. The 3 and 10 mR/nn are fixed at 4 secs. The 30 and 100 mR/nn ranges are fixed at 2 secs.
Features	Interchangeable probes, retractable probe cord (40"); Miniature earphone for audible monitoring.
Cost	Unknown
Requirements	Power: Four 1.5 V "D" cells, 300 hours @ 8 hr/day Size: 5" H x 4" W x 12" L Weight: 4.5 lbs
Address	Nuclear Chicago Corp. 333 Howard Avenue Des Plaines, Illinois 60018 (312) 837-4456

X-Ray Dosimeter

Nucleus Model 06-002, 050, 099
(Bendix)

06-050
Low-Energy Dosimeter

Class	Portable, pocket
Principle of Operation	Plastic walls allows low energy X-rays to penetrate the ion chamber
Sensitivity and Range	

Model	Range
06-002	0-200 mR
050	0-5 R
099	0-100 R

Sampling	Continuous
Performance	Accuracy: ±15% of true dose for 30 keV x-rays ±10% of 30 keV reading for 15 to 100 keV +20% -10% of 30 keV reading for 30 to 225 keV Leakage 2% of full scale/24 hours
Requirements	Power: use charger Size: 4" in length Weight: about 2 ounces
Cost	$75
Address	Nucleus, Inc. P.O. Box R Oak Ridge, Tenn. 37830 (615) 483-0008

RAD-GAM, XRA
Survey
Nuclear Associates Inc.
Oct. 1972

Survey Alarm

Prima I, II

Prima I
05-100

Prima II
05-200

Model	Prima I	Prima II
Radiation Detected	Gamma, X	Gamma, X
Detector	G.M. Tube	G.M. Tube
Energy Dependence	200 keV - 3 MeV	90 keV- 3 MeV
Ranges	Background to 2 R/hr	Background to 2 R/hr
Accuracy	30%	30%
Features	Audible Output	Audible Output
Power Required	4.2V mercury cell, 6 mo.	4.2V mercury cell, 6 mo.
Size	2 cm D, 13 cm 0.75" D, 5" L	6cm, 9cm, 2.5cm 2.3",3.5",1"
Weight	100 grams 3.5 ounces	120 grams 5 ounces
Price	$180.	$90

Address

Nuclear Associates Inc.
35 Urban Avenue
Westbury, NY 11590
(516) 333-9344

Laser Radiation Detection

I. INTRODUCTION

The wide variety of lasers now available with their different wavelengths, pulse durations, power densities, and energy densities makes detection with one particular instrument difficult. Thus, a variety of detectors have been utilized and can be classified under one of two general categories: photon devices and thermal devices. These two classifications of light detectors are based on the two ways in which light interacts with matter. Photon devices interact via the photoelectric effect, photoconductive effect, and photovoltaic effect. Thermal devices utilize the heating effect and corresponding temperature rise caused by energy absorption.

II. PHOTON DEVICES

Photon devices measure the rate at which light quanta are absorbed. The response at any particular wavelength is proportional to the rate at which photons of that wavelength are absorbed. These detectors have a strong wavelength dependence. The energy output of the laser is directly related to the number of photoelectrons produced, and is based on the response of the particular detector.

There are three ways to categorize photon devices: photoelectric, photoconductive, and photovoltaic. Electrons in a material may absorb energy from incident light quanta. When the electron is ejected or completely removed from the metal upon absorption of a light photon, the *photoelectric* effect has occurred. If, however, the electron is liberated from a particular atom but is not ejected from the metal, this is termed the *photoconductive* effect. When the photoconductive effect occurs at the P-N boundary of semiconductors or at the boundary between a metal and a semiconductor, a potential difference will develop. This is classified as the *photovoltaic* effect.

A. Photoelectric

A single light photon is absorbed by a photocathode and a photoelectron is emitted. This electron is then attracted to a positive anode. As a laser beam consists of many light photons, numerous electrons will be emitted from the photocathode and attracted to the anode. The resulting current or voltage can then be measured.

The light-sensitive photocathode is usually placed inside an evacuated glass tube. (See Figure 1.) This is called a vacuum photodiode. It has good stability and good range (linearity over large intensity range) and can be used for continuous wave (C.W.) lasers in the 10^{-8} to 10-watt range and also for pulsed lasers with energy from 10^{-8} to 0.1 joules per pulse.

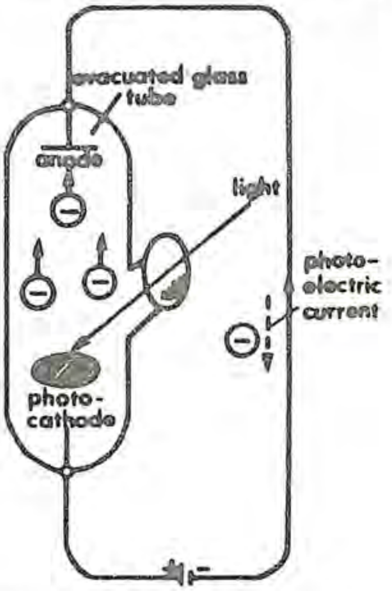


Figure 1.—Vacuum Photodiode

The most sensitive of all the light detectors is the photomultiplier tube (PMT). Similar to the vacuum photodiode, the PMT consists of a photocathode and a positive anode. In addition, however, it contains accelerating photodynodes which amplify the number of electrons emitted from the photocathode. (See Figure 2.)

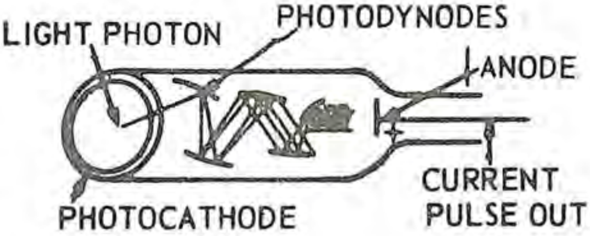


Figure 2.–Photomultiplier Tube

Since the photocathode is so sensitive, it can only be used to detect very low power levels (around 10^{-5} watts or less) and is effective for measuring power from continuous wave lasers. (There are photomultiplier tubes which are able to detect one photon.) They are difficult to use with pulsed lasers because of the problems of calibration. The sensitivity derives from the high gain or amplification that comes from the dynodes: with 13 stages, gains of 10^6 to 10^7 can be realized. There are two major disadvantages: different photocathodes have different spectral responses (dependence on the incident wavelength), and PMT's tend to lack linearity over wide intensity ranges.

B. Photoconductive Detector

Photoconductive materials do not generate electricity (electron current) as do the photoelectric devices. Instead, these detectors possess the very useful characteristic of changing resistance when absorbing light. This resistance change may be on the order of millions between light and dark exposures. Characteristic photoconductive cells are cadmium sulphide and cadmium selenide. (See Figure 3.)

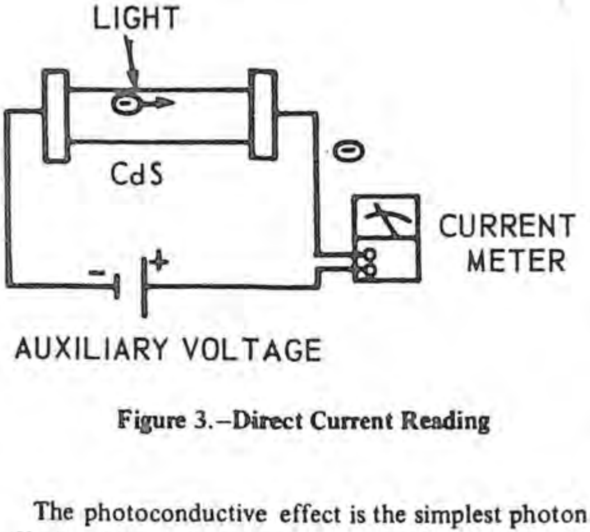


Figure 3.–Direct Current Reading

The photoconductive effect is the simplest photon effect. When this occurs in a semiconductor the electron is not removed from the material but merely liberated from a particular atom (electrons are moved from the valence band or "doped" electron energy level into the conduction band). The resistance to electron flow is then greatly reduced, and the conductivity greatly increased. This change in resistance or conductivity can be easily measured. Figure 3 indicates a direct current reading, while Figure 4 shows voltage measurement across a resistor in series with the semiconductor.

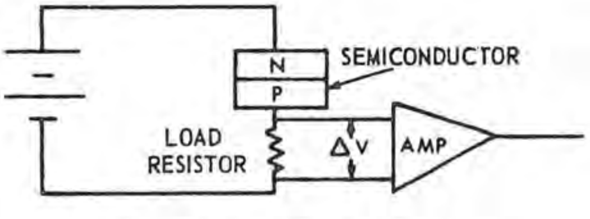


Figure 4.–Load Resistor Reading

Note that an auxiliary voltage supply is required for the photoconductive detectors. They can be used to measure C.W. lasers of powers 10^{-5} to 0.5 watts; they also are wavelength-dependent.

Although CdS is used for photometric applications with diffuse white light, it is not satisfactory for measuring laser power quantitatively.

C. Semiconductor Photodiode

The silicon semiconductor photodiode is another popular laser detector. The semiconductor silicon acts as a current generator, with the current dependent on the incident light. When a semiconductor is "back-biased" it operates in the photoconductive mode.

The semiconductor photodiodes are operated with an applied reverse bias (voltage) so that a very low concentration of charge carriers exist at the interface between the two semiconductor regions. When a light photon is absorbed, the charge from the electron-hole pair creation is separated by the applied electric field. This effect produces a measurable voltage across the interface, called the depletion region. Measuring this voltage change gives an indication of the power or energy of the incident light. (Note Figure 5.)

Semiconductor photodiodes have many characteristics that make them useful in measuring output powers of small C.W. lasers: 10^{-5} to 0.5 watts. Low-power (e.g., He-Ne) and semiconductor lasers are adequately measured along with short-pulsed lasers with energies from 10^{-8} to 0.1 joules per pulse. Some

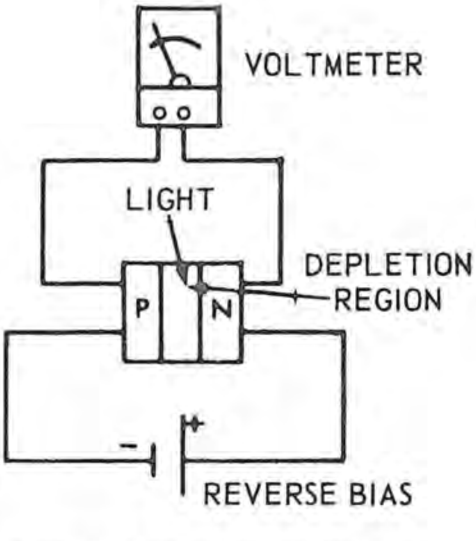


Figure 5.–Semiconductor Photodiode

of the advantages are: (1) good linearity over seven orders of magnitude; (2) reasonable spectral response, though not good in the ultraviolet region; (3) fast response time with a 4 to 5 nsec rise time and a 10 nsec decay time. The semiconductor photodiode's small size can be advantageous in monitoring small beam areas or fields.

Efficiency is such that power levels down to 50 microwatts can be measured directly without an amplifier.

Some disadvantages are the wavelength dependence (note Figure 15) and the small area of the detector. For large power densities, filters, gratings, or beam splitters can be used to attenuate the beam (or sample a smaller area) and then calculate the actual power level from the sampled portion.

D. Photovoltaic Detectors

All practical photovoltaic cells consist of a junction between two dissimilar semiconductor materials. When light is absorbed at this boundary, an electron will be liberated from an atom, but not ejected from the material (photoconductive effect). There will also be a potential difference arising which can be detected (photovoltaic effect). No battery or electrical power supply is necessary. Photovoltaic detectors may be classified in two ways: photocells and solar cells.

1. PHOTOCELL (SELENIUM)

Photocell or selenium cells have found widespread application as light meters in cameras and as automatic exposure devices. Cadmium oxide is usually coated on a selenium base, fastened to a metal baseplate. As light is absorbed, a potential difference arises between the cadmium oxide and baseplate which can be measured, as in Figure 6. The response of the selenium cell to light is similar to that of the human eye.

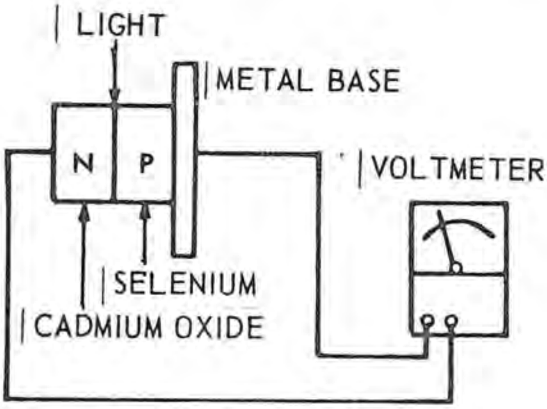


Figure 6.–Photocell

2. SOLAR CELL (SILICON–A SEMICONDUCTOR)

Another type of cell, used as a source of electrical power for rockets and satellites, is the solar cell. This is made of the most common element found on our planet, silicon. In actuality, this can be classified as a photoelectric device since an electron current is generated when light is absorbed. However, since no external voltage supply is necessary, this is usually classified as photovoltaic. The current can be measured directly or as a voltage across a load resistor. (See Figure 7.)

The silicon photovoltaic cell is a very popular laser detector. Having ranges from 0.1 mW to 100 mW, it has found much use in He-Ne laser power meters. Section V describes a particular silicon photovoltaic detector in more detail.

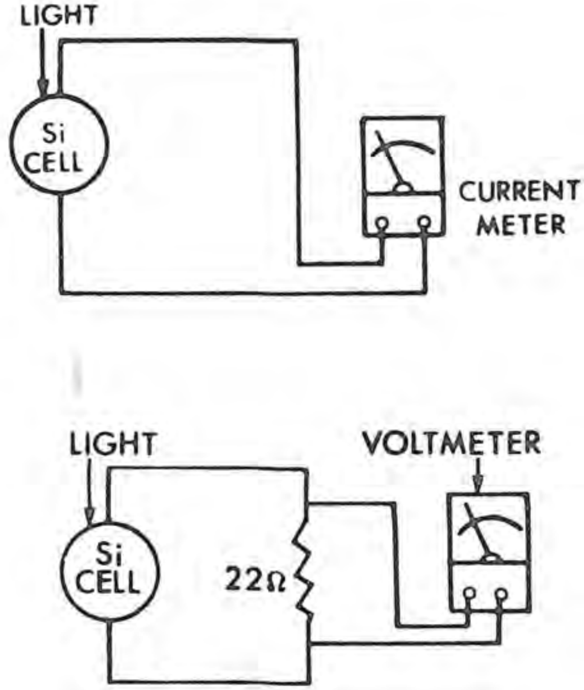


Figure 7.–Solar Cell Current Measurement

III. THERMAL DEVICES

Thermal devices measure the effect of heat and temperature changes on materials when absorbing light energy. There are three general categories: calorimeters, bolometers, and thermocouples.

A. Calorimeters

Calorimeters absorb the total light energy, and the corresponding temperature rise indicates the amount of energy absorbed. They are useful in measuring pulsed laser outputs from 10^{-3} to 100 joules per pulse. The response time is slow; they should not be used for measurement of rapid trains of pulses since it takes some time for the calorimeters to equilibrate to ambient temperature. The energy supply to the calorimeters from lasers can be compared with energy supplied from an accurately known source (e.g., an electric heater). Calorimeters can also be used to measure C.W. outputs greater than 0.1 watts. Wavelength dependence is determined by the absorbing medium. They are also used as conventional standards in photometry and radiometry.

B. Bolometers

Bolometers are detectors whose resistance changes when heated. Measuring this change in resistance provides a means of determining the incident power of the absorbed radiation. The most common bolometer is the thermistor. A thermistor consists of a short length of fine wire with a small bead of semiconducting metal on the end. As radiation impinges on the bead, the temperature rises, and resistance to electron flow decreases. Measuring the change in resistance (caused by heating the thermistor) is an indication of the incident light energy. The advantages of a thermistor are its uniform response to all wavelengths of light, and its simplicity of operation. The major disadvantage is its very slow response time. Another device similar to the thermistor is the baretter. In a baretter, an increase of temperature causes an increase in resistance.

C. Thermocouple

Another thermal device to measure temperature rise is the thermocouple. A thermocouple consists of a pair of junctions between two different metals, such as antimony and bismuth. Since the two metals have different thermal properties, a small voltage difference can be produced when their junctions are at different temperatures. If a closed loop of two dissimilar metals is made, current will be observed to flow around the loop when the junctions are kept at different temperatures. The current will flow across the hot junction, and will depend on the thermal properties of the metals used. In Figure 8, the current flows from bismuth to antimony. Depending upon the two materials used, the direction of flow follows the order: bismuth, nickel, cobalt, platinum, copper, lead, zinc, cadmium, iron, and antimony. Any pair of

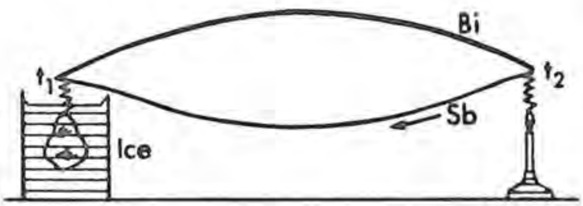


Figure 8.–Thermocouple

these metals is called a thermocouple. Normally, the thermocouple is in contact with a receiving element which absorbs the incident radiation. (See Figure 9.)

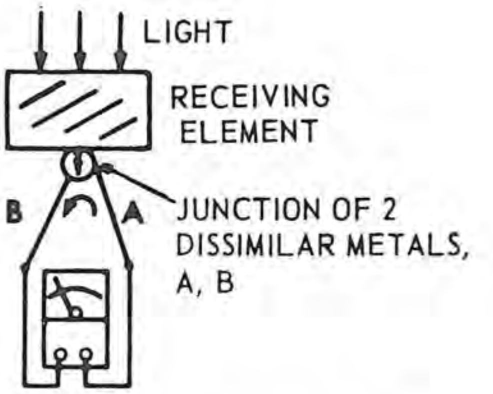


Figure 9.–Thermocouple Use

As incident light is absorbed by the receiving element, the corresponding temperature rise is quantitatively measured by the thermocouple, the measured voltage being proportional to the temperature rise. The thermal voltages can be quite small, however, and a larger net voltage can be obtained by connecting several thermocouples in series. This is called a thermopile. (See Figure 10.) The total thermally produced voltage across the output terminals is the sum of the individual thermocouple voltages. As the receiving elements absorb incident radiation, the temperature of each junction is increased and the thermopile voltage increases accordingly.

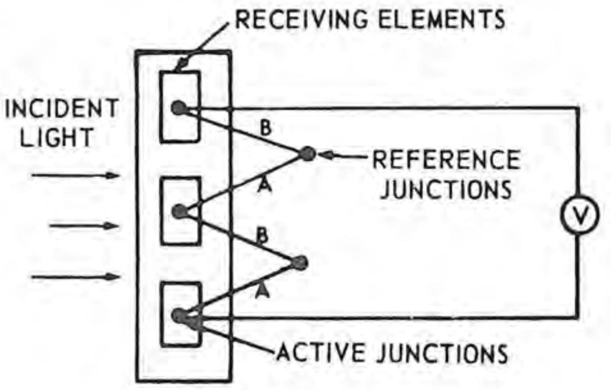


Figure 10.–Thermopile

Since the receiver element is quite sensitive, care must be taken; high levels of 1 watt/cm^2 or greater will deteriorate the surface. (Common receiver coatings are goldblack, lampblack, and Parson's black.)

Thermopiles are generally unaffected by the beam orientation, the wavelength of the incident light, the pulse length, or the beam diameter. However, they are not as sensitive as the photon devices.

The ballistic thermopile has found use in determining pulsed laser energy levels in the range of 10^{-3} to 100 joules per pulse. It has two Mendenhall wedges and two thermocouples sensing the temperature of each wedge. A Mendenhall wedge is simply a polished cone which absorbs the incident light energy. The light bounces about 12 times before hitting the apex, losing approximately 8% of its energy per bounce. The second cone compensates for ambient light; the temperature difference detected by the two thermocouples can be measured as an output voltage. (See Figure 11.) It takes almost 5 seconds for the cone to dissipate the absorbed energy; thus, pulses longer than 5 seconds would give erroneous readings. Power levels from C.W. lasers would be difficult to determine.

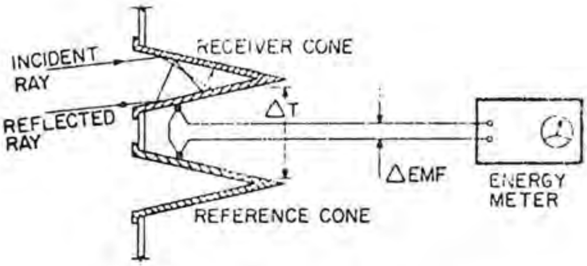


Figure 11.–Ballistic Thermopile

IV. DETECTION ACCESSORIES

Several laser detection accessories are very useful for versatile measurements. (1) *Filters* can be used to select specific wavelengths of the operating laser; they also attenuate the beam so the full energy of the laser does not damage the detector (such as the photodiode detector). (2) *Gratings* also are wavelength selectors which prove to be more exact than filters. (3) When the beam is small compared to

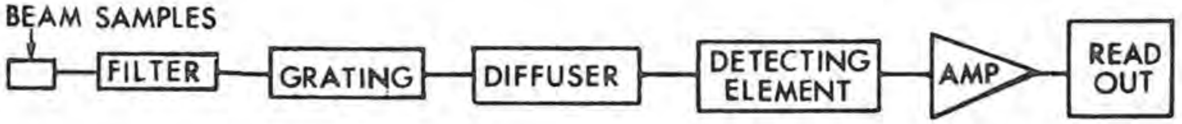


Figure 12.–Beam Sampling System

the active detector area, *diffusers* spread the beam over the entire detector surface. (4) Measuring high-power lasers calls for a *beam sampler* to split the beam and select only a fraction to be incident on the detector. This percentage can then be extrapolated to the total power. (5) A *multiple-aperture* dish is utilized to increase or decrease the power level falling on the detector. It is simply a dish with numerous holes. (6) Another handy accessory is the *ambient light compensator* which permits ambient light to be electronically dialed out. Figure 12 shows a possible detection system.

V. A TYPICAL DETECTOR

The laser beam can enter the sensing head within a 20-degree solid angle. (This detector is insensitive to off-axis beam incident to the sensing head at angles greater than 20 degrees.) The incident beam is then diffused, spreading the beam into a much larger spot, and thus covering a larger area of the detecting element (silicon cell in this case). By providing even detector illumination, the light diffuser prevents the narrow and highly intense laser beam from being localized on the detector and causing nonlinear operation. A practical schematic of a photovoltaic system is shown in Figure 13. Figure 14 depicts the electrical configuration of a practical detector. Light incident on the photocell will produce a proportional current that can be measured on the 20 microampere d.c. meter. It should be stressed that most photocells have a strong wavelength dependence, and most instruments are calibrated for only one particular wavelength (e.g., 632.8 nm of red light). Figure 15 illustrates a spectral response curve for a silicon cell. Note that the relative response of the cell is strongest in the infrared region around 860 nm (0.86 μm). If an argon laser output were being measured (e.g., the 514.5 nm line) the curve would indicate a relative response of about 0.5 and a correction multiplier of about 1.66. Thus, a 10 mW argon reading would be corrected to 10 mW × 1.66 = 16.6 mW

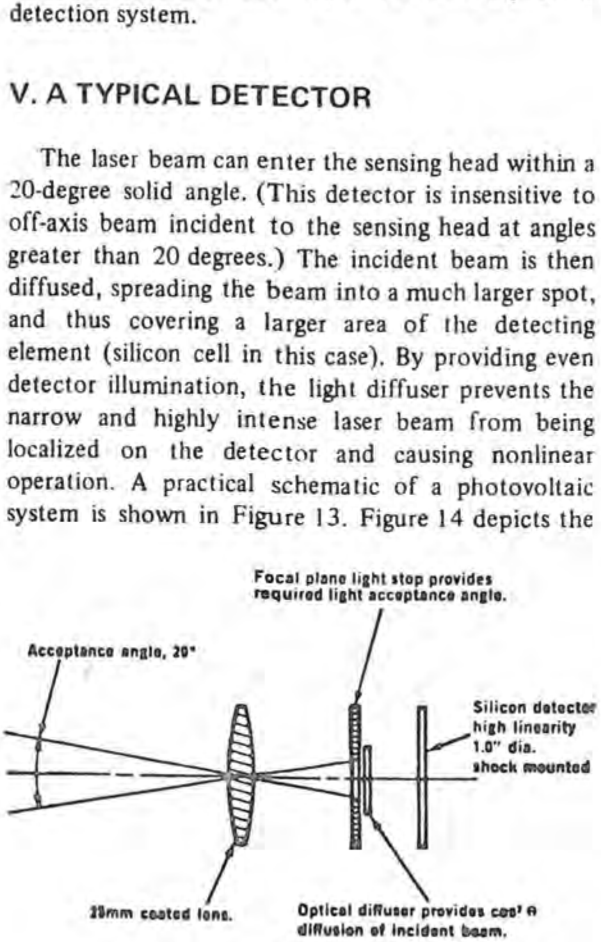


Figure 13.–Sensing Unit Optical System

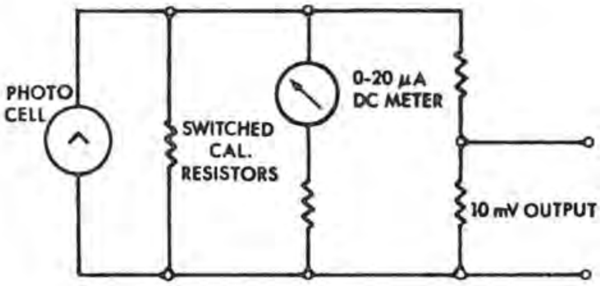


Figure 14.–Electrical Circuit

VI. SUMMARY

A summary of laser detectors is shown in Table 1. The approximate intensity ranges were taken from commercially available detectors.

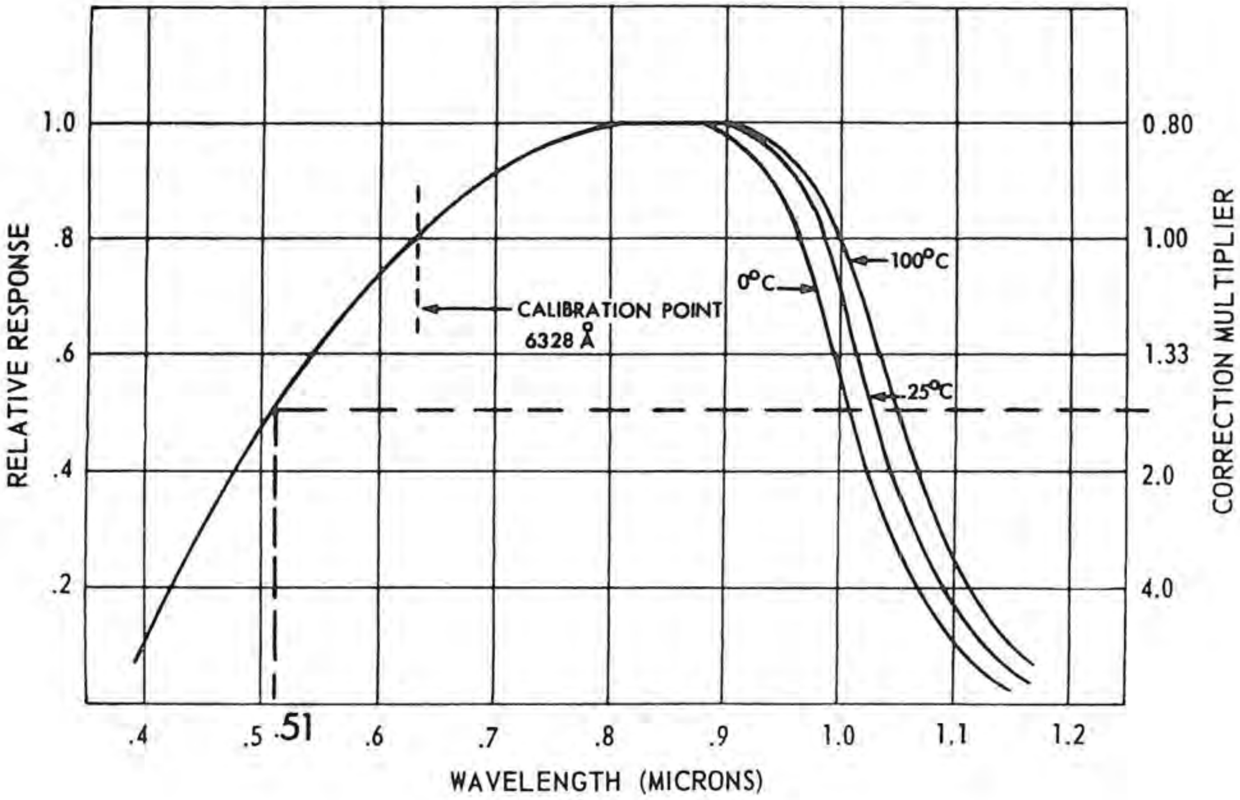


Figure 15.–Spectral Response of Silicon Cell

BIBLIOGRAPHY

Goldman, L., *Biomedical Aspects of the Laser* (New York: Springer-Verlag New York, Inc., 1967).

Laser and Microwave Hazards, Course Manual (Edgewood Arsenal, Md.: U.S. Army Environmental Hygiene Agency).

Marshall, S. L., *Laser Technology and Applications* (New York: McGraw-Hill Book Co., Inc., 1968).

"Model 560 B Lite-Mike" Instruction Manual (Boston: EG&G Inc., 1968).

"Optical Power Meter Model 450 B" Instruction Manual (Ann Arbor: Jodon Engineering Associates, Inc., June 1970).

Price, W., *Nuclear Radiation Detection* (New York: McGraw-Hill Book Co., Inc., 1964)

Solar Cells and Photocells (Booklet No. HB-30 [El Segundo, Calif.: International Rectifier Corp., 1969]).

Stoner, Donald L., *Solar Cells for Experimenters* (Booklet No. HB-99 [El Segundo, Calif.: International Rectifier Corp.]).

Way Things Work (New York: Simon and Schuster, Inc., 1967).

Zimmerer, R. W., "Power and Energy Measurements," *Laser Focus*, Sept. 1970.

This material was prepared by Mr. John D. Boice, Jr., Northeast Radiological Health Laboratory Training Section, Winchester, Mass.

Detector	Approximate Intensity Range	Comments
Vacuum Photodiode	0.1 μW - 10 W	Best stability, wavelength-dependent
Photomultiplier Tube	$< 10\,\mu$W	Most sensitive, wavelength-dependent, lack of linearity over intensity ranges, for very low C.W. power levels
Photoconductive Detector (Silicon back-biased)	10^{-9} - 10 W	Good linearity, wavelength-dependent, requires separate power source
Photovoltaic Detector	0.03 - 1000 mW	Self-powered, popular He-Ne power meter
Calorimeter	0 - 1 W 1 - 10,000 W 1 - 100 J	Cooled by air, water, or oil; laboratory standard; wavelength range depends on absorbing surface
Thermopile	0.25 W max.	Can be water-cooled, not as sensitive as photon devices, standard
Ballistic Thermopile	10^{-3} - 500 J	Laboratory standard, wavelength range depends on absorbing material

TABLE 1.–Summary of Laser Detectors

Update on power measurement

by Robert W. Zimmerer

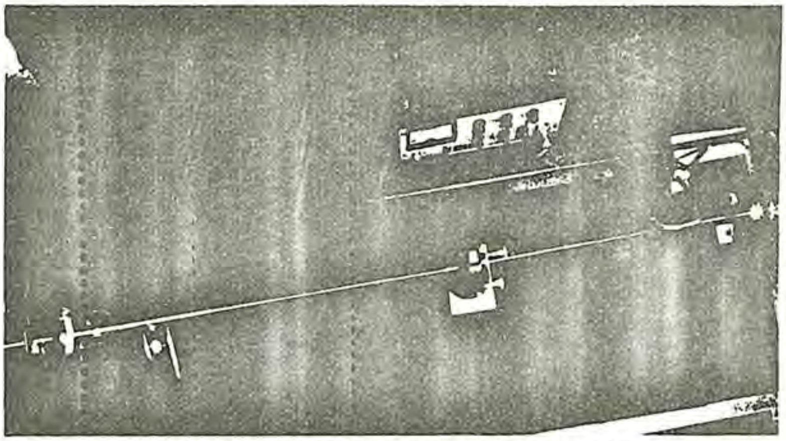
Laser Focus, Vol. 8, No. 3, March 1972, pp. 25-27.
Reproduced with permission, February 1973.

LEGISLATION is increasing the importance of precision in measuring laser power and energy. Far more influential than technical demands will be safety requirements being drafted by two federal organizations: the Labor Department's Occupational Safety and Health Administration, and the Department of Health, Education and Welfare's Bureau of Radiological Health.

While advocates debate the hazards of laser radiation, the National Bureau of Standards is refining measurement techniques. At its Boulder laboratories, scientists are making calorimetric measurements of laser power with precision within 0.08% and accuracy within 1%,[1] using the calorimeter shown in photograph accompanying this article. The C series measures energy up to 20 joules and power to one watt.[2] The goal is a calorimetric instrument simple enough for operation by a technician, rugged enough to ship between laboratories, and accurate enough to provide a valid comparison with NBS electrical standards. Such a standard can assure maintenance of high calibration accuracy in manufacturers' instruments.

Developing power and energy standards

Except for raman spectroscopy, where analytical performance is sensitive to power level, most scientific and industrial applications for lasers require power-level or pulse-energy information to within an order of a magnitude. Yet refined techniques in welding and cutting are likely to demand better accuracy and control, requiring more precise power measurement and then automatic control of the laser. The NBS is well on the way to having power and energy standards ready when they are needed.



PRECISE MEASUREMENT of power and energy is performed by NBS's C-series calorimeter

Instrument makers also are showing advances. Since the previous survey in *Laser Focus* (LF Sept '70 p39), notable gains include addition of pyroelectric-effect detectors by the Laser Precision Corp., Barnes Engineering Co. and Apollo Lasers Inc., as well as a mirror-disk calorimeter by Scientech Inc. that handles carbon-dioxide powers up to one kilowatt, basing its calibration on direct-current substitution power.

In the accompanying table, information emanates from manufacturers, whose addresses are published in the *Laser Focus Buyers' Guide.*

The bibliography following this article updates the longer list of references given in my earlier article.[3]

ROBERT W. ZIMMERER *is president of Scientech Inc. in Boulder. This is his second appearance in Laser Focus. His first article was in September, 1970 (p39).*

References and bibliography

1. National Bureau of Standards *Technical News Bulletin* (May 1971)
2. E. D. West et al *J Res Natl Bur Std (U. S.) 76A (1) (Jan-Feb 1972)*
3. "Data analysis for isoperibol laser calorimetry" *NBS Technical Note 396* by E. D. West (Feb 1971)
   "Power and energy measurement of repetitively pulsed lasers" *NBS Technical Note 398* by D. A. Jennings (Mar 1971)
   "Laser energy and power measurement with a double reflecting plate calorimeter" by A. L. Rasmussen *Rev Sci Inst 41* 1,479 (1970)

Max. Power Rating (W)	Max. Energy Rating (J)	Spectral Range (μm)	Sensitivity (mV/J)	Rise Time (μsec)	Delay Time (μsec)	Accuracy (%)	Aperture (mm)	Type	Price Range	Model No.
ALCYON ELECTRONIQUE & PHYSIQUE										
1 GW	30	.4 to 1.1	10,000	.0005	ng	2.5	20	Photocell (flat)	$1,000	Alcyon 102
APOLLO LASERS										
.5	.1	2 to 25	1000	1	ng	ng	4 dia	Pyroelectric Built-in pre-amp battery	$ 695	700
COHERENT RADIATION										
100	ng	.3 to 30	ng	ng	ng	± 5	25	Thermopile	$ 975	201
20	ng	.3 to 30	ng	ng	ng	± 5	10	Thermopile	$ 850	205
10	ng	.45 to 1.06	ng	ng	ng	± 5	8	Silicon cell	$ 895	212
1000	ng	1 to 30	ng	ng	ng	± 5	38	Thermopile	$1,295	213
EG&G ELECTRO-OPTICS										
10^{10}	300	.35 to .8	10^{-2}A/W	.001	.001	± 8	16	Radiometer	$4,685	580 5-20
10^{10}	300	.35 to 1.2	10^{-3} A/W	.001	.001	± 8	16	Radiometer	$4,685	580 S-1
.25	10^{-3}	.35 to 1.13	14.6×10^{6}	.004	.004	±10	2.5	Lite-Mike	$ 450	5600·
F&H MANUFACTURING										
150MW	150	.2 to 10×10^{3}	200	Ballistic integrating time constant	ng	4	10	Calorimetric device using cones & thermocouple harnesses	$ 389	E20
1GW	500	.2 to 10×10^{3}	50	ng	ng	4	20		$ 589	E21
GCO										
300	ng	.6328, .5145, .4880	2mW	ng	ng	ng	100 mm²	Si photodetector	$ 495	750
100	ng	.6328	ng	ng	ng	± 5	7.96 dia	Si photovoltaic	$ 275	760
50×10^{-3}	ng	.6328	ng	ng	ng	± 5	9.5 dia	Si photovoltaic	$ 125	770
HADRON										
1.5×10^{8}	150	.3 to 2	.150	7×10^{6}	8×10^{7}	± 5	10	Cone	$ 385	100
1.5×10^{8}	150	.3 to 2	.150	7×10^{6}	8×10^{7}	± 5	10	Cone w/photodiode	$ 525	101
5×10^{8}	150	.3 to 2	.035	1×10^{7}	1.2×10^{8}	± 5	20	Cone	$ 550	107
5×10^{8}	150	.3 to 2	.035	1×10^{7}	1.2×10^{8}	± 5	20	Cone w/photodiode	$ 690	108
1×10^{9}	150	.3 to 2	.022	6×10^{7}	2×10^{8}	± 5	40	Cone	$1,180	117
1×10^{9}	150	.3 to 2	na	6×10^{7}	2×10^{8}	± 5	40	Cone w/photodiode	$1,320	118
na	150	na	na	2×10^{5}	2×10^{6}	± 2	na	Energy meter	$ 680	102C
Depends on filter set		.3 to 1.2	15V/kW	.003	.003	±15	40	Vacuum photodiode	$1,800-1,900	105C
200	10	.3 to 11	.2mV/W	4×10^{6}	4×10^{6}	± 5	20	Cooled disc radiometer	$ 385	114
10^{12} w/filter set	1000 w/filter set	.3 to 2	.02	10^{3}	10^{8}	± 5	64	Cone	ng	CG64
HY-CAL ENGINEERING										
3	ng	.3 to 12	360mV/W	3×10^{6}	3×10^{6}	± 3	13	Calorimeter	$ 620	C-1839-A
1	ng	.3 to 12	720mV/W	3×10^{6}	3×10^{6}	± 3	25	Calorimeter	$ 620	C-1839-B
500	ng	6 to 14	.5mV/W	10^{7}	10^{7}	± 2	25	Calorimeter	$ 620	C-1829-A
ng	up to 2000	.5 to 11	5×10^{6}	10^{6}	ng	± 5	up to 250	Liquid Calorimeter	$3,420	C-1845-A
ng	up to 100	.5 to 11	.3	10^{6}	ng	± 2	20	Cone type calorimeter	$ 510	C-1837-A
ng	up to 100	.5 to 11	5×10^{-5}	10^{6}	ng	± 2	50	Liquid Calorimeter	$1,895	C-1846-A
INSTRUMENT TECHNOLOGY										
ng	30	.3 to 400	ng	ng	ng	± 5	25	Calorimeter	$ 888	LC

INTERNATIONAL LIGHT										
60	6	200 to 1200	ng	10^{-6}	ng	1	10	Vacuum photodiode	$948	IL600
INTERNATIONAL RESEARCH & DEVELOPMENT										
1000	ng	.5 to 35	ng	$\sim10^{5}$	$\sim10^{5}$	± 5	28	Thin film bolometer	ng	CO₂ power meter
KORAD										
10^{8}W/cm²	100	.53 to 1.06	20×10^{-3}	ng	ng	6	10	Calorimeter	$1,000	KJ2
5×10^{8}W/cm²	500	.53 to 1.06	5×10^{-3}	ng	ng	6	25.4	Calorimeter	$1,000	KJ3
LASER INSTRUMENTATION										
	(in 1 ms)									
.2	.2	.3 to 15	250mV/W	50×10^{6}	$.2\times10^{6}$	1	10	Radiometer	ng	14BT
ng	.3	.4 to 1.2	28	50×10^{6}	$.2\times10^{6}$	2	10	Radiometer	ng	14NO
20	ng	.3 to 15	2.7mV/W	50×10^{6}	ng	3	50	Radiometer	ng	15
100	ng	.3 to 15	0.3mV/W	2.5×10^{6}	ng	3	25	Radiometer	ng	16
2	ng	.3 to 15	200mV/W	60×10^{6}	ng	3	30	Radiometer	ng	17
ng	30	.3 to 1.5	.23	ng	5×10^{6}	2	24	Calorimeter (cone)	ng	52
ng	10	.3 to 1.5	1.5	ng	2×10^{6}	2	10	Calorimeter (cone)	ng	53
2000	10	.53 to 1.06	Direct reading	7.5×10^{-3}	ng	2	50	Photodiodes	ng	11
ng	150	.65 to 1.6	.18	ng	15×10^{6}	5	12	Calorimeter (glass disc)	ng	21
MARCO SCIENTIFIC										
200	2×10^{-4}	.22 to .71	50mA/W	$.5\times10^{-3}$	$.5\times10^{-3}$	ng	30	Photodiode	$450-540	1400's
MICRONETIC SYSTEMS										
15	ng	.35 to 1.13	.1	.005	ng	5	16	Photodiode	$750-1,350	330
MOLECTRON										
10^{-12} to 10^{-5}	ng	1 to 1000	10^{5}V/W	ng	ng	10	10	1.5°K calibrated bolometer	$4,000	D1.5S
PERKIN-ELMER INDUSTRIAL PRODUCTS										
.1	na	.45 to 1	na	na	na	± 5	30	Si detector cell	$ 425	5000
QUANTRONIX										
300	300	.4 to 10.6	5	4×10^{6}	ng	3 to 5	20	Calorimeter	$500-1,300	500, 502, & 504
ng	ng	.4 to 1.06	.1 V/W	.1	ng	ng	6	Photodiode	$ 250	506
SCIENTECH										
50	200	.3 to 30	100	24×10^{6}	ng	3	100	Calorimeter	$ 785	LTM-11
50	200	.3 to 30	100	24×10^{6}	ng	3	75	Calorimeter	$ 785	LTM-21
3	10	.3 to 30	100	14×10^{6}	ng	3	25	Calorimeter	$ 375	3600
1000	1000	.3 to 100	1	14×10^{6}	ng	3	25	Calorimeter	$1,950	3701
SPACERAYS										
10^{10}	10^{3}	.3 to 1.15	ng	3×10^{-4}	ng	5	50	Photoemissive	$1,550	FPD125
SPECTRA										
5	na	.4 to 1.1	Direct rdg.	.05	.05	2.5	9	Flat response power meter	$ 489	900
.25cw	3	.48 to 1.2	>10mV/mW ≥ .8μm	~.0001	~.0001	5	.06	High-speed detector	$ 839	32

na — not applicable ng — not given

A COMPARISON OF MICROWAVE DETECTION INSTRUMENTS

INTRODUCTION

Microwave energy is currently being employed in several different ways, with increased emphasis on use in consumer products. When used as a source of power for a consumer product, microwaves are generally intended to be used in a completely shielded enclosure which allows no access while the microwave source is operating. Since there is concern about the biological effects of such radiation, it is necessary to detect and quantitate leakage from products using this type of energy source.

All of the commercial instrumentation available at the time of this evaluation respond to the electric field intensity and are calibrated in terms of power density measured in free space.

TYPES OF MICROWAVE POWER DENSITY INSTRUMENTATION

Several classification methods for microwave power density instrumentation are possible. The three categories we have chosen are intended use, method of detection, and method of indication. There are two distinct equipment use categories, either as a laboratory instrument or as a survey instrument. A laboratory instrument would ideally be sensitive enough to measure whatever power densities are desired and would be capable of covering an extremely wide dynamic range. It should create no disturbance to the propagating field and should be stable with a very fast response time. It should be able to indicate accurately at any distance from the source.

If the instrument is designed for survey use, it should meet additional major requirements; i.e., it should be lightweight, battery operated with low battery drain, easily readable, rugged, and have a minimum number of switch settings. The probe should be burnout-proof and directionally independent. For operator safety, it is also very important that a survey device not read low when it is in a potentially hazardous field.

The detection methods category can be divided into thermal detectors and electrical detectors. Thermal detectors act on the principle of producing a detectable physical change (temperature) in a thermally sensitive element. This change is then measured, usually by electrical means. There are three general types of thermally sensitive elements in use today. The first is the thermistor. The resistance of the thermistor decreases when its temperature rises. The thermistor is heated by coupling it to the electromagnetic field. It is the RF (radiofrequency) current which causes the heating of the thermistor, but the detection of this heating is done by measuring the d.c. resistance of the thermistor. Another device closely akin to the thermistor is the baretter which has a positive temperature coefficient of resistance rather than a negative one. These are both known as bolometer detectors, a term meaning any device which changes its resistance as it changes temperature.

Another type of temperature-sensitive device is the thermocouple. A thermocouple produces a voltage when heated. Therefore, all that is necessary to make a detection device from a thermocouple is an antenna and a current or voltage measuring device. Since voltage and current levels encountered when using these detectors are very small, a sensitive meter must be used, generally in conjunction with some type of direct-current amplifier.

A third and rather novel approach to thermal microwave measurement is the air-pressure system. This system involves the measurement of a small pressure change in a confined gas when its container is heated slightly by absorbing some RF energy. The container for the gas is usually some sort of electrical insulator covered by a carbon compound which absorbs RF energy quite well.

The three thermal detection schemes discussed have individual and common deficiencies. They all are, of course, ambient temperature dependent in their simple form. More sophisticated methods of measuring the difference in output from matched thermal detectors with only one exposed to RF heating have been developed, and such instruments are superior for general application.

A somewhat different approach to power density measurement is that of direct electrical energy conversion. The detected RF power directly activates the meter needle for measurement. This effect is accomplished by using a semiconductor diode or rectifier. This device, of the same type as used in early radio sets, rectifies the alternating RF current into direct current which may then be applied to a meter movement calibrated to indicate power. Knowing the effective antenna area, the power density may be calculated. The diode detector type of indicator may be made extremely sensitive. In fact, this is one of the drawbacks of high frequency diodes -- even moderate signal strengths must be attenuated before reaching the detector in order not to overload it. This is sometimes rather complicated and may lead to measurement inaccuracies. This is probably the reason that the thermal detectors are preferred over diode detectors for survey-type power density meters.

With the exception of the air-pressure detector, all detectors or sensors require an antenna to convert the propagating radiofrequency wave into wire-conducted radiofrequency currents which are then detected by either a thermistor, thermocouple, or diode. It is this antenna that determines the major characteristics of the measuring instrument. There are two attributes of an antenna which are important to the user of the instrument: directionality and polarization sensitivity. Directionality of an antenna is the dependence of its response on the direction from which the wave comes. One would like an antenna which is somewhat directional so that the effect of reflections from survey personnel will be minimal, but at the same time it should not be too directional so that orientation towards the source becomes critical.

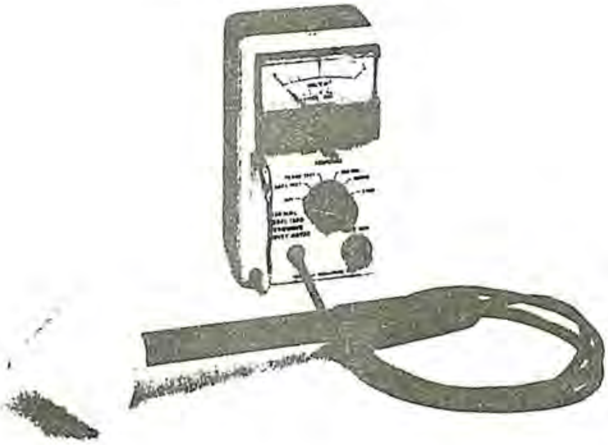
The second attribute is polarization sensitivity. Polarization of an electromagnetic wave refers to the direction of the electric field vector. This vector may be varying in orientation (random polarization), fixed in orientation (plane polarization), rotating in orientation at the radiofrequency (elliptical polarization), or any combination of these. There is no single antenna which will respond to all polarizations simultaneously. This causes a great problem in antenna design. To achieve true polarization independence, one must use two antennas which are identical to each other except that they accept orthogonal polarizations. The power captured by these antennas must be added arithmetically in the metering circuit, which places added constraints on the design. To design a survey meter with true polarization independence is no easy task. Generally this is accomplished by using two perpendicular dipole antennas with independent detectors.

The third category for classification of microwave power density instrumentation is method of indication. Quantitative methods are an analog scale and digital indication calibrated either in milliwatts per square centimeter or decibels relative to some reference. These methods seem to be the most practical in a laboratory or survey meter. If the instrument is used to measure product performance against a standard then it is very helpful to have the indication in the same terms as set forth in the standard. Visual qualitative devices such as variously colored gaseous glows or an audible alarm which sounds when some power density limit is exceeded are useful devices under certain conditions; e.g., quickly locating microwave leakage from an oven.

RAD-MIC
Oven
Holaday Ind.
Mar. 1972

Microwave Oven Leakage Meter

Holaday Model HI 1500

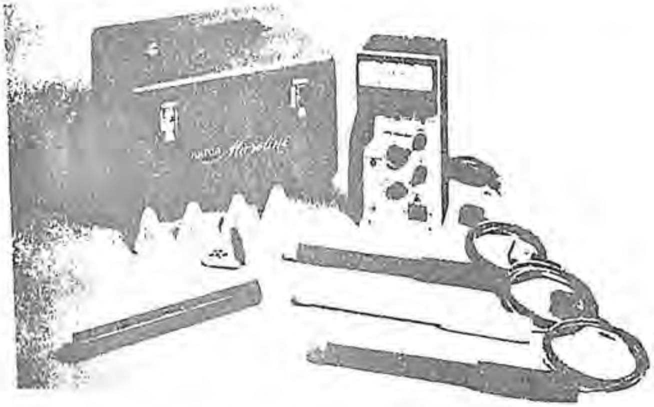


Class	Portable
Principle of Operation	An antenna array composed of eight diodes is biased for square law detection of the electric fields in a plane perpendicular to the probe axis; amplifier, meter read-out.
Sensitivity and Range	Frequency: 2450 MHz Three ranges: 0-2 mW/cm^2 0-10 mW/cm^2 0-100 mW/cm^2 Maximum power density: 1.5 W/cm^2 Minimum measurable flux:
Performance	Accuracy: ± 1 db Calibrated down to 0.2 mW/cm^2 Time response: For a step input from 0-90% Fast - 1 second Slow - 3 seconds Temperature Compensation from 0°C to 50°C
Requirements	Power: Two 9 volt batteries, 216 series, 100 hrs. continuous use Size: 6 cm, 9 cm, 15 cm (2.5", 3.5", 6") Weight: About 1.4 Kg (3 lbs)
Features	Measurement independent of field polarization, replaceable probe spacer cones. Fail-safe circuit, battery test circuit.
Cost	$174
Address	Holaday Industries, Inc. 1001 Second Street, South Hopkins, Minn. 55343 Attn: Reed Holaday (612) 935-5518

RAD-MIC
Oven
Narda
Mar. 1972

Microwave Oven Leakage Meter

Electromagnetic Radiation Leakage Monitor, Model 8100



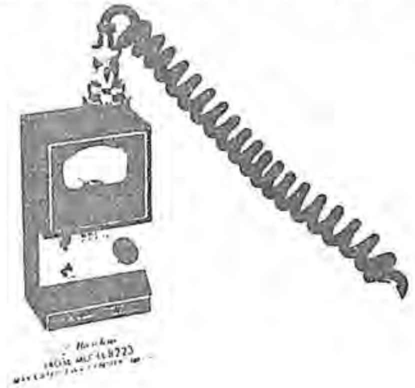
Class	Portable, hand-held oven leakage monitor
Principle of Operation	Three different probes each having a dynamic range of 23 dB which use thermocouples as the sensing elements, battery operated, meter readout.
Sensitivity and Range	Operates at either 915 or 2450 MHz Full scale (two ranges) Probe Model 8120A, 200 μW/ cm^2 to 2 mW/cm^2 Probe Model 8181A, 2 mW/cm2 to 20 mW/cm^2 Probe Model 8122A, 20 mW/cm^2 to 200 mW/cm^2 Maximum permissible flux= 5 db above full scale Minimum measurable flux = 23 dB below highest full scale
Sampling	Continuous, settling time to obtain reading is from .75 sec (min) (35 ms with 8120A) to 3 sec (max) selected by front panel switch
Performance	Manufacturer's specifications Probe accuracy ± .75 dB Instrument accuracy ± 3% of full scale Stability 0.5%/°C max zero offset, 0.05%/°C temperature sensitivity Calibration of probes by manufacturer is at 2 mW/cm^2 for Models 8120A and 8121A, and 20 mW/cm^2 for Model 8122A
Requirements	Power: Rechargeable Ni-Cad battery, 2:1 use to charge ratio, 20 hr use time Size: Probe, 11.5" long x .75" diameter Meter, 10" x 4.5 " x 4" Weight: 12.5 lb with case
Features	Color coded probes, 5 ft cable, recorder output 100 mV full scale into 100 Ω min, fast/slow response to check instantaneous peak or average leakage. Adjustable audible alarm, insensitive to polarization
References	a.) Manufacturer's data sheet b.) Only instrument recommended by R. H. Groom, Chairman, Radiation Hazards Subcommittee, A. T. and T., 195 Broadway, New York, New York 10007, (Nov. 1970) c.) Only instrument recommended by Dr. Robert Elder, Director of Electronics Products Div. HEW during a Bureau of Radiological Health committee meeting, (1970) d.) Edward E. Aslan, "Electromagnetic Radiation Survey Meter", IEEE Trans. on Instrumentation and Measurement, Vol IM-19, No. 4, (Nov. 1970)

Cost	Three probes and a zero power density simulator $960
Remarks	Best sensitivity and accuracy currently available, fail-safe circuit
Address	Narda Microwave Corporation Plainview, New York 11803 Attention: Edward E. Aslan (516) 433-9000

RAD-MIC
Oven
Narda
Mar. 1972

Microwave Oven Leakage Meter

Electromagnetic Leakage Monitor Mini-Surveyor, Model 8200



Class	Portable, hand-held oven leakage monitor
Principle of Operation	Three different probes, each having a dynamic range of 23 db which use a thermocouple (as the sensing element), amplifier, and meter.
Sensitivity and Range	Operation: 2450 MHz Probe Model 8223: 10 mW/cm^2 and 100 mW/cm^2 Probe Model 8221: 2 mW/cm^2 and 20 mW/cm^2 Maximum Permissible Flux: 5 db above full scale Minimum Measurable Flux: 23 db below highest full scale
Sampling	Continuous, 1.2 sec to obtain reading
Performance	Manufacturer's specifications Meter Accuracy: ± 3% of full scale Probe Accuracy: ± .75 db Stability: 0.5%/°C max zero offset; 0.05%/°C temperature sensitivity Calibration of Probes: 20 mW/cm^2 Maintenance: Available Response Time: 1.2 sec typical
Requirements	Power: 9 V expendable battery Size: Probe 28 cm long, 2 cm dia (11" L, 3/4" D) Meter 12 cm L, 7 cm W, 4 cm H (4.6"x 2.6"x 1.7") Weight: 0.6 kg (1.3 lb)
Features	Color coded probes for different ranges, battery test switch, furnished with one probe
References	Manufacturer's data sheet
Cost	Model 8200 including case \$335 Each additional probe 105
Address	Narda Microwave Corporation Plainview, New York 11803 (516) 433-9000 Attention: Edward E. Aslan

Laboratory VI

20. EVALUATION OF A LASER INSTALLATION

21. Survey of Industrial X-Ray Installations

I. INTRODUCTION

A. The purpose of the survey is to evaluate the safety status of the installation and to establish conditions for safe operation.

B. The techniques suggested here are offered as interim procedures pending revision of ASA Code Z 54. 1.

A. Scope

The procedure for the survey and the content of the report is outlined in the accompanying inspection form. In general, the survey consists of the following:

1. Description of equipment
2. Description of normal operating conditions
3. Descriptions of protective barriers
4. Monitoring data
5. List of safety features, such as interlocks, etc.
6. Summary
7. Recommendations

B. Area Monitoring

1. Area monitoring with survey meters should be carried out under normal operating conditions and also under any special operating conditions which are sometimes used.

2. Special attention should be given to the following

a. door sills and jambs

b. door locks

c. electrical fixtures in walls (effective thickness of walls is less)

d. pipe holes, ducts, louvers, etc.

e. glass (common glass may be substituted for Pb glass following breakage)

f. sky-shine, especially when barriers are not all the way to the ceiling.

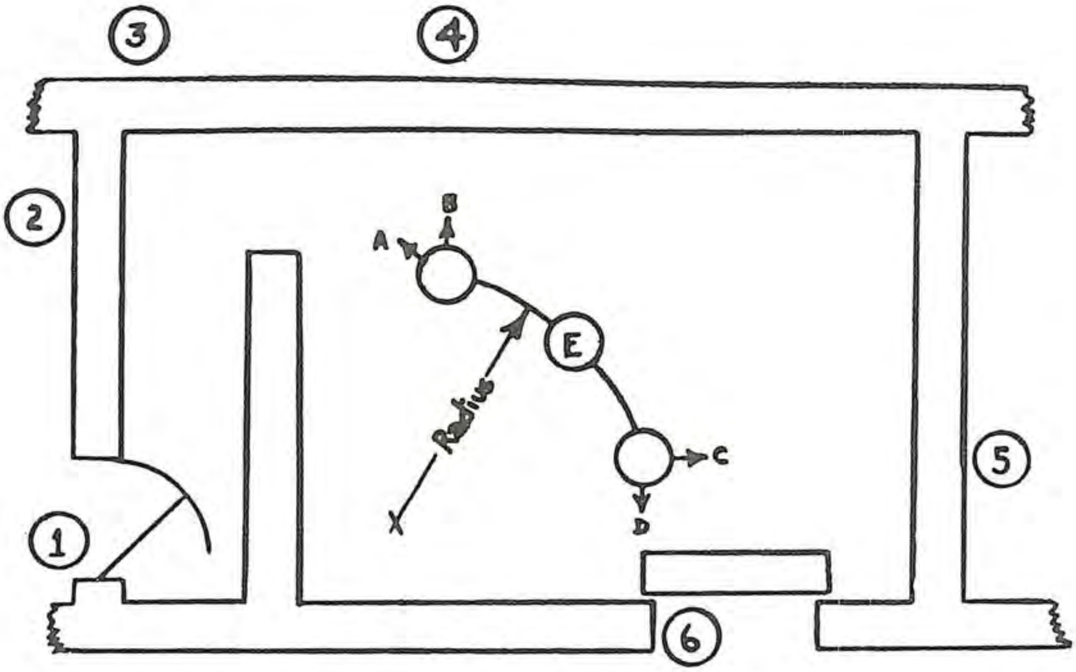
g. operator's position

3. Where x-ray unit is not enclosed, or where structural shielding is inadequate, determine isodose line within which personnel must not be permitted during exposure. Dose rate at this line should be based on maximum practicable use of equipment.

4. Where dose rates are measured at a number of positions for each of several positions of the tube, the orderly recording of data becomes difficult. It is recommended that each tube position be designated by a capital letter, and that each position monitored be designated by a number. Then the meter readings can be recorded in tabular form. (See Figure 1.)

5. The summary should designate areas where dose is excessive under any practicable operating conditions. (The maximum permissible limit is 100 mr/wk for controlled areas, and 10 mr/wk for uncontrolled areas). The summary should list deficiencies in all necessary safety features.

6. Recommendations may include restrictions on mode of operation, restrictions on workload, restrictions on occupancy of adjacent areas or plans for additional structural shielding. During the survey, enough background information should be obtained to determine which of these alternatives would be most acceptable to the management.



Position of Tube →	A	B	C	D	E
Position Monitered ↓	horiz	horiz	horiz	horiz	down
1	5	0	0	0	0
2	8	0	0	0	0
3	10	3	0	0	0
4	3	20	0	0	0
5	0	0	17	0	0
6	0	0	2	30	0
7 Basement	0	0	0	0	18

Figure 1

Showing Method of Recording Dose Rates when Monitoring Multiple Tube Positions

GPO 874-980

Laboratory VIA

22. SURVEY OF MICROWAVE OVEN

MICROWAVE OVEN SURVEY

Written by William E. Murray, directed by Stephen G. Bayer, visuals by Glenda White, outline preparation by Pauline Elliott, modelling by Donna Welage, and music by Mark Conrad.

MICROWAVE OVEN SURVEY

This presentation is concerned with the microwave oven and will describe its operating principles, the standards which apply to the oven, and the procedure for determining compliance with the standards. With this information, you should be able to:

1 Describe the components of the microwave oven and their function in the cooking process.

2 List the standards for leakage radiation and the necessity for having standards.

3 Select the appropriate measuring instrument and survey the oven.

There are several components found in all ovens. A magnetron tube is most often used as the microwave source. The power supply provides electrical energy for conversion to electromagnetic microwave energy by the source. The control unit consists of an off-on switch for the power supply and a timer to regulate the length of time microwaves are being produced. The microwaves are directed into the oven cavity by the wave guide and uniform distribution of the waves in the cavity is assured by the stirring mechanism. The interlock prevents generation of microwave radiation when the door is open.

Microwaves are electromagnetic radiation similar to visible light. In the electromagnetic spectrum, microwaves occupy the portion between radio frequency and infrared radiation. All types of electromagnetic radiation have some common characteristics. The first characteristic is the wave length of the radiation. A sine wave is a good way to represent electromagnetic radiation. The wave length, then, is the distance between two similar points on the sine wave and the symbol used is the Greek letter λ. The wave length is usually measured in centimeters. Microwaves have wave lengths between 30 meters and 3 millimeters. Another characteristic is the frequency of the radiation represented by the Greek letter ν. This is the number of wave lengths which pass a given point in each second. It used to be given in terms of cycles per second, but the preferred term is the unit Hertz. One cycle per second is now referred to as one Hertz. The abbreviation for this unit is capital H, small z. The microwave frequencies range between 10 megahertz and 100 gigahertz. 1 megahertz is 1 million Hertz while 1 gigahertz is 1,000 megahertz.

Most foods which constitute peoples' diets are usually more than 50% water. A water molecule consists of two hydrogen atoms and one oxygen atom. The hydrogen atom has a charge of +1, whereas the oxygen has a charge of -2. The overall net charge on the water molecule is zero because the plus charge of the two hydrogen atoms is neutralized by the negative charge of the oxygen; however, looking at the charge distribution of the molecule, we find that the oxygen end is primarily negatively charged while the hydrogen is primarily positively charged. Any molecule which has a charge distribution such as this is called a polar molecule or dipole. When a polar molecule is placed in a changing electric field, it tries to line itself up with the field. Consequently, the molecule will undergo up to a 180° direction shift everytime the field changes its polarity. The microwave radiation produced in most ovens has a frequency of 2450 MHz. Thus, the water molecule will change its direction by 180° almost 2-1/2 billion times every second and, with each shift, the molecule gives off heat. This has often been referred to as molecular friction and is the process by which foods can be cooked in a microwave oven.

Microwave radiation will cook food because the interaction of the radiation with the water molecules in the food produces heat. From a chemical standpoint, the human body is very similar to the food we consume. Most of our body's soft tissue, such as muscle, internal organs, etc., is approximately 70% water by weight. The major exception is bone which contains comparatively little water. This means that microwave radiation will heat up most of our body tissues as rapidly and efficiently as it will any type of food. Thus, microwave radiation from an oven, radar system, or any other source, is a potential health hazard to people who work with such sources. There are three effects which may result from excessive exposure to microwave radiation and are believed to be caused primarily by the buildup of heat in the affected organ. The first effect is cataracts which occur in the lens of the eye and prevent incident light from being transmitted to the retina causing a loss of visual acuity and, in later stages, total blindness. This is an irreversible process, but can be cured by removing the lens and using corrective lenses. Second, microwave radiation can cause temporary subfertility or sterility in males by increasing the testicular temperature above its normal level of 95°F. By increasing the temperature to the normal body temperature of 98.6°F, sperm production will cease and, if this temperature were maintained for several days, the sperm count would decrease to zero. Maintaining a testicular temperature between 95°F and 98.6°F would result in a decreased sperm count which is called subfertility. Both effects are reversible and sperm production will resume at normal levels when the temperature is reduced to 95°F. The third effect is whole body heating which could result in a potential heat stress situation. This probably would not happen with a microwave oven, but would be a very definite hazard in some other industrial applications. Microwave radiation can also affect heart pacemakers. Because microwaves are oscillating electric fields, they can interfere with the signals generated by the pacemaker to stimulate the heart beat. The practical solution to this problem is to prevent persons with a pacemaker from entering an area where a microwave oven is located. Warning signs are usually employed for this and are placed about 25 feet from the oven at every access point.

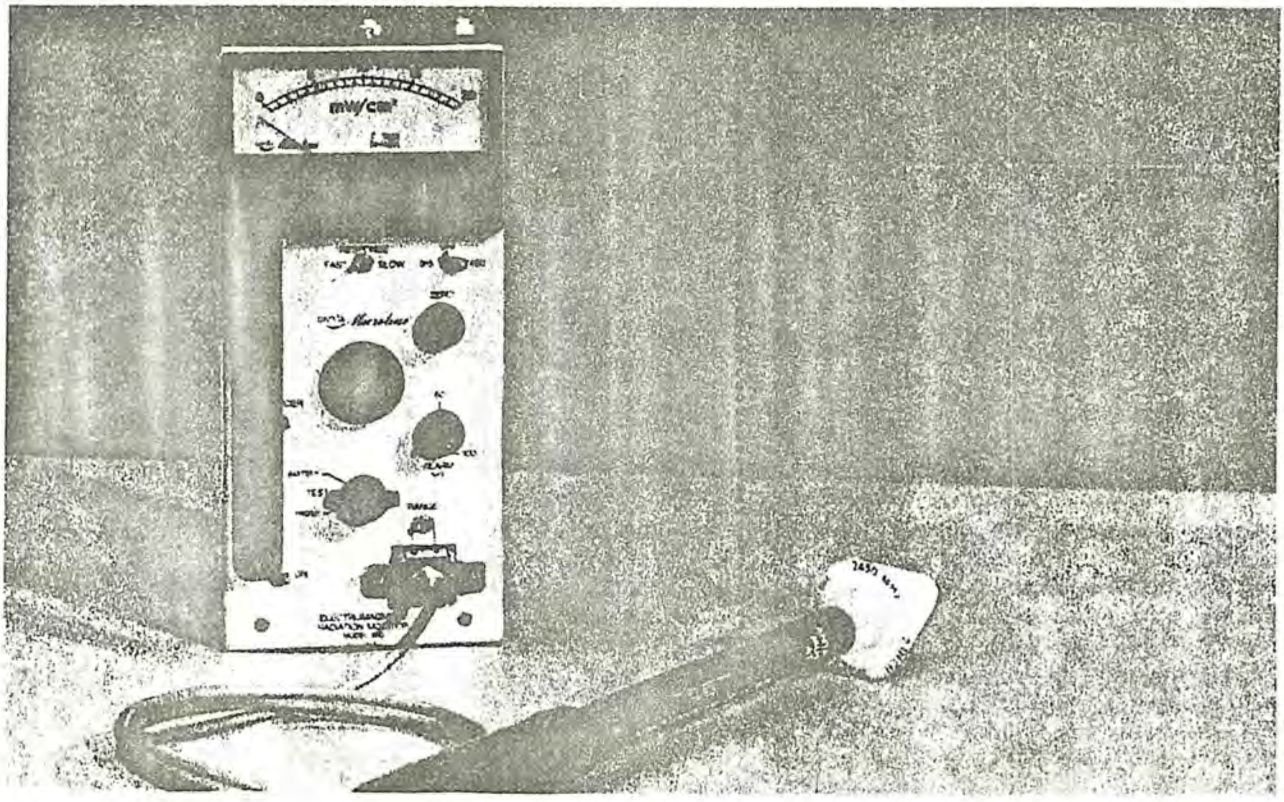
To protect people from being exposed to excessive levels of microwave radiation, standards have been promulgated by two Federal agencies, the Bureau of Radiological Health of the Department of Health, Education and Welfare and by the Department of Labor. Both standards utilize the term power density expressed in terms of milliwatts per square centimeter (mW/cm^2). A milliwatt is $\frac{1}{1000}$ of a watt.

The Bureau of Radiological Health standard is an equipment performance standard and is not a personnel exposure standard. At the time of manufacture, the microwave leakage at a distance of 2" from an oven is limited to a maximum of 1 mW/cm^2. After the acquisition by the purchaser at the retail level and at anytime during the lifetime of the oven, the leakage is limited to a maximum of 5 mW/cm^2, again at a distance of 2". In addition, there are requirements for other safety features, recordkeeping, etc., but our concern is strictly for the maximum leakage levels. The standard applies only to ovens manufactured on or after October 6, 1971, and these ovens must be labeled with a statement indicating that the oven meets all the safety requirements of the performance standards for microwave ovens by the U.S. Government, Department of Health, Eudcation and Welfare as specified in the code of Federal Regulation, Title 42, Section 78.212. Ovens manufactured before that date were subject to a voluntary limit of 10 mW/cm^2 agreed to by the manufacturers.

The standard adopted by the Occupational Safety and Health Administration of the U.S. Department of Labor is the limit recommended by the C95.1 committee of the American National Standards Institute. The standard is a time-weighted-average limit which is used as follows. The workday is divided into 0.1 hour or 6 minute periods. During any 6 minute period, the product of the power density in mW/cm^2 and the exposure time in fractional hours must not exceed 1 $mW\text{-}hr/cm^2$. To illustrate how to use the standard, a few examples are necessary. If a worker were exposed to microwave radiation for the whole 0.1 hour period, the maximum power density to which the worker could be exposed to is simply 1 $mW\text{-}hr/cm^2 \div .1$ hour which equals 10 mW/cm^2; thus, for a continuous exposure situation the exposure limit is 10 mW/cm^2. On the other hand, if the worker were exposed for only 1 minute out of every 6 minutes, the maximum power density would be 60 mW/cm^2 for the 1 minute period; but for the remaining 5 minutes, the worker could not be exposed to any microwave radiation. Theoretically speaking, there is no upper limit on power density as long as the exposure time is decreased proportionally. For instance, a power density of 3,600,000 mW/cm^2 would be acceptable if the worker's exposure time were only 1/1000 of a second in any 0.1 hour period. More practically, however, exposure times of less than 1 to 2 minutes corresponding to a maximum power density of 60 to 30 mW/cm^2 are difficult to control. Microwave exposure from ovens would probably be far lower than these levels depending, of course, on the age of the oven and its mechanical condition. Although a personnel exposure may not exceed the Occupational Safety and Health Administration limit, the oven could still be in violation of the Bureau of Radiological Health standard.

There are three instruments presently available for measuring leakage radiation from a microwave oven. Two of these are manufactured by the Narda Microline Corporation, Plainview, New York, and the model numbers are the 8100 and the 8200. The third is the Holaday Model HI 1500 from Holaday Instruments, Inc., Hopkins, Minnesota.

The Narda 8100 consists of the meter, three probes, 2 styrofoam cones, a zero power density simulator, a power cord, and the carrying case. The meter has several controls and indicators which require a functional description. The on-off toggle switch provides operating voltage to the meter. The probe plugs are connected to the meter through the probe connector. A range switch allows selection of two sensitivity ranges differing by a factor of ten which are indicated on the probe plug. Using the test switch, both the battery and the probe can be checked for proper operation. The alarm control is used to set the approximate percentage of

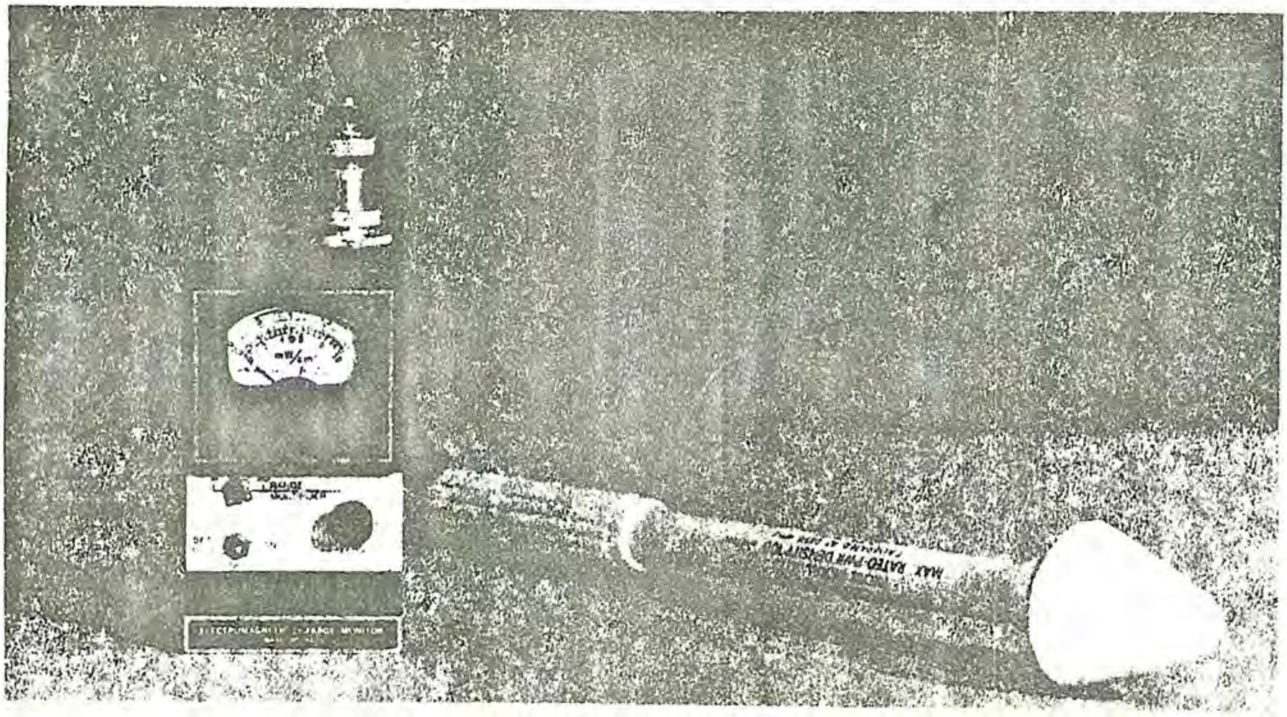


Narda 8100

full scale reading at which the audio alarm will sound to indicate a power density greater than the present level. Electrical adjustment of the meter zero setting is done with the zero adjust control. The meter response switch allows selection of fast or slow meter response. Because most ovens operate at a frequency of 2450 MHz, the frequency switch will normally be set at 2450. The General Electric Versatronic model operates at a frequency of 915 MHz and the switch has to be set at 915 to measure these ovens. The meter itself indicates the intensity of the microwave radiation sensed by the probe in mW/cm^2 and varies between 0 and 20—although an external record can be made using the recorder jack. The actual power density reading is determined by the range of the probe and the range switch. The line on the meter face indicates the minimum response for probe and battery test. The meter is powered by a 15 volt rechargeable nickel-cadmium battery but can also be operated by connecting the AC cable provided to a 115 or 230 VAC line with the plug connector on the meter. The 115/230 VAC slide switch must be set to the appropriate setting and the power switch turned on. With the power switch off, the normal charge rate is 2:1 use-to-charge ratio with a maximum use time of 20 hours. Replacement batteries can be ordered from the Narda Corporation. The three probes available for the 8100 are the Models 8120A, 8121A and 8122A. The Model 8120A is the most sensitive and has a full scale range up to 0.2 mW/cm^2 or 2.0 W/cm^2 (depending on the range switch setting) with a minimum sensitivity of .01 mW/cm^2. The Model 8121A probe has a range of 2 or 20 mW/cm^2 with a minimum of .1 mW/cm^2. The 8122A probe can measure up to 20 or 200 mW/cm^2 with a minimum of 1 mW/cm^2. One word of caution must be given concerning these probes. If they are exposed to microwave power density exceeding 6 mW/cm^2 for the 8120A, 60 mW/cm^2 for the 8121A, and 600 mW/cm^2 for the 8122A, the probe will burn out and have to be replaced. To prevent such damage, the case is shielded; but, it is a good idea to wrap the probes in aluminum foil especially during shipment. Two styrofoam cones are provided for two purposes. First, they allow easy measurement of the oven at the required distance of 2". Because probes will respond to heat, the second function is to prevent false readings due to any heat given off by the oven. It is important to make sure that the cone labeled 2450 MHz is used when measuring an oven which operates frequency because the 915 MHz cone has a special, built-in antenna element. Erroneous readings will result if the 915 MHz cone is used to measure an oven operating at 2450 MHz and vice versa. The zero power density simulator is used to shield the probe when electrically zeroing the meter prior to use. The 8100 costs $960, including the case, meter, 3 probes, and zero power density simulator.

The Narda 8200 is considerably less expensive ($335) and consists of a meter, a single probe, a styrofoam cone, and the carrying case. There are only three controls on the meter. A toggle switch serves as the power switch to turn the meter off and on, and also as a battery test. There is also a range multiplier switch which can be set to the X 1 or X 10 position. The zero adjust control electrically zeros the meter. There are two scales on the meter. The white scale reads from 0 to 2 mW/cm^2 and is used for the white 8221 probe. The yellow scale reads from 0 to 10 mW/cm^2 and is used for the yellow 8223 probe. There is also a line on the meter which is the minimum response for the battery test. The instrument is powered by a 9 volt expendable battery. The probe connector is on the top of the meter. There are two probes available for this meter, but only one is included at the above price. A second probe can be be purchased for $105. The Model 8221 probe has a full scale range up to 2 or 20 mW/cm^2 depending on the range selection with a minimum sensitivity of 0.1 mW/cm^2. The 8223 probe has a range up to 10 or 100 mW/cm^2 and a minimum of 0.5 mW/cm^2. These probes are subject to burnout at 60 mW/cm^2 for the 8221, and 300 mW/cm^2 for the 8223. The case is also shielded. A styrofoam cone is provided to prevent false readings due to heating and to maintain the 2" distance.

The Holaday HI 1500 is similar to the Narda 8200 with some exceptions. The meter probe and styrofoam cap are connected and cannot be separated. The meter has a single



Narda 8200

rotary switch which activates the battery and probe tests and adjusts the range to a maximum of 100, 10 or 2 mW/cm^2. There is also a zero adjust control and a meter time response switch. The meter has two scales 0-2 and 0-10, and both use the same markings. The meter also indicates the minimum response for the battery test and a range in which the probe test must fall. The range switch can be adjusted to read from 0-2, 0-10, or 0-100 mW/cm^2. The minimum measurable value is approximately 0.2 mW/cm^2. The styrofoam cap is permanently attached and serves as a heat absorber and spacer. The probe can be exposed to power densities up to 1500 mW/cm^2. This instrument costs $174.

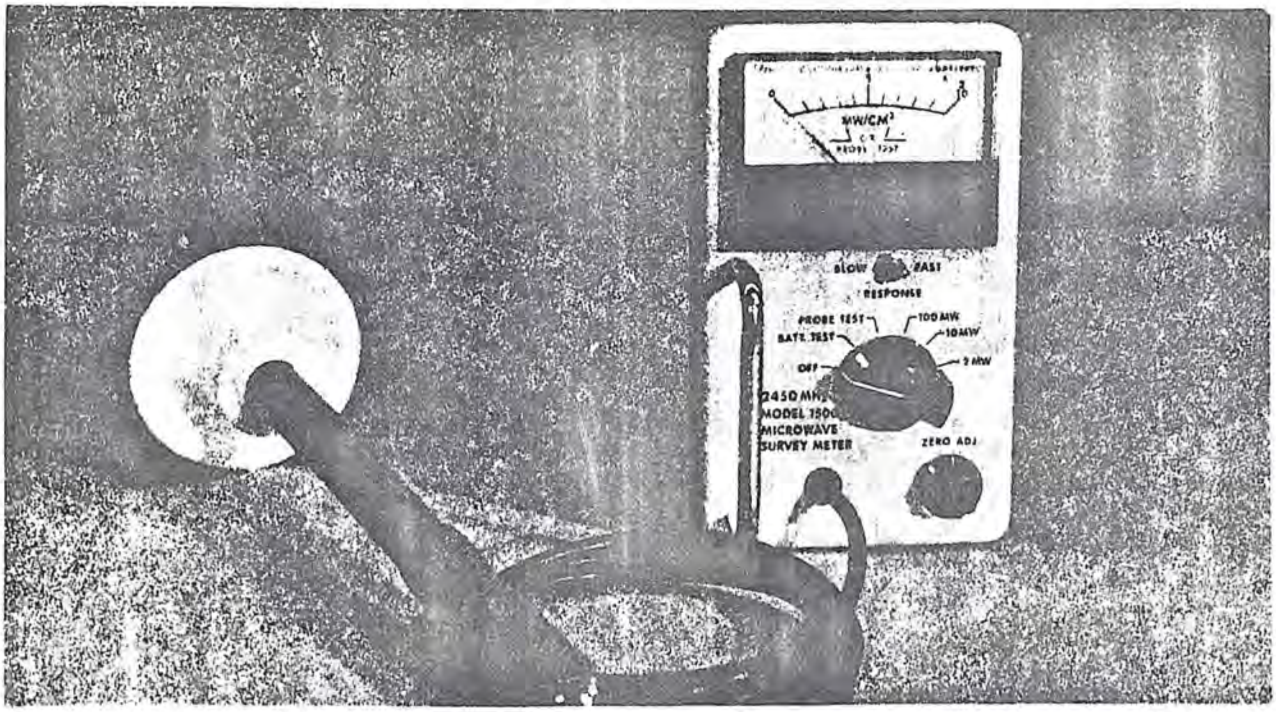
These are the only approved instruments for measuring leakage from an oven. They are all accurate to about the same degree and are calibrated by the manufacturers.

Before carrying out the actual measurement of the microwave leakage from an oven, certain information concerning the installation, the oven, personnel exposed, etc., must be obtained in a preliminary interview.

A sample survey form is included in your script.

The actual measurement procedure utilized will depend to some extent on whether the survey is checking the oven for compliance with the Bureau of Radiological Health or the Occupational Safety and Health Administration standard. The differences in technique will be pointed out as the situation arises and a more or less general procedure will be presented as follows:

1 Place a load in the oven to stimulate the normal cooking conditions. The Bureau of Radiological Health standard specifies that the load should be 10 ounces of cool tap water. For the Occupational Safety and Health Administration standard, use a food item representing the average conditions or smaller. In either case, center the load on the cooking surface. Never operate the oven empty or serious damage may result to the microwave generating tube.



Holaday 1500

2 Check out the measurement instrument. The following steps should be taken when possible before any measurements are made:

   a Attach the probe having the highest power density rating.

   b Check battery and probe condition.

   c Zero the instrument.

   d Set the frequency switch to the oven frequency.

   e Set instrument to the highest range.

   f Select the fast meter response.

3 Close the oven door normally to activate interlocks and turn on the oven allowing for enough time for measurement. When using the water load, the water must be replaced if it starts to boil.

4 For the Bureau of Radiological Health standard, the leakage at 2" from any surface must not exceed 5 mW/cm^2. Usually it will be necessary to measure around the door, doorscreen, and any vent openings. When measuring, the probe must always be perpendicular to the surface being measured and the maximum probe speed is approximately one inch per second. If any high leakage areas are found, remeasure those areas using slow response and record the measurements and their locations.

5 With the oven operating, open the door 1 inch to determine if the oven will still operate. It should not operate at this distance.

6 Although the fore-mentioned measurement procedure is geared to the Bureau of Radiological Health standard, it should be conservative as far as personnel exposure is concerned because most employees would not be as close as two inches to the oven. If at 2", the levels exceed 10 mW/cm^2, measurements should be made at the operator's actual location to determine compliance with the Occupational Safety and Health Administration standard.

If the levels do exceed the standards, check the condition of the oven with regard to cleanliness, mechanical function, and the presence of alterations or abuse which may cause excessive leakage.

MICROWAVE OVEN EVALUATION

(Student Practice Survey Form)

A. Installation Information

Company/Division: ____________________

Location: ____________________

Telephone: ____________________

Supervisor: ____________________

Person(s) Interviewed: ____________________

B. Equipment Specifications

Manufacturer: ____________ Model: ____________

Serial Number: ____________ I. D. Number: ____________

Date Manufactured: ____________ Date Purchased: ____________

Approval: ______ UL ______ FCC ______ DHEW/BRH

Condition of Oven __ Good __ Fair ____ Poor

Operating Frequency: _____ 915 MHz ___ 2450 MHz

C. Survey Information

Oven Operable: ___ Yes ___ No

On Time: __________ Minutes Per Day

Persons Exposed Operators: ____________________

Others: ____________________

1. Instrumentation

Instrument Used: ____________ Serial Number: ____________

Probe Used: ____________ Serial Number: ____________

Probe Range: ____________ Date Calibrated: ____________

Instrument Checks: ____ Battery _____ Probe ____ Zero

2. Measurements

Load Used: ____________________

Maximum Leakage, Door Closed: ____________________

Location of Maximum Leakage:

Interlocks Operational: ______ Yes ____ No

Power Cut Off by Timer: _____ Yes _____ No

3. Conclusions

Oven Meets BRH Standard: _____ Yes _______ No

Personnel Exposures are Less Than OSHA Standard: ____ Yes _____ No

D. Recommendations

The Following Action Should Be Taken:

____ None

____ Repair and Resurvey

____ Take Out of Service

____ Other (Specify)

Surveyor: ____

Signed: ____

Telephone: ____________________________

Date: ____________________ Date of Next Survey: ____________________

7

CHARACTERISTICS OF NOISE

I. INTRODUCTION

A. Definition

  1. Noise

  2. Sound

II. BASIC REQUIREMENTS OF SOUND

A. Source

B. Medium

C. Receiver

III. SOUND PRODUCTION

A. Wavelength

B. Frequency

C. Speed

IV. TRANSMISSION

A. Gas

B. Liquid

C. Solid

V. PROPERTIES OF SOUND

A. Intensity

B. Intensity Measurement

C. Frequency

D. Sound Power Level

E. Sound Pressure Level

J. M. Yacher, NIOSH, 01/75, 01/75, IHE(551)-01.

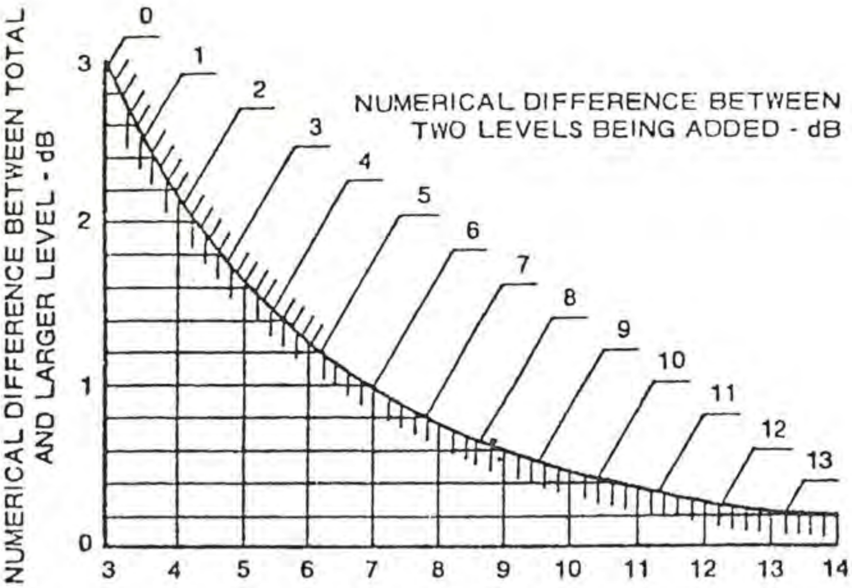


*FIGURE 1.3 - Method for combining decibel levels**

---

* From Handbook of Noise Measurement, General Radio Co., Concord, MA.

TABLE 1.2 - Method for approximating decibel combinations

Difference	Add to Larger Scale (dB)
0	3.0
1	2.6
2	2.1
3	1.8
4	1.4
5	1.2
6	1.0
7	0.8
8	0.6
9	0.5
10	0.4
11	0.3
12	0.2

PROBLEM SET: NOISE WORKSHOP (550)

1. Combine the following groups of decibels:
   - a. 68 dB and 68 dB
   - b. 87 dB and 88 dB
   - c. 47 dB, 65 dB, and 81 dB
   - d. 85 dB(A) and 81 dB(C)
   - e. 86 dB, 86 dB, and 86 dB

2. Two adjacent machines operate intermittently in a room. Each machine was studied individually and the overall noise level due to the blue machine was 91 dB(A). The overall noise level due to the maize machine was 88 dB(A).
   - a. What overall noise level is to be expected when both machines operate simultaneously?
   - b. If the maize machine were treated to reduce its overall noise level by 10 dB(A), what would be the new combined level when both machines were operating?
   - c. Could we have better utilized the 10 dB(A) reduction? How? What would be the result?

J. M. Yacher, NIOSH, 03/74, 01/75,
IHM(550)-02.

3. The following octave band analyses were obtained in two plating rooms.

HZ	Room B-1 dB	Room B-12 dB
31.5	85	71
63	89	73
125	91	76
250	97	86
500	95	90
1000	91	94
2000	88	90
4000	83	93
8000	85	91
16000	86	88

What are the overall noise levels in each plating room?

4. It is planned to add a second dust collector and fan to a ventilation penthouse. Measurements show an overall sound pressure level of 71 dB when the first fan is off. Operation of the fan raises the sound pressure level to 75 dB. The second fan and dust collector will be identical to the first. Ignore any space absorption. What will be the resultant SPL in the penthouse when both fans are operating?

5. A fan is purchased having the following characteristics: belt drive, 1750 rpm, backward curved blades, 30 blades, to deliver 1500 cfm at 0.5" FSP. What predominate frequency can be expected from the fan?

6. A fan is being installed outside a plant to handle the incinerator exhaust gases. The fan suppliers' specifications state that the fan will produce 1 watt of acoustical power. What would the sound pressure level be 10 feet from the fan under free-field conditions?

SOUND AND NOISE

Introduction

Airborne sound refers to rapid pressure variations, that is, alternate increases and decreases in normal atmospheric pressure, caused by a vibratory object, and also the sensation experienced when such pressure changes strike the ear. One complete vibration of the object corresponds to one complete cycle of pressure change. The number of object vibrations per second (or pressure cycles per second) defines the frequency of a sound which is expressed as cycles per second (cps).

The frequency range of audible sounds for healthy young ears is usually considered to extend from 20 to 20,000 cps although there is evidence to indicate that man's hearing extends beyond these limits. The simplest type of sound, called a pure tone, is described as having a single frequency. Sounds, as encountered in nature, rarely consist of a single frequency. Indeed, music, speech and noise are each composed of many frequencies. The frequencies comprising speech are found principally between 250 and 3000 cps. This frequency range is considered most important to man since hearing losses for speech sounds would handicap the individual in most daily activities.

The magnitude of the pressure variations constituting a sound provide a measure of its strength or intensity. Actually the pressure variations producing audible sound are quite small. Normal atmospheric pressure is approximately one million dynes per square centimeter. The faintest sounds which can be detected by the ear are produced by pressure variations of approximately 0.0002 dyne per sq. cm. The pressure involved in producing the background noise levels which we encounter in offices or similar places is of the order of one dyne per sq. cm. or about one-millionth of the barometric pressure. The unit microbar is equal to one dyne per sq. cm. and the terms are used interchangeably.

The Decibel Scale

The ear is able to respond without difficulty over a remarkable pressure range. A pressure one million times as great as that of the faintest audible sound can be tolerated before discomfort or pain begins to develop. To eliminate the difficulties arising from handling large numbers, it is customary to employ the decibel system which is logarithmic in nature. The formula for computing sound pressure level in decibels (dB) is

$$dB = 20 \log_{10}\frac{P_1}{P_0}$$

where P_1 is the pressure of the sound being measured and P_0 is a reference pressure. In industrial hygiene work, 0.0002 dynes per sq. cm. is usually the reference pressure. This value corresponds to the weakest sound that the ear can detect under the most ideal listening conditions. Sound pressure level measurements must always state the reference value being used. Unless otherwise stipulated, all sound pressure level measurements in this presentation will be given as re .0002 dynes/sq. cm. The sound pressure and decibel equivalent for some common sounds are given in Table 1.

Combining Decibel Readings

Since the decibel scale is logarithmic, decibel values cannot be added directly. If the values for two sounds measured separately are known, the approximate sound pressure level that would result

---

Prepared by: Charles D. Yaffe
Revised by: Alexander Cohen

Table 1

Sound Pressures and Decibel Values for Some Everyday Sounds

Sound Pressure (microbars)	Sound Pressure Level (dB re 0.0002 microbar)	Example
0.0002	0	Threshold of hearing
0.00063	10	
0.002	20	
0.0063	30	
0.02	40	
0.063	50	Residence
0.2	60	Conversational speech
0.63	70	
1.0	74	
2.0	80	
6.3	90	Subway
20	100	Looms in textile mill
63	110	Woodworking
200	120	Hydraulic press
2000	140	Jet plane

from combining them is obtained from the following table:

Difference between levels in dB	No. of dB to be added to higher level
0	3
1	2.6
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
10	0.4
12	0.3
14	0.2
16	0.1

In combining more than two sound pressure levels, the two highest levels should be combined first by this procedure. The total thus obtained is next combined with the highest remaining level, and this procedure is continued to completion.

Loudness Levels

It is important to realize that sounds of equal sound pressure level may not be equally loud. At sound pressure levels near 100 dB, frequencies between 20 cps and 1000 cps sound equally loud. At lower sound pressure levels the lower frequency sounds do not seem as loud as the 1000 cps tone. For example, a pure tone of 70 cps having a sound pressure level of 50 dB does not sound any louder than a 1000 cps pure tone having a sound pressure level of only 10 dB. At sound pressure levels below 40 dB, frequencies below 80 cps are inaudible.

Curves showing the sound pressure levels and frequencies required to produce similar loudness levels have been developed through tests on trained observers. These curves are called loudness-level contours. Loudness level is expressed in phons, and is numerically equal to the sound pressure level in dB, re 0.0002 dynes/sq. cm., of a 1000 cps pure tone which sound equally loud to a normal observer.

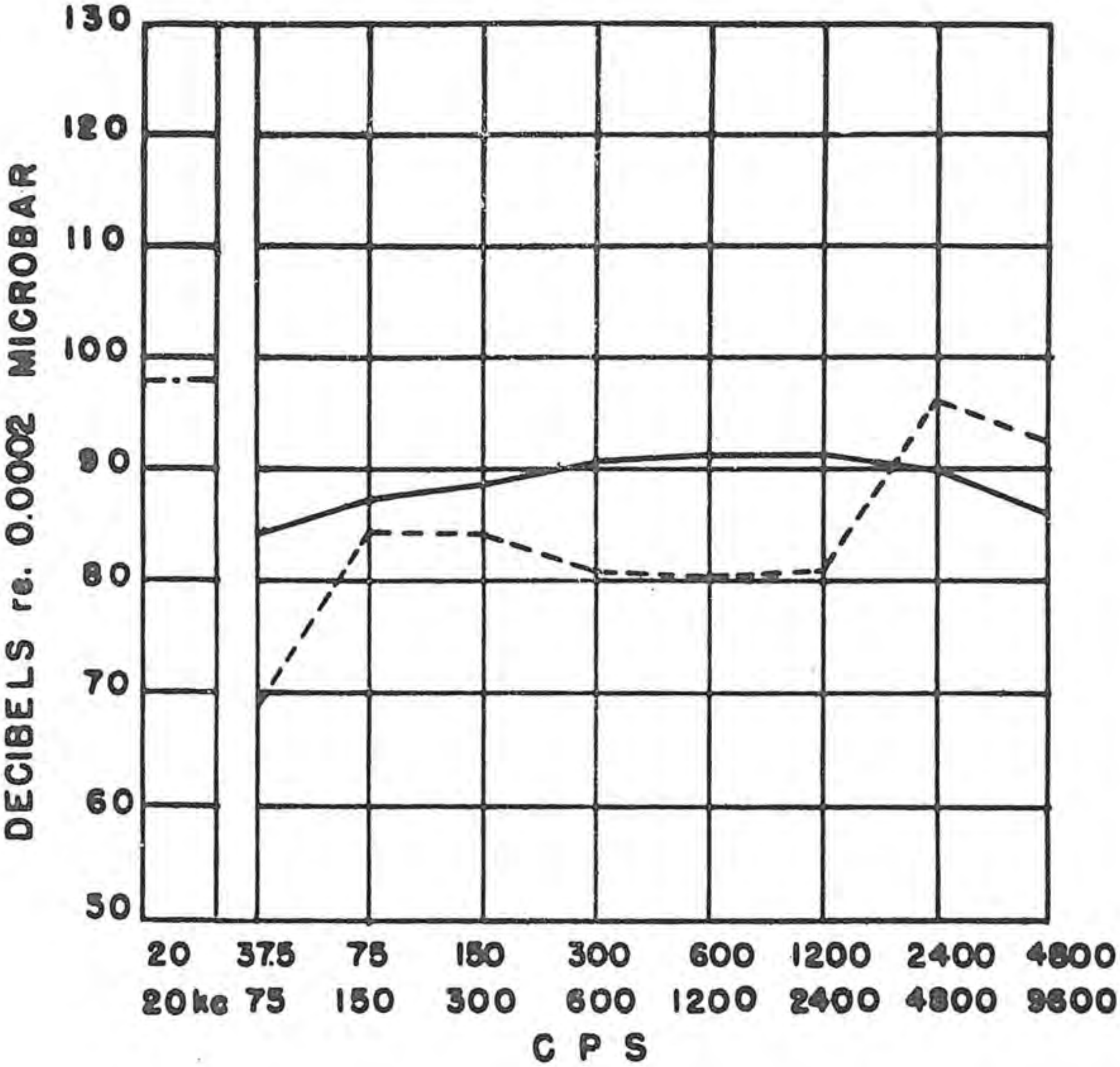
The sone is the unit of loudness. By definition a 1000 cps tone 40 dB above the listeners hearing threshold (or any sound having a loudness level of 40 phons) produces a loudness of 1 sone. The loudnesses of other sounds are compared with this value. Thus, a sound which seems twice as loud to that listener is said to have a loudness of 2 sones.

Through the relationships of decibels, phons and sones, it is possible to translate, at least to some extent, sound pressure levels, which can be measured, to the ear's response in terms of loudness.

Noise and Its Effects

Noise is defined as unwanted sound and may be arbitrarily classified into three basic types, namely, wide-band noise, narrow-band noise, and impulse-type noise. The total acoustical energy of a wide-band noise is distributed across a broad range of frequencies. Descriptions of such distributions, called spectra, can be obtained by dividing the noise into eight frequency bands, each one octave wide, and measuring the sound pressure level within each band.

Figure 1 illustrates data obtained from an octave band analysis of two different wide-band noises having the same total sound pressure level (98 dB). The energy contained in one sound appears to be uniformly distributed across the 8 octave frequency bands. The other noise, however, shows the acoustical energy to be concentrated largely within one or two bands. Information about the spectra of these sounds is helpful in making judgments about their loudness. As already noted, the ear does not respond equally to different frequencies. Hence, noises having the same total sound



OCTAVE BAND ANALYSIS

Figure 1. Spectral Differences between Two Sounds Having the Same Overall Sound Pressure Levels

pressure level may not be equally loud due to differences in frequency content or in the manner in which the various frequency components contribute to the total sound pressure level. As will be noted below, knowledge about the spectrum of a noise is also important in evaluating its potential harmfulness.

Types of Noise

Narrow-band noises have most of their energy confined to a narrow range of frequencies or concentrated about single frequencies. Accurate spectral determinations of such noises require an analysis of the total sound pressure-level into frequency bands which are smaller than an octave in width. The noise caused by circular saw, planer or power cutting tool operations is of the narrow-band type.

The impulse-type of noise consists of transient pulses, occurring in repetitive or non-repetitive fashion. Repetitive impulse noise is associated with the operation of a rivet gun or a pneumatic hammer. The impact of a drop hammer and the firing of a gun are examples of non-repetitive impulse noise. Techniques used to describe impulse noise differ from those used for narrow or wide-band types of noise. Repetitive impulse noise which occurs at a rate exceeding 200 pulses per minute, however, can be measured and evaluated in a manner similar to that used for wide- or narrow-band noise.

Effects of Noise

Noise may cause hearing loss, disruption of noise communication, annoyance and some impairment in performance. Losses in hearing may be temporary or permanent depending upon the length and severity of the exposure. Temporary hearing loss, also called auditory fatigue, represents losses which are recoverable after a period of time away from the noise. Such losses may occur after only a few minutes of exposure to intense noise. With prolonged exposures (months or years) to the same noises, there may be only partial recovery of the hearing losses, the remaining loss being indicative of a permanent hearing impairment.

Damage Risk Criteria

There exists a definite need to determine the maximum conditions of noise exposure which are tolerable to the ear. Specifications of such conditions, called "damage risk criteria", would be useful in serving as guides for

(a) hearing conservation programs in industry as well as the military service,
(b) noise control procedures and techniques as applied to machinery and work environments, and
(c) equitable rulings in court cases involving compensation for noise-induced hearing loss.

Many different damage risk criteria for noise exposure have already been proposed but none are considered to be sufficiently valid. Confirmation of these criteria will require, in particular, more knowledge of the effects of different types of noise upon hearing, the time required for the ear to become damaged given either continuous or intermittent types of exposure, the reversibility of any apparent hearing loss, and the importance of individual susceptibility to noise. In the absence of any well established noise criterion, it has been recommended that ear protective devices be used and periodic audiometric examination be administered to all personnel routinely exposed to noise having sound pressure levels of 85 dB or more in the octave bands 300-600, 600-1200, 1200-2400, 2400-4800 cps. Adjustments in the prescribed 85 dB limit are noted in such procedures to take into account short term exposures and noises having predominant concentrations of energy in a narrow range of frequencies or at single frequencies.

Hearing Loss and Aging

It is to be noted that the hearing losses caused by noise are similar to those associated with the aging process. Difficulty in distinguishing between these creates problems especially where compensation issues are involved. Much research has been conducted in recent years to determine the normal deterioration in hearing with increasing age for populations which have experienced only limited amounts of noise exposure. This information can be used to separate the amount of hearing loss due to excessive noise exposures from that due to aging.

Speech Interference

Noise which is not intense enough to cause hearing damage may still disrupt speech communication and the hearing of other desired sounds. While communication is essential in many places of employment, the levels of acceptability vary with the nature of the work involved. Being able to communicate by shouting, for example, may be satisfactory when doing maintenance work on certain machinery. On the other hand, raising the voice slightly to overcome typical office noises may be quite undesirable for a conference room. The average of the sound pressure levels found in the three octave bands 600-1200, 1200-2400, 2400-4800 cps provide a simple measure of the ability of a noise to interfere with speech communication. This average is referred to as the speech interference level which together with subjective ratings of noise has been used to establish guidelines for noise control in various types of work and living areas. Suggested criteria for selective areas in terms of the maximum permissible speech-interference-value are given in the following table:

Type of Room	Maximum Permissible Speech-Interference Level (measured when room is not in use)
Small private office	40 dB
Conference room for 20	30 dB
Conference room for 50	25 dB
Movie Theater	30 dB
Theaters for drama (500 seats, no amplification)	25 dB
Concert halls (no amplification)	20 dB
Secretarial offices (typing)	55 dB
Homes (sleeping areas)	25 dB
Assembly halls	25 dB
School rooms	25 dB

Speech-interference-level has been used also to predict the expected usability of a telephone under given noise conditions. The following schedule has been found generally useful in this regard.

Speech Interference Level	Telephone Usage
less than 60 dB	Satisfactory
60 to 75 dB	Difficult
above 75 dB	Impossible

Annoyance Factors

Perhaps the most widespread reaction to noise is that of annoyance. Some characteristics of sound seem to be more annoying than others. These characteristics are as follows:

(1) loudness - the more intense and consequently louder noises are considered more annoying
(2) pitch - a high pitch noise, that is, one containing predominantly frequencies above 1500 cps is more annoying than a low pitch noise of equal loudness
(3) intermittency and irregularity - a sound that occurs randomly or is varying in intensity or frequency

is believed more annoying than one which is continuous and unchanging.

(4) localization - a sound which repeatedly seems to change in its location relative to the listener is less preferred than one which remains stationary.

A measure of noise intended to describe its annoyance value has recently been developed and found to be highly correlated with observers' ratings of the acceptability of flyover noise produced by various types of aircraft. This measure, called perceived noise level in dB, is derived from calculations based upon the octave band intensity levels of the noise in question together with data showing equal annoyance ratings for different octave bands of noise. While of some value, perceived noise levels and other annoyance measures based upon single judgments of the noise stimulus, are expected to have only limited usefulness in gauging the complaint potential of a noise. This is due to the many non-acoustical considerations which enter into such judgments. Some of these factors are cited below with examples to illustrate each of them:

Factor	Example
1. The sound has unpleasant associations.	The annoyance caused by the intrusion of aircraft noise into communities around airports is based, in part, upon the residents being fearful of the planes crashing into their homes.
2. The sound is inappropriate to the activity at hand.	Music tolerated during waking hours may be annoying during the hours of sleep.
3. The sound is unnecessary.	People may complain of the noise made by the neighbor's pets but not by the delivery trucks in the same neighborhood.
4. The sound has an advantage associated with it.	The comforts derived from air conditioning outweighs the noise of such units. Similarly, the economic value of nearby plants to a community may balance out the noise produced by the plants; annoyance due to military aircraft noise may be offset by the assurance against surprise attack by an enemy.
5. Individual tolerance to noise.	Some individuals complain about all kinds of noise as well as other types of nuisances.

* * * * * * * * * *

Several models for predicting the complaint potential of a community noise now exist which take into account acoustical as well as the non-acoustical considerations outlined above. The accuracy of the predictions made by these models, however, is yet to be determined.

Noise and Performance

The effects of excessive noise on efficiency and work output seem to be slighter than is often thought. Performance on tasks involving simple repetitive operations, does not appear to be affected by noise, while apparent losses in efficiency on most complex tasks tend to become dissipated with increased exposure time. The relationship between excessive noise in a work situation and accident rate, absenteeism, and rate of employee turnover has not as yet been clearly determined.

References

1. __________: Industrial Noise Manual. American Industrial Hygiene Assn., 14125 Prevost, Detroit 27, Mich., 1958.

2. Glorig, Aram: Noise and Your Ear. Grune and Stratton, New York, N. Y., 1958.

3. __________: Guide for Conservation of Hearing in Noise. Subcommittee on Noise in Industry, American Academy of Ophthalmology and Otolaryngology, 111 N. Bonnie Brae, Los Angeles 26, Calif., 1957.

4. Exploratory Subcommittee Z24-X-2 of the American Standards Assn.: The Relations of Hearing Loss to Noise Exposure, American Standards Assn., Inc., 10 East 40th, New York 16, N. Y., 1954.

5. Kryter, K. D.: The Effects of Noise on Man. Monograph Supplement 1, Journal of Speech and Hearing Disorders, 1950.

6. Glorig, A.; Wheeler, D. E.; Quiggle, R.; Grings, W. W.; and Summerfield, A.: Wisconsin State Fair Hearing Survey: Statistical Treatment of Clinical and Audiometric Data. American Academy of Ophthalmology and Otolaryngology, 111 N. Bonnie Brae, Los Angeles 26, Calif., 1957.

7. Noise - Causes, Effects, Measurement, Costs, Control. Proceedings, Inservice Training Course on "The Acoustical Spectrum - Sound, Wanted and Unwanted." University of Michigan, Ann Arbor, Mich., 1952.

8. Broadbest, D. E.: Perception and Communication. Pergamon Press, New York, N. Y., 1958.

9. Schneider, E. J.; Peterson, J. E.; Hoyle, H. R.; Ode, E. H.; and Holder, B. B.: Correlation of Industrial noise exposures with audiometric findings. Am. Ind. Hyg. Assoc. J. 22: 245, (1961).

10. Ward, W. D.; Glorig, A.; and Sklar, D. L.: Temporary threshold shift from octave-band noise; applications to damage risk criteria. J. Acoust. Soc. Amer. 31: 522, (1959).

11. Yaffee, C. D. and Jones, H. H.: Noise and Hearing Relationship of Industrial Noise to Hearing Acuity in Controlled Population. U. S. Public Health Publication No. 850, Washington, D. C., 1961.

12. Corso, J. F.: Age and sex differences in pure tone thresholds from 18 to 65 years of age. Research Bulletin No. 25, Department of Psychology, Pennsylvania State University, University Park, Pa., 1962.

13. Riley, E. C.; Sterner, J. H.; Fassett, D. W.; and Sutton, W. L.: Ten years experience with industrial audiometry. Am. Ind. Hyg. Assoc. J. 22: 151-159, (1961).

14. Hinchcliffe, R.: Threshold of hearing as function of age. Acoustica 9: 303-308, (1959).

15. Beranek, L. L.; Kryter, K. D.; and Miller, L. N.: Reaction of people to exterior aircraft noise. Noise Control, 5: 23, (Sept. 1959).

16. Eldredge, D. H.: The problems of criteria for noise exposure. Armed Forces-National Research Council Committee on Hearing and Bio-Acoustics (CHABA), 1960.

17. Kryter, K. D.: The meaning and measurement of perceived noise level. Noise Control, 6: 12, (Sept.-Oct. 1960).

NOISE MEASURING INSTRUMENTS

I INTRODUCTION

II TAPES AND OVERHEADS

A Understanding Noise

B Degrees of Hearing Impairment

III HANDOUT

A Primer of Plant-Noise Measurement

B Discussion of Handout

IV TYPES OF NOISE SURVEYS

V DISCUSSION OF INSTRUMENTS

A B and K

B GR Meter

C GR Calibrator

D GR Impact Meter

E Nagra Tape Recorder

F GR-OBA

G Unico-Exposimeter

Prepared by Edward D. Leininger, Industrial Hygiene, Division of Training, NIOSH, 2/73.

NOISE MEASUREMENT

Introduction

The industrial hygienist is being called on more frequently to make noise measurements and to evaluate noise problems. These may be problems of potential hearing loss of employees due to excessive noise exposures, annoyance from a noise in a building or community, compliance with noise specifications, or requirements for a low noise background for audiometric testing. In any of these situations the industrial hygienist will need to determine:

(1) total sound pressure level,
(2) distribution of this sound pressure or energy with frequency, and
(3) distribution of this sound pressure or energy with time.

The type of noise source will dictate which equipment is necessary in order to make an accurate evaluation of these three factors.

Types of Equipment

At present there is a wide assortment of equipment available for noise measurements. The choice of equipment used will depend on the type of noise encountered and the purpose of the measurements. Specific types of equipment will be discussed, including the general features of each type. In most cases commercially available instruments will incorporate all of these features but it should be pointed out that the manufacturer's instructions for the specific instrument being used should be consulted freely. It has been the author's experience that manufacturers modify equipment electronically, which results in changes in operating procedures even though the exterior appearance of the instrument remains unchanged. Therefore, it is essential that the instruction book be used, which was obtained with the instrument.

Sound Survey Meter

The sound survey meter is a small instrument that usually consists of a nondirectional microphone, an adjustable calibrated attenuator, an amplifier with three weighting networks, and an indicating meter.

The instrument has a function switch with an off position, A, B, and C weighting network positions, and a battery check position. It has either a continuously variable or stepped attenuator. The sound pressure level is the sum of the attenuator setting and the reading from the indicating meter.

Even though the sound survey meter does not meet American Standards Association specifications for sound level meters it is a good instrument for rapid screening and surveying of a large area or number of locations.

Sound Level Meter

The sound level meter is the basic instrument used for noise measurements. It comprises a microphone and an electronic circuit including an attenuator, an amplifier, three frequency response networks (weighting networks), and an indicating meter. The attenuator in the circuit controls the current within limits that can be handled by the indicating meter, which is calibrated in decibels. The value obtained is the root-mean-square sound-pressure level expressed in decibels re 0.0002 dynes per sq. cm.

Sound level meters are available in the range of 20 to 180 decibels (dB) (re 0.0002 dynes/sq. cm.). The newer sound level meters provide an amplifier with a flat frequency response from 20 to

---

Prepared by: Herbert H. Jones

20,000 cycles per second (cps), and the overall response depends on the microphone used. The design criteria for sound level meters (American Standards Association, 24.3 - 1944 and S1.4 - 1961) permit large tolerances at both low and high frequencies. This emphasizes the need for the proper calibration of each instrument.

Three weighting networks, A, B, and C are included. The purpose of these is to give a number which is an appropriate evaluation of the total loudness level. Human response to sound varies with its frequency and intensity. The ear is most sensitive to the low and high frequencies at low sound intensities. On the other hand, at high sound levels there is less difference in human response at the various frequencies. The three weighting networks also provide a means of compensating for these variations in human response.

The A network is less sensitive to low frequencies and is intended for use at sound pressure levels below 55 dB. The B network is an intermediate step for the range of from 55 to 85 dB. The C network has a flat response and is used for everything above 85 dB. The C network is the only one which indicates the actual sound pressure level, since the sound pressure level is based on a flat response.

Microphones

The microphone is by far the most important part of the equipment, since the quality of the final result can be no better than the signal produced by the microphone. The function of the microphone is to pick up the sound energy and convert it to electrical energy, which is fed to the electronic circuit.

The frequency response, sensitivity, directionality, and range of a sound level meter are primarily determined by the microphone; therefore, its importance cannot be overemphasized.

Three major types of microphones are in general use for the measurement of sound. Each type has advantages and disadvantages, and final selection depends on the requirements of the job to be done.

Rochelle salt crystal microphone. The Rochelle salt crystal microphone was supplied as standard equipment on sound-level meters for many years. The reasons for this were its low cost, ruggedness, availability, and high sensitivity. It has a frequency range of 20 to 8000 cps and an intensity range of 24 to 150 dB. Its frequency response varies widely with the incidence of the sound and the response is far from flat above 2000 cps.

One of the disadvantages of the Rochelle salt crystal microphone is its sensitivity to heat and humidity. Temperatures above 115°F may damage the crystal and temperatures above 125°F will destroy it. Also, there is a reversible change in sensitivity produced by temperature change. When an extension cable is used and the input impedance of the meter is high, a temperature correction is necessary.

Ceramic crystal microphone. Since 1963 a PZT (lead titanate-lead zirconate) piezo-electric - ceramic diaphragm type microphone has been regularly supplied with many of the sound level meters. This is a stable and rugged microphone with a smooth frequency response and it is relatively unaffected by normal temperature and humidity changes. It has a frequency range of 20 to 9000 cps and an intensity range of 24 to 150 dB. It will withstand temperatures of 22 to 205°F without damage. A correction is necessary when the PZT microphone is used with an extension cable. A correction of about 7 dB is made when a 25 foot cable is used between the microphone and the instrument.

Dynamic microphone. This is probably the second most commonly used type. It operates on the principle of a coil moving in a magnetic field, resulting in an induced voltage. This type of microphone has a dynamic range of 20 to 140 dB and a frequency response in the range 40 to 10,000 cps ±5 dB. Its frequency response is less erratic than the crystal microphone; but the frequency response drops off sharply below 40 cps.

The dynamic microphone has the advantage of low self-noise, permitting noise measurements down to less than 20 dB in an octave band. Sensitivity to temperature change is small up to $180^{o}F$, and it can be used with long extension cables without correction. This microphone cannot be used in strong magnetic fields such as those encountered around large transformers, generators, or electric arc welders. Care must be taken to avoid getting the microphone wet because of the possibility of internal shorts.

Condenser microphone. This is the least commonly used of the four microphones. It consists of two plates which act as a condenser; one is a thin diaphragm, the other a solid backing. Movement of the diaphragm changes the capacitance of the condenser in proportion to the displacement of the diaphragm. This change in capacitance produces an electrical signal which is proportional to the sound pressure level.

This microphone has the best frequency response of all types in current use. It is available in models which are essentially flat in response to frequencies from 20 to 8,000 and ±3 dB at 15,000 cps to models which are essentially flat from 20 to 40,000 cps. The dynamic range is from 40 to 145 dB in the standard models with special models available with an upper limit of 200 dB. Its temperature sensitivity corresponds to that of a dynamic microphone. It can be used at higher temperatures and with longer cables without corrections.

Disadvantages are its high cost, high self-noise, limited humidity range, and additional electronic complexity due to the preamplifier which is required. High humidities may increase internal noise but this can be corrected by keeping the microphone in a dessicator when not in use.

Noise Analyzers

When the sound to be measured is complex, consisting of a number of tones, or having a continuous spectrum, the single value obtained from a sound level meter reading often is not sufficient for analytical purposes. It may be necessary to determine the sound pressure distribution according to frequency.

In general, there are three types of noise analyzers:

(1) octave, half octave, and third octave bandwidth,
(2) constant bandwidth, and
(3) constant-percentage narrow band.

Octave band analyzer. The most practical and widely used analyzer for industrial noise studies is the octave band analyzer. As indicated by the name, the upper cutoff frequency is twice the lower cutoff frequency. For a half-octave analyzer the upper cutoff frequency is $\sqrt{2}$ times the lower, and for a third-octave analyzer the ratio is $\sqrt[3]{2}$. A commonly used set of octave pass bands in commercial equipment is 20 to 75, 75 to 150, 150 to 300, 300 to 600, 600 to 1200, 1200 to 2400, 2400 to 4800, and in excess of 4800 cycles. This analyzer provides sufficient data on industrial noise to evaluate its physiologic significance and to provide a basis for noise control. The small number of bands makes it possible to perform an analysis in a reasonable length of time, and the bands are wide enough to reduce the problem of transient components affecting stability of the meter.

This analyzer may be equipped with one of two types of filters. In one type there is a choice of eight pass-bands and the selection is made by a single switch. The second type consists of a low cutoff filter, which filters out all frequencies below the setting of the dial; and a high cutoff filter, which filters out all frequencies aobve the setting of this dial. Measurements can be made in bands of one octave or multiples of an octave to cover the complete spectrum using the second type of analyzer. The attenuator, which is 50 dB in 10 dB steps, and the amplifier serve the same purpose as in the sound level meter. The meter has a 16 dB range. The sound pressure level within the chosen band is the sum of the sound level meter attenuator setting, the analyzer attenuator setting, and the analyzer meter reading. The analyzer has a rheostat for adjusting the indicator to correspond to the meter reading on the sound level instrument when the analyzer is set to the overall position.

All octave band analyzers are equipped with an output jack permitting the use of headphones, a recorder, or an oscilloscope.

At the present time there are being introduced some octave band analyzers using the American Standards Association's preferred frequencies. In these analyzers the octave bands are centered around the following mid frequencies: 63, 125, 250, 500, 1000, 2000, 4000 and 8000 cycles per second. Although there is a shift in octave bands utilized on the standard analyzers, there is no practical difference in the interpretation of data of industrial hygiene significance.

Constant bandwidth. This instrument has a fixed bandwidth that is a specific number of cycles wide. Common bandwidths range between 5 and 200 cps. These are essentially laboratory instruments requiring line voltage for operation. Because of the transient nature of industrial noise and the narrow bandwidth of the analyzer, this instrument is seldom used in industrial noise studies.

Constant-percentage bandwidth. The constant-percentage narrow band analyzer has a bandwidth which is a fixed percentage of the mid-band frequency. Thus, at low frequencies the bandwidth will be only a few cycles, while at high frequencies the bandwidth will cover a wide range of frequencies. This instrument has essentially the same limitations as the constant bandwidth analyzer but it can be used in some noise control problems.

Accessories

A number of accessories are available for use with sound level meters and frequency analyzers to give additional information about the noise situation under study.

Impact noise analyzer. This instrument operates directly from the output of the sound level meter or frequency analyzer. It can be used to measure the peak level and duration of impact noise.

Through the use of electrical storage systems, three characteristics are measured by the analyzer for every impact noise. These are: the maximum instantaneous level, the average level, and a continuously indicating measure of peak sound levels. The values can be read individually on the same meter by means of a selector switch. A reset position of the selector switch restores the meter to its prereading condition.

Cathode-ray oscillograph. An oscillograph affords a useful means for observing the wave form of a noise and also for observing many general noise patterns, particularly short duration or impact noises. The oscillograph can be operated from the output signal of a sound level meter, octave band analyzer, or magnetic tape recorder. It can be used to measure the peak amplitude, the rate of decay, and the shape of a wave.

A cathode-ray oscillograph with a sweep rate extending down to at least two seconds and a long persistence screen is preferable for acoustic measurements. If the wave form is to be photographed a short persistence screen should be used. A five-inch oscillograph tube is normally used for this latter purpose.

The output of the sound level meter, sound analyzer or magnetic tape recorder is connected to the vertical input of the oscillograph. The controls are set as explained in the instruction manual for the oscillograph. A reference signal of 60 cps, or 400 cps can be fed into the sound level meter to adjust the gain of the vertical amplifier. The reading on the meter is noted and the vertical gain is adjusted to obtain a peak-to-peak deflection according to the table below for a five-inch screen.

Meter Reading dB	Peak-to-Peak Deflection Inches
0	1
1	1.12
2	1.26
3	1.41
4	1.59
5	1.78
6	2.0
7	2.24
8	2.51
9	2.82
10	3.16

Once set, the gain control of the oscillograph should not be changed, adjustments being made with the attenuator on the sound level meter to keep the maximum deflection within the range of the table above.

The peak-to-peak sound-pressure level for a noise is the decibel value obtained from the table above, plus the sound level meter attenuator setting, plus 9 dB.

Magnetic tape recorder. The magnetic tape recorder can be used for recording noise in the field with subsequent analysis in the laboratory. Detailed and repeated studies can be made immediately or the tape can be kept for later analysis or for comparison purposes.

If meaningful measurements are to be made from a recording, a high quality recorder must be used. It should have a flat frequency characteristic over a wide range, low hum and low noise levels, low non-linear distortion, a constant speed drive, and it should be of good mechanical construction. A tape speed of 15 inches per second is recommended, since these characteristics are more readily obtained and maintained at high tape speeds.

The gain control should be set according to instructions supplied with the recorder. After it is set a reference signal should be recorded, such as the signal from an acoustical calibrator. Whenever the gain control is reset, a reference signal should again be recorded.

When an analysis is desired a representative sample of the tape should be selected and that portion of the tape is spliced to form a loop so it can be repeated continuously. If the absolute level needs to be known also, a sample of the recorded reference signal should be measured with the same control settings as were used for the original noise recordings.

It might appear that the only instrument needed in the field would be a good tape recorder; but in many situations it will be better to make the analysis in the field with the usual sound equipment to make certain that the desired data have been obtained.

Graphic level recorder. The graphic level recorder provides a permanent record of the noise characteristics by tracing a graph on a moving paper. The recorder can be operated from the output of the sound level meter or the octave band analyzer to record the level of a noise as a function of time. It is subject to the same limitations as the sound level meter in the analysis of noise of short duration.

When using the graphic level recorder it must be calibrated with an acoustical calibrator. The gain control should be adjusted according to instructions supplied by the manufacturer.

Acoustic calibrator. An overall acoustical check can be made of the sensitivity of a sound level meter, including its microphone by use of an acoustic calibrator. Calibration may be accomplished either by electronic or mechanical devices. The electronic calibrator consists of a small speaker mounted in an enclosure which fits over the microphone of the sound level meter. The enclosure is designed in such a way that the measurements can be repeated with a high degree of accuracy. Signals may be supplied to the calibrator from either an audio oscillator or random noise generator depending on which calibrator is being used. The designated operating voltage of the supplied signal and the sound level output can be found in the operating instructions furnished by the manufacturer when the calibrator is purchased.

Two types of mechanical acoustical calibrators are available commercially. One is a piston activated diaphragm mounted in an enclosure which is placed over the microphone. The other type consists of a diaphragm which is activated by steel balls. It is located a specified distance from the microphone to be calibrated. Each type of calibrator, when operated according to the manufacturer's instructions, will produce sound of a specified level.

Dosimeters. Three different types of noise dosimeters are available at present. These are designed to indicate in some manner the total noise dose during a specified time interval. Each of these uses a different approach; one measures the total amount of sound energy to which a worker is exposed for a workday, another one measures the amount of time that a specified decibel level is exceeded, and the third one measures the rate at which sound energy impinges on the exposed person for selected short-term periods of time. Correlation of these dosimeter readings with hearing loss is lacking. They cannot be used to evaluate damage risk to hearing from variable noise exposure situations at the present time.

Field Measurements

Evaluation of a noise problem depends upon accurate and meaningful measurements. Even though the equipment is electronic and may appear to be simple to operate, one should use it with caution and be on the alert to detect errors in the operation of the equipment and the influence of the environment.

In general, there are three types of noise studies and the equipment used will depend upon the type of study being made. The simplest of the three is a screening survey which can be done with a sound survey meter or sound level meter. This involves making a number of measurements in an area for rapid evaluation of the problem and determining where a more detailed study is needed.

The second type is a study to determine the characteristics of, and to evaluate the potential effects of a noise. This involves the use of a sound level meter and a noise analyzer in order to determine the sound pressure distribution with frequency. For industrial work, an octave-band analyzer would probably be used.

The third type of study is one for research or noise control purposes. This might require a large number of measurements and analyses in the field and also magnetic tape recordings to be analyzed in the laboratory. A sufficient number of samples should be taken to determine the exact nature of the source, including power and directionality.

Operation of Instruments

The sound level meter has an on-off

switch, a means of checking battery voltages, a weighting network switch, a fast-slow meter response switch, an attenuator switch with steps of 10 dB and an indicating meter (16 dB range). The instrument is turned on, batteries are checked, the instrument is permitted to warm up for a few minutes, and the attenuator is adjusted until the indicating meter is on scale. The sound pressure level is the sum of the attenuator setting plus the meter reading.

The octave-band analyzer operates from the output of the sound-level meter. The analyzer has an on-off switch, battery voltage check switch, a fast-slow meter response switch, an attenuator switch and a switch permitting the selection of the band to be measured. The analyzer is connected to the sound-level meter by a cable, both instruments are turned on. The batteries should be checked. The analyzer band selector switch is set at 20 to 20,000 cps and the two meter readings should agree. The overall sound pressure level is recorded, then the band selector switch is set to the 20 to 75 cps octave band, and the attenuator on the analyzer adjusted until the indicating meter is on scale. The sound level in the octave-band is the sum of the attenuator setting of the sound-level meter, the attenuator setting of the octave-band analyzer and the octave-band analyzer indicating meter observing the appropriate signs.

Maintenance of Equipment

Because of the nature of the equipment, one should constantly be on the lookout for faulty operation. The equipment should be checked before it is taken from the laboratory because of the availability of a quiet location and availability of other test instruments if repair is necessary. The following steps should be taken:

1. The instruments should be connected, turned on, and allowed to warm up for a few minutes.
2. Check batteries.
3. Make electrical and acoustical calibrations.
4. Make octave-band measurements of a convenient wide band steady noise.
5. Remove the microphone and make electrical background measurements.
6. Recheck calibration.

If any of the above steps yield unsatisfactory results the instrument instruction manual should be consulted for necessary adjustments or repairs. If the first three steps are completed satisfactorily, this usually means that the equipment is operating properly. Step 4 can expose a defective octave-band which might be overlooked in making measurements in the field. Step 5 will indicate whether there is an excessively noisy tube or faulty oscillating amplifier. This can be corrected by replacing the defective tube. Step 6 could indicate weak batteries if the calibration has changed by more than 1 dB. If it has changed, the batteries should be replaced before making a number of measurements.

Precautions for Handling Equipment in the Field

Most sound level meters available today come equipped with a Rochelle salt crystal microphone which can be damaged by excessive heat and humidity. The microphone should not be subjected to temperatures above 115°F; it should never be left in the trunk or inside a closed automobile on a hot summer day.

Since electronic equipment can be damaged by intense shock, extreme care must be taken in shipping or transporting these instruments by commercial carrier.

Calibration of Equipment in the Field

On reaching the area where the measurements are to be made the six steps listed under Maintenance of Equipment should be repeated, preferably before the equipment is taken into a noisy area. The acoustical calibration should be performed in an area where the background noise, with the calibrator in place, is 10 dB less than the calibration signal.

The acoustical calibrator can be used also to determine the temperature corrections needed for an extension cable between the microphone and sound level meter. The reading should be taken without the cable and then with the cable inserted. The difference is the correction to be added to the readings obtained with the cable. This should be done after the microphone temperature has reached the room temperature where the measurements are to be made. This correction is a function of ambient temperature of the microphone, but not a function of frequency.

If a large number of readings are made at one time, the batteries should be checked every two hours and the equipment calibrated a minimum of four times a day.

Selection of Sampling Locations

After it has been determined that the equipment is operating satisfactorily, the next step is to determine the sampling locations. This will depend on the reasons for making the measurements and other factors. If it is a preliminary survey to determine if a noise problem exists, then a large number of measurements are taken with the sound survey meter or sound level meter throughout the area, paying particular attention to the noise sources.

In the evaluation of noise exposure to individuals the microphone would be placed as near to the individual as possible without interfering with his work. It is also best to make several measurements with the sound level meter in the area to determine if the sound pressure level is relatively uniform and if the measurements being made represent the individual's exposure.

Another type of survey is for noise control purposes. In this case, measurements would be made to determine the total acoustical output and directional characteristics of the source. Measurements at one point yield information about that point only and in that environment. In order to determine how a source differs in another environment, the acoustic power characteristics must be determined. A number of measurements must be made in a geometrical pattern about the source and at some distance from the source. This type of survey is basically an engineering problem and the measurements are made with particular attention to the physical characteristics of the source and environment and without regard to personnel in the area.

Sources of Error

The reliability of noise measurements depends upon the manner in which the instruments are used and their operating condition. The immediate recognition of faulty equipment is essential if accuracy is to be maintained.

Position of the microphone. In general, the location of the microphone is determined by the type of measurements to be made as was discussed under sampling locations.

The microphone should be located so that it is at the side of the observer or operator and not between the noise source and observer or operator. When making measurements around a single source large errors may result; but, in a large room with a number of sources, measurements are made at quite some distance from the source and the error would be small.

The sound field should be explored to make sure that the measurements are representative. The possible effects of obstacles upsetting the distribution of sound, particularly at high frequencies, should be kept in mind when making this exploration.

Wind will produce a low frequency noise which can be appreciable when using a microphone that is very sensitive to low frequencies. If it is necessary to sample in the wind, a wind screen can be made out of wire, forming a sphere about 18 inches in diameter.

Circuit noise. All vacuum tubes are affected by mechanical vibration. The tubes used in sound measuring equipment have been selected to be less sensitive to shock than the usual tubes. But at high noise nevels some of these tubes may be vibrated to such an extent so as to produce extraneous noises in the equipment. A test for this is to disconnect the microphone from the sound level meter and observe whether there is a reading on the meter. If there is a reading, the meter can be placed on a rubber pad or rubber-tired cart which should eliminate the trouble. In very intense noise fields it may be necessary to remove the meter from the area and use an extension cable to the microphone.

When making measurements around electrical equipment a check should be made to see if there is an appreciable pick-up of the electromagnetic field by the sound measuring equipment. This check is particularly important when using a dynamic microphone. A pair of good quality earphones can be used to monitor the output of the sound level meter or octave band analyzer. The hum produced by the electromagnetic field will be of the same frequency as the power source, usually 60 cycles per second. The orientation of the instruments and microphone should be changed to determine if there is a difference in the meter reading; also, the microphone should be disconnected to check if the pickup is in the microphone or the instruments. If the pickup is in the instruments they can be removed from the area under study and an extension cable used; if it is caused by the dynamic microphone, a crystal or condenser microphone may have to be used.

When making noise measurements at low levels, the inherent circuit noise may be the limiting factor. A check for this is made by removing the microphone and substituting a capacitor of the proper size. The lowest reading that can be obtained with the sound level meter or analyzer is determined. This will be the lower limit of measurement.

Background. In some cases, when making measurements to determine the amount of noise generated by a particular source, it may be necessary to make corrections for background noise. If there is any evidence that the background noise is contributing to the noise being measured, a background measurement should be made with the noise source turned off. It is possible to make a rough correction for this background noise by applying the factors given in the table below:

Total noise level less background level (dB)	Subtract from the total noise level to get the noise level due to the source (dB)
10	0.5
9	0.6
8	0.7
7	1.0
6	1.2
5	1.6
4	2.2
3	3.0
2	4.3
1	6.9

Recording Data

One important part of making noise measurements is the recording of sufficient data. Data that should be recorded will depend on the purpose of the survey, that is, whether it is a hearing loss, noise control, or nuisance problem. To a certain extent each noise survey is unique, and the report resulting from it must have its own pattern that fits the needs of the particular situation. There are, however, certain basic data which are essential and must be recorded in almost all surveys:

1. Equipment used for the measurements type and serial numbers of all

microphones, sound level meters and analyzers.

2. Corrections for measured values, such as cable, temperature, and acoustical calibration.
3. The time and date that measurements are made and name of person conducting the study.
4. Description of space in which the measurements were made such as, dimensions and nature of ceiling, walls and floor, and locations of windows and doors.
5. Description of the noise source under test (primary noise source). This should include a clear description of the machine as to size, name plate data, speed and power rating. Types of operations and operating conditions and number of machines in operation, locations of the machines and types of mountings.
6. Description of secondary noise sources including location and types of operations.
7. Noise control measures instituted, including the types and effectiveness of ear protectors.
8. Overall and band levels at each microphone position and the extent of meter fluctuation.
9. The meter speed and weighting network used.
10. Position of the microphone and the direction of the sound with respect to the microphone, tests for standing wave patterns and the decay of sound level with distance.
11. Time pattern of the noise, that is, whether continuous, intermittent or impact.
12. Personnel exposed, directly and indirectly.

In recording data it is helpful to have a blueprint or sketch of the building on which locations of measurements can be noted. Frequently, location of columns in a building can be used to form a grid system such as shown in Figure 1.

It is helpful to have a survey data sheet on which the data can be recorded. A typical one is shown in Figure 2 which was provided by the Subcommittee on Noise in Industry of the American Academy of Ophthalmology and Otolaryngology.

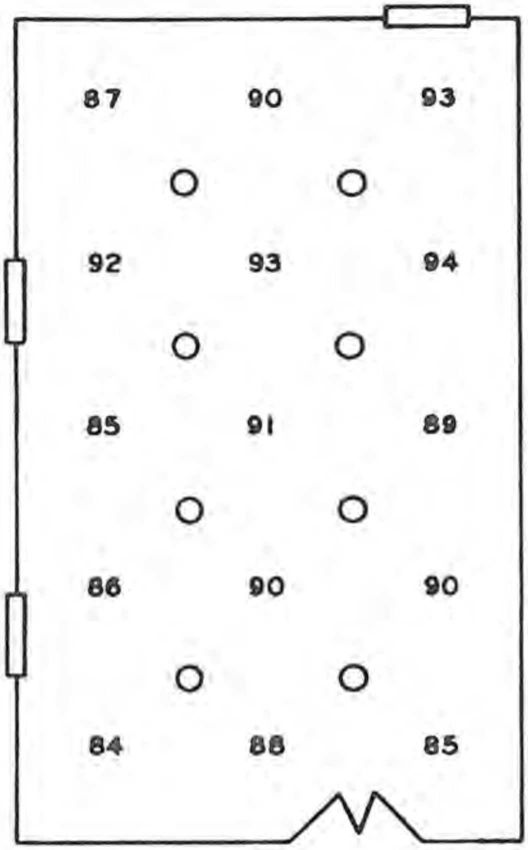


Figure 1.

Analysis of Data

After a survey has been completed and before a report can be prepared, it is necessary to analyze the data. The necessary corrections must be made and the accuracy of the final results determined.

Corrections should be made for any errors produced by an extension cable or any other errors revealed by the acoustical calibration. If a calibration curve is available for the microphone being used, the appropriate corrections should be

SOUND SURVEY

Page ___ of ___

Date: ______________________ Time: ______________________

Wind Velocity: ______________________ Wind Direction: ______________________

Sound-Level Meter: Type ____________ Model ____________ Serial No. ____________

Microphone: Type ____________ Cable Length ______________________

Analyzer: Type ____________ Model ____________ Serial No. ____________

Other Equipment: ____

____

____

Location: ______________________ **Sketch**

____

____

____

Calibrated: 60 cps: Acoustic: Corr. Factor:

Location	Weighting Network	Over-all Level	Octave-Band Pressure Levels Re. .0002 microbar							
			200-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	Above 4800
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										

Remarks: ____

Recorded By: ______________________

Figure 2.

made. When measurements have been made to determine the sound pressure level of a particular source, corrections for background noise should be made if necessary.

With proper acoustical calibration the meter should be accurate within ± 1 dB at the calibrated frequency. With electrical calibration, the meter should be accurate within ± 2 dB at the middle frequencies. The average response curves for various microphones are probably within ± 1 dB in the middle frequencies and from ± 2 dB to ± 10 dB in the first and last octave bands. Also, with proper precautions, the readings should be accurate within ± 2 dB in all but the first and last octave bands.

Preparation of a Report

The type of report will depend on the purpose of the survey and for whom the report is prepared. In general, it is better to present the data in the same form that is used in the field, that is, showing overall and octave band levels. This may be plotted on ordinary linear graph paper with the dB as the ordinate scale and the octave band levels as the abscissa, or it may be plotted on special graph paper shown on the next page.

The criteria that apply to the situation should be presented and then the appropriate recommendations made.

References

1. Peterson, A. P. G. and Gross, E. E., Jr. Handbook of Noise Measurement. General Radio Company. West Concord, Mass., 1963.
2. Harris, Cyril M. Handbook of Noise Control. McGraw-Hill Book Company, Inc. New York, N. Y., 1957.
3. Beranek, L. L. Acoustics. McGraw-Hill Book Company, Inc. New York, N. Y., 1954.
4. Industrial Noise Manual. American Industrial Hygiene Association. 14125 Prevost, Detroit, Mich. 1st Edition 1958, 2nd Edition, 1964.

Laboratory VII — Noise

23. CALIBRATION OF SOUND LEVEL METER

1. Refer to manufacturer's instructions for operation of sound level meter, calibrator, and calibration procedure.

2. Record instrument identification numbers, date, and name of operator(s).

Date: ______________________ Sound level meter # ________________

Operator(s): ________________ ________________

________________ Calibrator # ______________________

3. Comments on calibration:

4. Design - Center Readings in dB for Sound Level Meter

using ______________________ microphone:

Weighting		Frequency, Hz				
		125	250	500	1000	2000
C	Read					
	Design					
B	Read					
	Design					
A	Read					
	Design					

5. Proceed to 23. Shop Noise Survey and 24. Measurement of High and Low Frequency Noise.

6. Check calibration. Comment:

Prepared by John M. Yacher, Chemical Engineer,
Division of Training, NIOSH, 2/73.

24. NOISE SURVEY

Location: ______________________ Date: ______________________

______________________ Meter #: ______________________

Operator: ______________________ Calibrator #: ______________________

______________________ Calibration: ______________________

Sketch of survey area with notes:

Time of day: ______________________ Post survey calibration check:

Recommendations: ______________________ ______________________

____

____

Prepared by John M. Yacher, Chemical Engineer,
Division of Training, NIOSH, 02/73, 10/74.

NOISE CONTROL

I. METHODS FOR CONTROLLING NOISE PROBLEMS

A. Substitution

1. Process
2. Equipment
3. Material

B. Isolation

1. Process
2. Equipment
3. Workmen

C. Personal Protection

D. Education

E. Administrative

II. SOURCE———PATH——RECEIVER

A. Source

B. Path

1. Airborne
2. Structure borne

C. Receiver

	Sound	Vibration
D. Isolation or confinement		
E. Energy absorption		

Prepared by John M. Yacher, Chemical Engineer, DTMD, NIOSH, 1/77.

SKETCH OF AREA SURVEYED

Include:

Approximate dimensions

Location of sound sources (capital letters)

Location of sound–level observations

Date of survey:

Location:

SURFACES

Ceiling:

Walls:

Floor:

OCCUPANCY:

OTHER:

SOUND SOURCES

A: lecturer

B: background

C: Gelman Hurricane air sampler

D: bass drum

HIGH & LOW FREQUENCY SOUND — — — CLASSROOM DEMONSTRATION

Prepared by William H. Perry, Chemist, DTMD, NIOSH, 4/76.

worksheet 4/76 a

DATE OF SURVEY:
LOCATION:

OBSERVED SOUND - LEVELS

PART 1

SOUND SOURCES: A (LECTURER)

LOCATIONS	a	b	c	d
dB (A)				
dB (B)				
dB (C)				

PART 2

SOUND SOURCES: B (BACKGROUND)

LOCATIONS	a	b	c	d
dB (A)				
dB (B)				
dB (C)				

PART 3

SOUND SOURCES: C (GELMAN HURRICANE AIR SAMPLER)

LOCATIONS	a	b	c	d
dB (A)				
dB (B)				
dB (C)				

PART 4

SOUND SOURCES: D (BASS DRUM)

LOCATIONS	a	b	c	d
dB (A)				
dB (B)				
dB (C)				

Prepared by William H. Perry, Chemist, DTMD, NIOSH, 4/76.

worksheet 4/76 b

SPECIAL TOPICS

THE "WALK-THROUGH SURVEY"

I INDUSTRIAL HYGIENE IS BASED UPON THREE ITEMS

A The Ability to Recognize a Process or a Hazard

B The Ability to Evaluate the Hazard or Process

C The Ability to Control the Hazard or Process

II THE RECOGNITION OF A HAZARDOUS PROCESS REQUIRES KNOWLEDGE

A All of Us Can Recognize Some Hazards

Lube oil
Ammonia
Exhaust fumes
Paint thinners
Ozone
Acrolein

B Each of Us Can Recognize Some Additional Hazards

Aldehydes
Diesel locomotives
Diesel fumes
Steam locomotives
Welding fumes

C Each of Us Can Utilize the Knowledge of Others

UDMH
Titanium
Boranes
Refinery problems
Beryllium

C Technical Literature is Another Source of Knowledge

Data sheets
Journals
Hygiene guides
Prior surveys

E Each of Us Can Obtain Specialized Education to Increase Our Knowledge of Hazards and Processes

III THE EVALUATION OF A HAZARD REQUIRES KNOWLEDGE AND OBSERVATION

A Evaluation Requires a Knowledge of All the Materials Used

1 The label will give the trade name and composition.

2 Additional information can be obtained from:

  a Manufacturer's data sheets.

  b The Trade Names Index.

  c NIOSH

B Evaluation Requires Observation of the Process

1 The size and shape of parts can effect the workers exposure.

Examples: spray painting, degreasing

2 The positions of the worker during one cycle of operations can effect his exposure.

3 The total time at the process can effect the exposure.

Prepared by John M. Blankenhorn, Chief, Extramural Activities, Division of Training, NIOSH, 1/73.

IV ESTIMATING THE EXPOSURE REQUIRES EXAMINATION OF THE PROCESS

A Skin Contact

1 Locate the body areas where contact can occur.

2 Observe the body areas for contact dermatitis.

B Inhalation of Process Materials

1 Solvents

a Odor may be used to evaluate some exposures, but must be used with extreme caution.

2 Fumes

a The presence of visible fumes in the breathing zone of the worker during most of the process cycle indicates high exposure.

b For welding fumes the standard "Safety in Welding and Cutting" (AWS) or OSHA regulations may be used.

3 Dusts

a There is no good way of estimating concentration or exposures.

b Visible concentrations over most of the work cycle require evaluation.

4 Noise

a If shouting is required to be understood at a two foot distance, the level is close to 90 dbA.

5 Lighting

a If the worker moves closer to the work or uses a light colored material behind the work, the lighting for that job is probably deficient.

V EVALUATION OF CONTROL MEASURES REQUIRES OBSERVATION OF THE PROCESS

A Skin Contact

1 Protective Equipment for All Areas of Possible Contact

B Inhalation

1 Local exhaust should be sufficient to remove the contaminant from the breathing zone of the worker.

a For solvents, the general inflow should be away from the worker, across the solvent surface, and into the local exhaust hood or slot. Odor may be used, with caution, to verify this flow.

b For fumes, there should be no visible fume recirculating behind the worker or into his breathing zone.

2 Dilution ventilation should not be used except to control the concentration of materials with a very low toxicity (high TLV): Stoddard solvent, mild steel welding E6011.

MAN AS A SAMPLING INSTRUMENT

I THE WORKER, THE ENVIRONMENT, AND THE INDUSTRIAL HYGIENIST

A The Overall Objective - Man

- 1 The industrial hygienist and medical knowledge
- 2 The industrial hygienist and toxicology

B The Environment and the Industrial Hygienist

- 1 Recognition, evaluation, and control
  - a The industrial hygienist and engineering

C Examples

D The Environment Which Cannot be Evaluated

- 1 Unanticipated exposures
- 2 Highly variable exposures
- 3 The highly sensitive individual

II MAN AS THE ENVIRONMENTAL SAMPLER AND INTEGRATOR

A Concentrations in the blood

- 1 True indicator of the status of the worker
  - a Lead
  - b Carbon monoxide
  - c Parathion

B Concentrations in the Urine

- 1 Lead - as an indicator of exposure in foundry
- 2 Benzene

C Concentrations in the breath

- 1 Carbon monoxide
- 2 Ethanol
- 3 Trichloroethylene

D Concentration in the hair and nails

- 1 Arsenic

E Concentrations in the lung

- 1 Minimal effects
  - a Siderosis
  - b Stannosis
  - c Silicatosis
- 2 Moderate effects
  - a Talcosis
  - b Byssinosis
  - c Bagassosis
- 3 Major effects
  - a Silicosis
  - b Asbestosis
  - c Coal Miner's Pneumoconiosis

Prepared by John M. Blankenhorn, Industrial Hygienist, Division of Training, NIOSH, 9/72

DATA QUALITY CONTROL

I INTRODUCTION

Quality control is as old as scientific investigation, industry, and analytical work themselves. Galileo in his experiment on the acceleration of gravity, and Millikan in his experiment on determining the surface tension of a liquid both gave explicit instructions for attaining a consistent set of results.(1) The artisan guilds of the Middle ages prescribed extended apprenticeship periods before a person was considered a master-craftsman. The training maintained a level of quality within the guild. Quality control in analytical work has always been practiced in many ways. Duplicate analyses, prescribed standard reagents, and concern about interference are just three examples.

Quality control of industrial hygiene analytical work involves many aspects of administration, personnel training, procurement of reagents and supplies, inspections; and probably least important, statistical calculations.

Quality control principles can be applied throughout the procedures involved in analytical work and in sampling. Only in some cases will statistics play an important role. Many times, the statistical techniques will simply verify the effects of the quality control practices.

II PHILOSOPHY OF QUALITY CONTROL

Quality control procedures are designed to remove all unnecessary sources of variation in sampling and/or analytical procedures. The sampling and/or analytical procedure must be defined as to proper operating conditions. If exposure to environmental temperatures or a delay between sampling and analysis is deleterious to the assay, proper quality control procedures would prevent such situations from arising.

A Quality Control Techniques

The basic quality control techniques used in assay can be considered as: 1) Calibration to assure Accuracy; 2) Duplication to assure Precision; and 3) Correlation of quantitatively related tests to provide verification of accuracy.

B Quality Control Program

The quality control program will require a determined effort that will include: 1) evaluation of equipment, 2) evaluation of the present state of the art, 3) evaluation of expected ranges of the normal analytical results, 4) evaluation of the precision of the analytical procedure (systematic bias having been eliminated), 5) setting up control charts, 6) setting up appropriate data sheets and procedures for the control of samples in the laboratory, and 7) evaluation of quality control results as produced.

III APPLICATIONS OF QUALITY CONTROL

A General

Quality control can be applied to any sampling and/or analytical procedure. Some examples will indicate the range of possibilities. Quality control procedures should specify the acceptable techniques in each of the areas of a procedure where variability can occur. These would include:

1. Sampling techniques
2. Sample integrity preservation
3. Aliquotting procedures
4. Dilution procedures
5. Chemical or physical separations and purifications
6. Instrumental procedures
7. Calculation and reporting of results

Prepared by W. D. Kelley, Acting Director, Division of Training, NIOSH, 6/72.

IV ERRORS

A General

A sampling and analytical method is subject to errors. These errors may affect the accuracy of the method because they introduce bias into the results. There are other types of errors which affect the precision of the method because they produce random fluctuations in the data. The most desirable situation for the analyst is shown in the diagram in Figure 1 where the results are both precise and accurate.

1 Accuracy

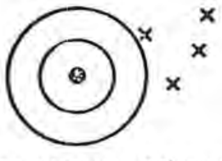
For results to be accurate, the analysis used must give values close to the true value. (See Figure 1)

2 Precision

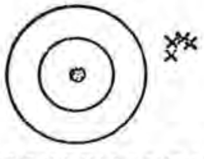
Precision is the degree of agreement among results obtained by repeated measurements on a single sample under a given set of conditions. It is a measure of the degree to which results "check." (See Figure 1)

3 Note

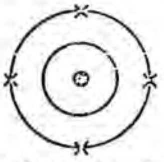
It is possible to have precision without accuracy. (See Figure 1)



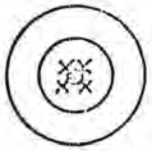
IMPRECISE AND INACCURATE



PRECISE BUT INACCURATE



ACCURATE BUT IMPRECISE



PRECISE AND ACCURATE

Figure 1. PRECISION AND ACCURACY

B Determinate Error and Accuracy

A determinate error is one which contributes a constant error or bias to results, causing them to be inaccurate. This constant error makes it possible for results to agree with each other (be precise) and still be inaccurate. (See Figure 1)

Determinate errors have "assignable" causes which can usually be identified and either eliminated or controlled. (The terms "determinate" error, "assignable" error, and "systematic" error are synonymous).

The sources of determinate error include 1) Method error, 2) Personal errors, and 3) Instrumental errors. These errors may cause either an additive or proportional effect on the accuracy of the procedure. In complex situations the effect is likely to be mixed. Determinate errors are detected by use of 1) spiked samples, 2) control charts(2) (to be discussed later), 3) independent methods of analysis, 4) aliquoting, and 5) Youden's 2-sample graphical technique.(3)(4) Determinate errors are eliminated or minimized through the "classical" approaches, including personnel training, procedural blanks, correction factors, standard addition techniques, internal standards, and standard compensation techniques.

C Indeterminate Error and Precision

Even when all determinate errors are eliminated, every replicate analysis will not give the same value. Such variation in results is due to indeterminate error, also known as random, chance or uncontrollable error. Indeterminate error affects the precision or agreement among results.

Once a method has been shown to be free of determinate errors, it then becomes necessary to test whether the method will be rugged under routine conditions (both intralaboratory and interlaboratory). In other words, the question must be answered, "Will slight variations in the technique of this method affect significantly the results obtained?" Dr. W. J. Youden has developed a procedure for such a test.(3)(4)

Before a method can be evaluated for its precision, it must prove to be reliable. A reliable method will give results that are predictable within consistent limits. These limits will define a band within which results can be expected to fall with calculated probability. Since the laws of probability are applicable only when chance mechanisms are operating, all assignable causes of variability must be removed.

V CONTROL CHART TECHNIQUES

The Shewhart control chart(6) (commonly abbreviated control chart) can serve several functions. The control chart can be used as a tool; 1) to empirically determine and define acceptable levels of quality, 2) to achieve the acceptable level defined, and 3) to maintain performance at that acceptable level of quality.

A Variation

The control chart technique, as well as other statistical techniques, makes several assumptions regarding the process or procedure to which it is applied. The first assumption is that of variation. There will be variation. No process or procedure is so perfect, so unaffected by its environment, that it will always give exactly the same assay value or product.

The sources of variation that will be present in an analytical procedure include(1): 1) difference among analysts, 2) differences among instruments, 3) differences among reagents and related supplies, 4) differences of (1, 2, 3) over a period of time, and 5) differences in the relations of (1, 2, 3) with each other and with time.

Since variation must be accepted as a way of life, its assessment and control become paramount. A stable "system of chance causes" is inherent in the nature of any process or procedure. The "system of chance causes" will produce a pattern of variation.(7) When this pattern of variation is stable, the process or procedure is said to be "in statistical control" or just "in control." Any variation outside this pattern will have an assignable cause. The assignable cause can be determined and corrected.

The presence of a "stable system of chance causes" allows one to apply the laws of probability to the analysis of the data. Statistical analysis techniques assume randomness of data and are valid only in such a system.

B Control Chart Theory

The control chart technique provides for a means of separating the stable pattern of variation from assignable cause variation. The control chart provides a graphical representation of the process or method test data such that the variability of all results is compared with the average or expected variability with small (arbitrarily defined) groups of the data.(3) The control chart then compares "within groups" variability to "between group" variability. The technique is in effect a graphical "analysis of variance."

The pattern of variation of a set of data may approximate the "normal curve."

The data from such a system can be plotted with the vertical scale in units of the test result and the horizontal scale in units of time or sequence of results. The average value or mean and limits on the dispersion or spread of results can be calculated. The resultant chart is the control chart.

The determination of appropriate control limits is a complex subject. Control limits may be based on the capability of the process itself and calculated from the observations made or can be arbitrarily defined at whatever value the analyst desires. It is common practice to set the control limits at $\pm 3\sigma$ around the mean. Where the distribution of the underlying data is normal in form, the probability of getting values outside the control limits are readily calculated. Non-normal distributions will differ in percentage of values beyond the $\pm 3\sigma$ limits. Many times warning limits are set at less than $\pm 3\sigma$. These warning limits serve as an alert. The $\pm 3\sigma$ limits indicate that a point would fall outside the control limit only about three (3) times out of a thousand due to chance causes alone. The $\pm 2\sigma$ or warning limits indicate that a point would fall outside the warning limit only about one (1) time in twenty (20) due to chance causes alone.

C Operating Characteristics

The control chart is then a graphical presentation of the observed test results plotted in relation to calculated limits generally in the order of production or sequentially in time. If the process is "in control," the forthcoming results should fall within the calculated control limits to the degree expected. There also should not be trends, cycles, runs above or below the average, or runs up or down.

When these conditions are met, the analyst has a degree of assurance that no drastic change has taken place in his procedure. That is, no assignable cause has disturbed the state of "statistical control."

If the analyst were to use several values as a single control chart point (an $\overline{X}$ chart), his chances of picking up small changes in the process average are increased. The protection against not detecting small changes in the process average increase as the sample size increases. Shewhart control charts ($\overline{X}$) were usually set up with a sample size of n = 4. The use of frequent sampling will detect changes more quickly with time. The ultimate in control would be large sample sizes taken frequently. However, an economic decision has to be made as to the value of closer control versus the increased cost of attaining that degree of control.

D Subgrouping

The basic procedure of the control chart is to compare "within group" variability to "between group" variability. For a single analyst running a procedure, the "within group" may well represent one day's output and the "between group" represents between days or day-to-day variability. When several analysts or several instruments or laboratories are involved, the selection of the subgroup unit is critical. Assignable causes of variation should show up as "between group" and not "within group" variability. Thus, if the analysts may be assignable causes of variation, their results should not be lumped together in a "within group" subgrouping.

E Example Application

Many times a laboratory will have much if not all of the information already available to develop and put into operation preliminary control charts. One such example is described below.

1 Program description

An analytical laboratory had been using the commercial Mercury flameless atomic absorption unit based on the work of Hatch and Ott.(8) The instrument was adjusted mechanically for both 100% and 0% transmission. The reagent blank and a 1.0 μgm Hg standard were routinely run with each batch of samples. The data of Table 1 represents all runs on the blank and the reference standard and the few replicate sample determinations made. Most samples were reported based on a single determination. The data was extracted from the laboratory notebook and is given below (unedited).

Table 1. MERCURY QUALITY CONTROL DATA

8-13, Set 1	8-16, Set 2	9-7, Set 3	9-9, Set 4	9-13, Set 5
1.0[1] - 70.0[3]	1.0 - 68.1	B - 98.2	B - 98.9	B - 99.5
1.0 - 70.0	1.0 - 68.0	1.0 - 71.9	1.0 - 71.0	1.0 - 69.5
B[2] - 97.0	B - 97.5	1.0 - 69.9	1.0 - 72.0	1.0 - 72.0
SAMPLES	SAMPLES	SAMPLES	5670 A - 97.8	SAMPLES
#5488 - 89.7	#5488 - 90.2	1.0 - 72.1	SAMPLES	1.0 - 73.0
1.0 - 70.2		B - 98.0	B - 99.0	B - 99.0
B - 97.1			1.0 - 74.0	
			5670 B - 98.0	
			5670 C - 98.0	

9-23, Set 6	11-1, Set 7	12-3, Set 8	12-16, Set 9	12-31, Set 10
B - 98.9	B - 98.5	B - 99.0	B - 99.5	B -100.0
1.0 - 69.1	1.0 - 72.6	1.0 - 69.0	1.0 - 69.8	1.0[4]- 84.5
1.0 - 69.2	1.0 - 73.8	1.0 - 68.3	1.0 - 68.5	1.0 - 68.9
SAMPLES	SAMPLES	SAMPLES	SAMPLES	1.0 - 69.0
579 A - 96.1	1.0 - 75.0	1.0 - 69.4	1.0 - 69.0	SAMPLES
B - 96.0	B - 99.0	B - 97.8		1.0 - 68.0
C - 96.1				B -100.0
1.0 - 70.0				
B - 99.0				
5720 A - 97.0				
B - 97.1				
C - 97.1				

Notes: [1] 1.0 represents the 1.0 μgm Hg reference standard sample.

[2] B represents the reagent blank determination.

[3] Reading represents the observed percent transmission.

[4] Based upon the nonconformity to prior experience, a new stock solution of the 1.0 μg Hg working reference standard was made up and used.

2 Discussion of data

It would be easy (with the benefit of hindsight) to say that the available data should have been different in some way. In reality, the laboratory had good data on hand upon which to recommend a program for future use.

Almost all analytical control chart techniques are based upon either replicate (usually two) analyses or individual values. Replicate analyses allow one to learn more quickly about the "state of control" of the analyses. A subsequent shift to control charts based upon individual values may be appropriate.

For this discussion, only replicate analysis quality control techniques will be discussed. Standard references (already cited) should be consulted for other types of control charts.

3 Reagent blank control chart

The data of Table 1 indicates that normal practice for the specific laboratory was to run the blank determination at the beginning and the end of the day's run. Since there are only eight (8) sets of data, any control limits calculated would be preliminary in nature. Normally, about twenty (20) sets of data are recommended for setting up the "trial control limits."

The calculations involved in setting up the control chart for this analytical situation are worked out on the attached work sheet.

Since the out-of-control points have occurred in the past, no definitive action to determine their cause may be appropriate. Any future out-of-control sets of data should be studied to determine the "assignable cause" responsible. Once determined, the assignable cause should be removed.

All new data sets should be recorded on the worksheet both in the data table and on the graph as they are generated. This process provides "real-time" analysis and feedback for appropriate control actions.

The appropriate actions in response to out-of-control points are analytical or technical actions and are not statistical in nature. The skills and expertise of the analyst or technologist will enable him to determine and resolve the technical problem that caused the statistical "out-of-control" point to appear.

4 Reference sample control chart

The data from Table 1 indicates that the laboratory made two determinations on the reference sample at the beginning of the run and one at the end of the day's run.

Several approaches could be used to handle the data. A control chart could be set up on the two samples run at the beginning of each day's run. If there is significant drift in the day's run, such action is appropriate. If, on the basis of experience, no drifts occur during a day's run, the number of reference sample determinations could be reduced.

The control chart (attached) is set up on the basis of the replicate samples at the beginning of the run. A specification limit for individual values can be set up based on the data. This "individual" specification limit can be used to judge acceptability of the single determination at the end of the day's run if it is determined that the basic process is in a state-of-control.

The procedure for setting up specification limits in conjunction with "control charts" can be determined from standard references.

The ideal type of reference sample would be a stable (or stabilized) environmental sample. The reference sample should be subject to all the handling of a routine sample. The sample should contain representative interferences, etc. The level of the constituent being measured may or may not be known. If not known, a value is established at the time that the procedure is known to be well calibrated. At any time later, the determined concentration will be consistent with the value established during calibration.

5 Recycle sample control chart

In many cases, it is not feasible or even possible to prepare a reference sample that meets the "ideal." When the reference sample cannot be an environmental sample, its determination may be made with a precision not achievable on routine environmental samples. It would be unfair and unrealistic to expect "real" samples to check as closely as spikes of pure material in distilled water.

The recycling of environmental samples provides a realistic measure of routine analytical precision. The determinations should be separate independent analyses. Submission of the recycle samples as "blinds" confirms the laboratory's or analyst's capability of reproducing his work independently.

Side-by-side duplicates cannot attest to the capability in performing independent analyses. It may be necessary to run the replicates at different times during the same run

NIOSH - Division of Training
Practice Worksheet
Laboratory Quality Control $\bar{X}$-R Chart

Laboratory ______________

Date Aug - Dec

Method of Test or Operation Hg Reference Std 1.0 µg/ml

Reference Value 1.0 µg

Increment of Measurement % T

Data

No.	X_1	X_2	X_3	$\bar{X}_{1+2}$	R_{1+2}
1	70.0	70.0	70.2	70.00	0.0
2	68.1	68.0		68.05	0.1
3	71.9	69.9	72.1	70.90	2.0
4	71.0	72.0		71.50	1.0
5	69.5	72.0	73.0	70.75	2.5
6	69.1	69.2	70.0	69.15	0.1
7	72.6	73.8	75.0	73.20	1.2
8	69.0	68.3	69.4	68.65	0.7
9	69.8	68.5	69.0	69.15	1.3
10	68.9	69.0	68.0	68.95	0.1
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Totals $\Sigma \bar{X}$ 700.50 ΣR 9.0

X_i = observed value R = largest - smallest
n = sets of values CL = control limit
Σ = summation WL = warning limit
U = upper L = lower
D_4 = 3.268 for n' = 2; 2.574 for n' = 3
A_2 = 1.880 for n' = 2; 1.0023 for n' = 3
n' = number of values in the set

Calculations

1. $\bar{R} = \Sigma R \div n$
$0.9 = 9.0 \div 10$

2. $UCL_R = D_4 \times \bar{R}$
$2.94 = 3.268 \times 0.9$

3. $UWL_R = 2/3(D_4\bar{R} - \bar{R}) + \bar{R}$
$2.27 = 2/3(2.94 - 0.9) + 0.9$

4. $\bar{\bar{X}} = \Sigma \bar{X} \div n$
$70.05 = 700.50 \div 10$

5. $CL_{\bar{X}} = A_2 \times \bar{R}$
$1.69 = 1.880 \times 0.9$

6. $WL_{\bar{X}} = 2/3 \times CL_{\bar{X}}$
$1.13 = 2/3 \times 1.69$

7. $UCL_{\bar{X}} = \bar{\bar{X}} + CL_{\bar{X}}$
$71.74 = 70.05 + 1.69$

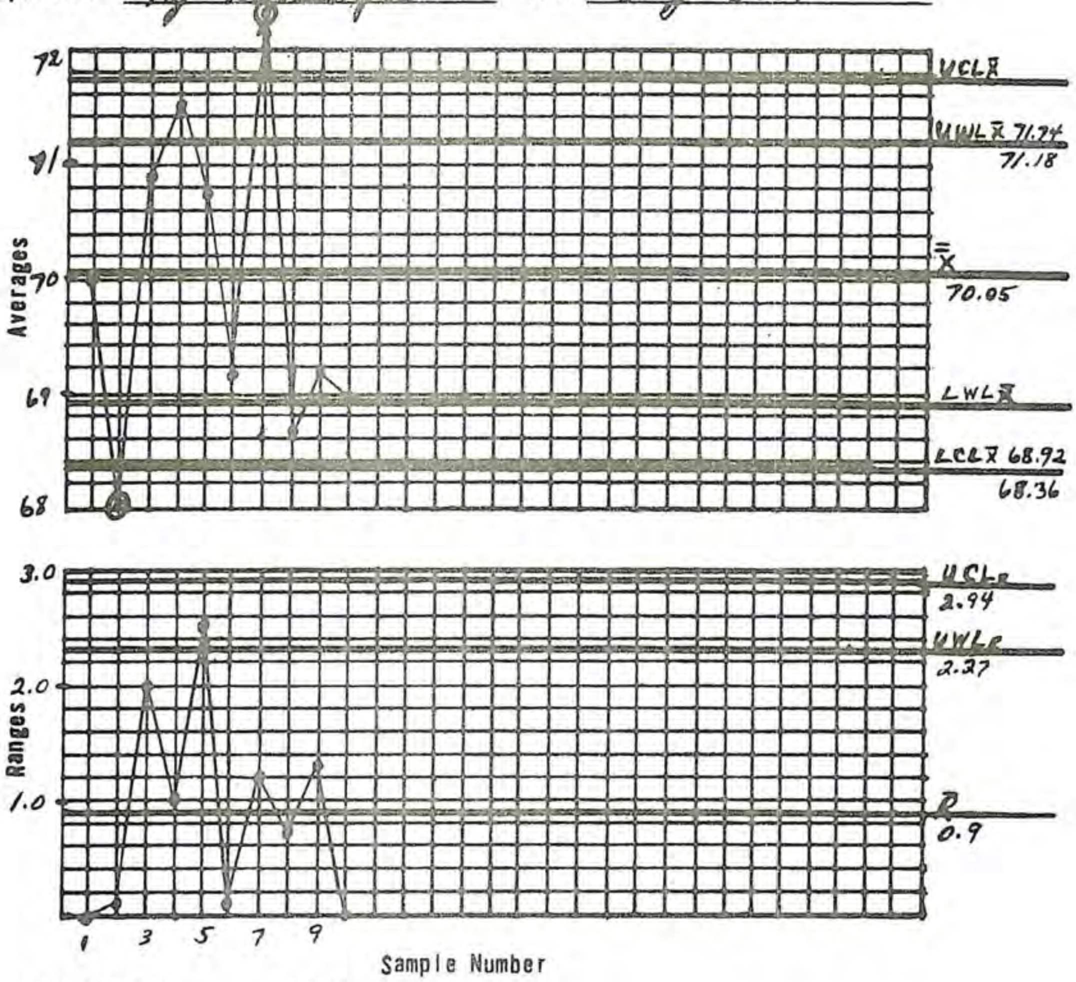
8. $UWL_{\bar{X}} = \bar{\bar{X}} + WL_{\bar{X}}$
$71.18 = 70.05 + 1.13$

9. $LWL_{\bar{X}} = \bar{\bar{X}} - WL_{\bar{X}}$
$68.92 = 70.05 - 1.13$

10. $LCL_{\bar{X}} = \bar{\bar{X}} - CL_{\bar{X}}$
$68.36 = 70.05 - 1.69$

NIOSH - Division of Training
Practice Worksheet
Laboratory Quality Control $\bar{X}$-R Chart

Operation Hg - Std Sample **Date** Aug - Dec.



Directions: Value
1. Draw $\bar{R}$ line 0.9
2. Draw UCL_R line 2.94
3. Draw UWL_R line 2.27
4. Plot $\bar{R}$'s as generated
5. Draw $\bar{\bar{X}}$ line 70.05
6. Draw $UCL_{\bar{x}}$ line 71.74
7. Draw $UWL_{\bar{x}}$ line 71.18
8. Draw $LWL_{\bar{x}}$ line 68.92
9. Draw $LCL_{\bar{x}}$ line 68.36
10. Plot $\bar{X}$'s as generated

5.72

NIOSH – Division of Training
Practice Worksheet
Laboratory Quality Control $\bar{X}$-R Chart

Laboratory ——————
Date Aug - Dec.
Method of Test or Operation Hg / Blank Determination
Reference Value Blank (0 added) Increment of Measurement % T

Data

No.	X_1	X_2	X_3	$\bar{X}$	R
1	97.0	97.1		97.05	0.1
2	97.5	—			
3	98.2	98.0		98.1	0.2
4	98.9	99.0		98.95	0.1
5	99.5	99.0		99.25	0.5
6	98.9	99.0		98.95	0.1
7	98.5	99.0		98.75	0.5
8	99.0	97.8		98.4	1.2
9	99.5	—			
10	100.0	100.0		100.0	0
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Totals $\Sigma \bar{X}$ 789.45 ΣR 2.7

X_i = observed value R = largest − smallest
n = sets of values CL = control limit
Σ = summation WL = warning limit
U = upper L = lower
D_4 = 3.268 for n' = 2; 2.574 for n' = 3
A_2 = 1.880 for n' = 2; 1.0023 for n' = 3
n' = number of values in the set

Calculations

1. $\bar{R} = \Sigma R \div n$
$0.34 = 2.7 \div 8$

2. $UCL_R = D_4 \times \bar{R}$
$1.11 = 3.268 \times 0.34$

3. $UWL_R = 2/3(D_4\bar{R} - \bar{R}) + \bar{R}$
$0.86 = 2/3(\underset{0.52}{1.11 - .34}) + .34$

4. $\bar{\bar{X}} = \Sigma \bar{X} \div n$
$98.68 = 789.45 \div 8$

5. $CL_{\bar{X}} = A_2 \times \bar{R}$
$0.64 = 1.88 \times 0.34$

6. $WL_{\bar{X}} = 2/3 \times CL_{\bar{X}}$
$0.43 = 2/3 \times 0.64$

7. $UCL_{\bar{X}} = \bar{\bar{X}} + CL_{\bar{X}}$
$99.32 = 98.68 + 0.64$

8. $UWL_{\bar{X}} = \bar{\bar{X}} + WL_{\bar{X}}$
$99.11 = 98.68 + 0.43$

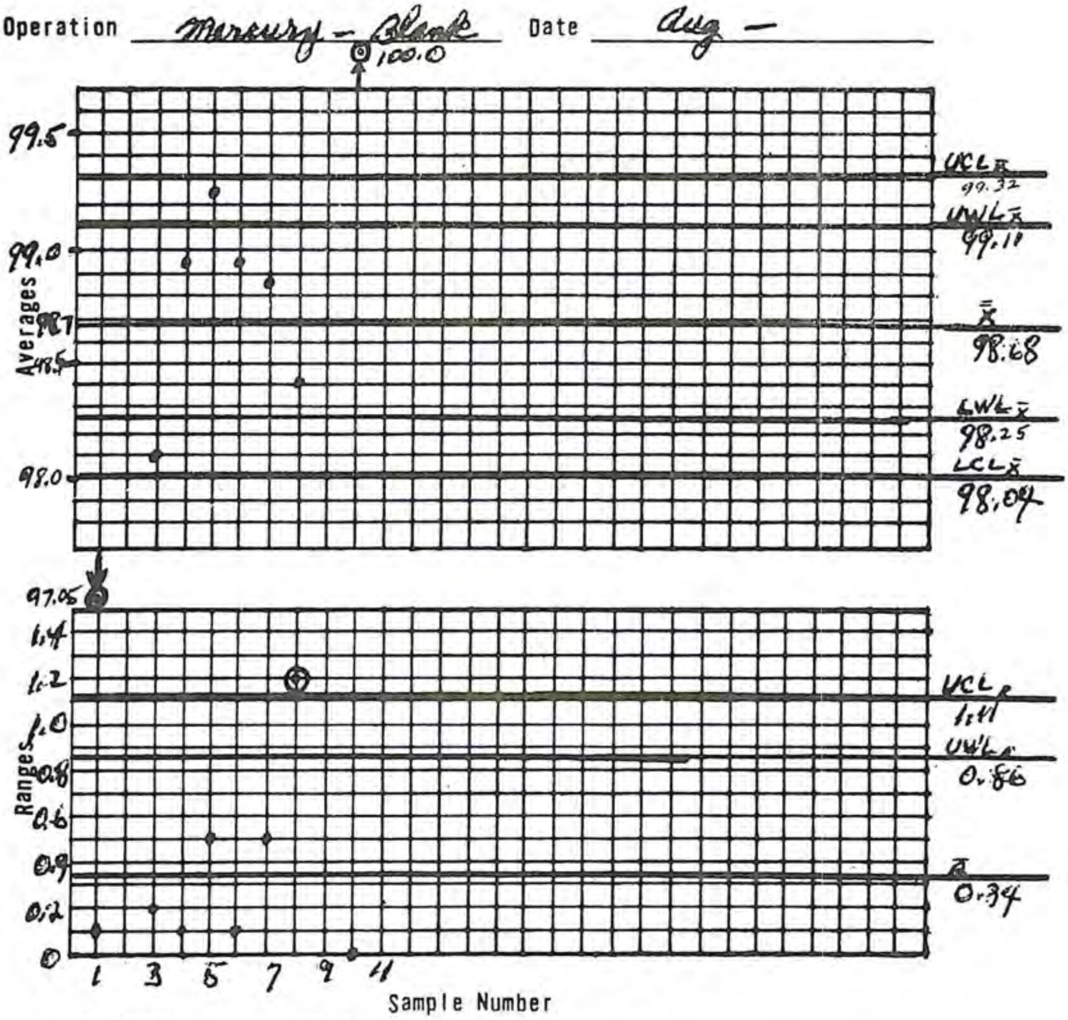
9. $LWL_{\bar{X}} = \bar{\bar{X}} - WL_{\bar{X}}$
$98.25 = 98.68 - 0.43$

10. $LCL_{\bar{X}} = \bar{\bar{X}} - CL_{\bar{X}}$
$98.04 = 98.68 - 0.64$

5.72

NIOSH – Division of Training
Practice Worksheet
Laboratory Quality Control $\bar{X}$-R Chart

Operation Mercury – Blank Date Aug –



Directions: Value

1. Draw $\bar{R}$ line 0.34
2. Draw UCL_R line 1.11
3. Draw UWL_R line 0.86
4. Plot R's as generated
5. Draw $\bar{\bar{X}}$ line 98.68
6. Draw $UCL_{\bar{X}}$ line 99.32
7. Draw $UWL_{\bar{X}}$ line 99.11
8. Draw $LWL_{\bar{X}}$ line 98.25
9. Draw $LCL_{\bar{X}}$ line 98.04
10. Plot $\bar{X}$'s as generated

5.72

rather than on separate days due to sample instability and other problems.

Recycle sample control charts provide information only on routine precision rather than on accuracy since the "true" level of constituent is not known. The Range or R chart of the $\overline{X}$ and R chart previously demonstrated is normally used.

6 Environmental control charts

There are many situations in a plant where the industrial hygienist can use the principles of quality control and control charts. The development of the normal variability of a process and its routine monitoring will provide information which may be more effectively used and acted upon if in a control chart form rather than data in a notebook.

The principles of control charts, demonstrated earlier, apply directly to controlling the environment of a given area or process in a plant.

VI SUMMARY

The application of statistics and, in particular, control charts can aid the analyst and/or industrial hygienist to perform his function more efficiently. The development and use of control charts will 1) determine the normal operational level of precision and accuracy to be expected; 2) will detect changes in the sampling and/or analytical process that have introduced systematic errors; and 3) will provide objective evidence of the continuing long-term level of quality of the sampling and/or analytical process.

REFERENCES

1 Eisenhart, C. Realistic Evaluation of the Precision and Accuracy of Instrument Calibration Systems. Journal of Research, N.B.S., Vol. 67 C, #2, April-June 1963, pp. 161-187.

2 American Society for Testing Materials ASTM Manual on Quality Control of Materials. Special Technical Publication 15-C. 1951.

3 Youden, W. J. Statistical Techniques for Collaborative Tests. Association of Official Analytical Chemists, Box 540, Benjamin Franklin Station, Washington, D.C. 1967.

4 Youden, W. J. The Sample, The Procedure, and the Laboratory. Anal. Chem. 32:23-37A. Dec. 1960.

5 Youden, W. J. The Collaborative Test. J. AOAC. 46:55-62, 1963.

6 Shewhart, W. A. Economic Control of Quality of Manufactured Product. D. Van Nostrand Co., Inc., Princeton, New Jersey, 1931.

7 Grant, E. L. Statistical Quality Control. 3rd edition, McGraw-Hill, New York, Part One, Chapter I. 1964.

8 Hatch, W. R. and Ott, W. L. Analytical Chemistry, Vol. 40, #14, pp. 2085-2087. Dec. 1968.

METHODS OF HAZARD CONTROL

Source ⟶ Air Path ⟶ Receiver

I. SOURCE

A. Substitution with a Less Harmful Material

B. Change of Process

C. Enclosure of Process

D. Isolation of Process

E. Wet Methods

F. Local Exhaust Ventilation

G. Adequate Maintenance Program

II. AIR PATH

A. Housekeeping

B. General Exhaust Ventilation

C. Dilution Ventilation

D. Increase Distance Between Source and Receiver

E. Continuous Area Monitoring

F. Adequate Maintenance Program

III. RECEIVER

A. Training and Education

B. Rotation of Workers

C. Enclosure of Worker

D. Personal Monitoring Devices

E. Personal Protective Devices

F. Adequate Maintenance Program

Ref: Fundamentals of Industrial Hygiene, ed. by J. B. Olishifski, P.E., and F. E. McElroy, P.E., National Safety Council, Chicago, Ill. 60611, 1971, p. 438.

Chapter 35: PRINCIPLES FOR CONTROLLING THE OCCUPATIONAL ENVIRONMENT

SUBSTITUTION

- Process
- Equipment
- Material

ISOLATION

- Stored Material
- Equipment
- Process
- Workmen

VENTILATION

- Local Exhaust/Supply
- General Exhaust/Supply

EDUCATION

- Management
- Engineers
- Supervisors
- Workmen

PERSONAL PROTECTIVE EQUIPMENT

A. Types of Protective Clothing/Devices

- Hat
- Shoes
- Glasses
- Suits
- Respirators
- Ear plugs
- Lanyards
- Fire extinguishers*
- Safety harness
- Buddy systems

B. OSHA Standards –

1910.132, .133, .134, .135, .137

C. Discussion of Each Type of Protection

D. Summation:

- a. Process evaluation
- b. Protection desired
- c. Supervision
- d. Training
- e. Surveillance

Prepared by Horace E. Dimond, Safety Engineer, DTMD, NIOSH, 8/76.

PERSONAL PROTECTIVE EQUIPMENT:
Head, Eyes, Face, Body, Extremities

C.H. Moline*

I THE LABORATORY WORKER IS SUBJECT TO NUMEROUS HAZARDS

A Laboratory Hazards Take Many Forms

1 Liquids
   a Attack skin and outer covering of the eye
   b High velocity ejection penetrate skin and eye
   c May reach blood stream
   d Most harmful chemicals: sodium hydroxide solutions and dimethyl sulfate

2 Gases
   a May act on skin and eyes
   b May reach blood stream

3 Vapors
   a Skin exposure
   b Respiratory tract exposure
   c May reach blood stream

4 Dusts
   a May enter respiratory tract
   b May be abrasive on skin
   c May set up reaction and cause heat (potassium, sodium)
   d May enter eyes

5 Fumes
   a May enter respiratory tract
   b May enter eyes

6 Smoke
   a May enter eyes
   b May enter respiratory tract
   c May contaminate skin and garments

7 Mists and Fogs
   a May enter eyes and contact cornea
   b May enter respiratory tract
   c May contaminate skin and garments

8 Noise
   a May affect auditory
   b May affect nerves
   c Sources of noise and agitators, grinders, mixers, pulverizers, blenders, pilot plant operations and errands to plant areas

9 Electro magnetic spectrum
   a May affect skin
   b May affect eyes
   c May affect internal tissues

B Expectations to be Considered

1 While handling chemical agents they can be expected to travel in all directions unless confined.
   a Gases and vapors diffuse everywhere
   b Dusts spread by the slightest breeze
   c Liquids seep readily
   d Danger even to those outside the laboratory areas
   e Danger with chemicals is that body functions may be interferred with as they enter the body

C Ten Basic Causes of Accident

1 Failure of person in charge to give adequate instructions or inspections

---

*Public Health Advisor. Reprinted by NIOSH, Division of Training.

2 Failure of person in charge to properly plan or conduct the activity

3 Improper design, construction or layouts

4 Protective device not provided or proper equipment and tools not provided

5 Failure to follow instructions or rules

6 Failure to use protective devices provided or improper use of equipment or materials

7 Physical condition or handicap

8 Poor knowledge or mental attitude

9 Use of devices with unknown defects

10 Agency representatives inform outside the organizations

D Injury Factors

1 Host, Environment, Agent Relationships

2 The barrier provided

3 Body systems most subject to injury

a Skin

b Outer covering of eyes

c Respiratory tract and digestive tract

4 High incidence of injury

a Skin - In 1 years time, 2/3 of industrial injuries due to chemicals

b Eyes - said to be subject to chemicals as are other parts of body

II CONTROL METHODS

A Hazard Surveys

1 Planning and plan review stages

a Assume accidents has occurred with existing installations

b Assume accidents will occur with new installations

2 Surveying on completion of new construction or installations

a Reduction and/or elimination

B Material and Process Changes

1 By using proper technique

a Sulfuric acid added to water

2 By changing form of reagents

a Using liquid caustic rather than solid form

3 Rule of thumb

a Chemicals not seen usually safest - with filler pipe inserted into receiving container, eyes protected from splash

4 Proper storage of spare parts and equipment to prevent

a Protruding

b Falling

c Tripping

C Clothing

1 Can reduce but not eliminate contact with chemicals

2 Chemicals can penetrate

3 Chemicals can collect on clothing which acts as reservoir so toxic materials diffuse toward skin

4 Double locker system

a 1 for lab clothing

b 1 for street clothing

c separate locker rooms

D Protective Equipment

1 Personal hygiene is important

a Daily bathing and clean clothing

- b Use much water to cool - many chemicals evolve heat
- c A solvent may be used before water

2 An effective barrier between skin and chemical is desirable "second-line" of protection

3 Closed-in apparatus

- a Ideal situation
- b Limited applications
- c Economic feasibilities must be considered

4 General

- a Clothing soaked with solvent accelerate irritating effect and absorption of toxic substances
- b Oil soaked is fire hazard
- c Should be capable of being sterilized
- d Not irritating to skin

5 Personal Types - some desirable features strong, light weight, adjustable, fire and corrosion proof

- a Rubber gloves
    - 1) Select with regard to chemical used
    - 2) Rubber protects against acids or alkalies
    - 3) No protection re: Carbon disulfide, aliphatic and aromatic amines, nitro-compounds
    - 4) Best gloves - those that can be discarded or discontaminated
- b Impervious sleeves, aprons, full suits
    - 1) Man can work only 20 min. in full clothing or circulatory collapse will occur.
- c Goggles
    - 1) Accidents causing temporary or permanent injury to eyes far exceed all others
    - 2) Do not exchange goggles
    - 3) Duty is to protect form particles flying from sides
- d Masks and spectacles
    - 1) Safety glass worn with masks
    - 2) Allow protection of eyes, head and neck
- e Protective foot wear features
    - 1) Steel cap
    - 2) Anti-static
    - 3) Non-slip
    - 4) Acid and oil resistant
    - 5) Substitutes must allow passage of moisture
    - 6) Maceration of skin, infection and severe injury occur if improper material used.
- f Lab coats, overalls, aprons, smock
    - 1) Resistive to corrosive materials
    - 2) Materials - Dynel and orlon resistant to acids and caustics
    - 3) Flame retardant
    - 4) Antistatic quality
- g Safety glasses - with or without side shields
    - 1) Cash: \$5-15 vs. Lost eye \$1600.00 - \$10,000.
    - 2) Protect against physical, chemical agents and radiant energy
    - 3) Contact lenses not acceptable - harbor chemicals
    - 4) Worn at all times
    - 5) Protection against ultra violet rays
    - 6) Explosions cause most severe eye injuries

7) Visitor protection too is imparative

8) Standard for safety glasses in effect ASA 2.1 - 1959 Re: defects, thicknesses, fracture resistance, plastics

9) Public Schools required to have safety glasses: Ohio '63, Maryland and Mass. '64, 18 states in all; model law by Nat. Sor. for Prevention of Blindness

h Face Shields

1) Plastic of minimum thickness

2) Wire gauze

3) Safety glasses under shields provides added protection

i Impervious Clothing

1) Must be ventilated type if used for long period

j Protective Creams

1) Developed '39-'45 era

2) "Invisible gloves" - used on hand and arms

3) Disadvantages - serve as carrier of contaminants

4) Should meet certain specifications

5) Impermeable gloves more satisfactory

6) Can be impermeable to specific materials - not all

7) May be inactivated by adsorption or chemical reaction

8) Have limitation as to amount of contaminating chemical creams can repel.

9) Massage forces contaminates into hair follicles

10) Protection limited, cream plus contamination may be consumed from hands while eating or allowed to stay on hands for prolonged periods

k Ear Protectors

1) Ear plugs

2) Ear muffs

a) Good ones reduce air blast effect on ears 90%

b) Tend to reduce after blast panic

c) Intervening shield with side vent to operators area reduces blast pressure to 1/5 or more

l Hard hats

1) Range: bump caps, leather caps, hard hats

2) Features - Laminated fiber glass, metal, rainbow colors, electrical conductivity, chemical reactivity

3) Examine lab for these types of hazards

4) Used for errands into plant and pilot plants

m Main Criteria for Safety Showers

1) Required to control hazards Re: acids, caustics, cryogenic fluids, clothing fires

2) Principles of operation, deluge of water: dilutions, warming, cooling, flushing chemicals, putting out clothing fires

3) Location - 25 ft. max., deluge type heads, away from electrical; flow rate 30-60 gpm.

n Body Shields and Barricades

1) Missiles of great energy may be thrown by all types of explosions

2) Missles may be broken parts of apparatus or parts of damaged shields

3) For complete missile protection

a) "No unshielded line of sight allowed between exposing apparatus and part of body"

b) "No deflected missile path (ricochet) should be allowed where the angle of incidence with deflecting surface exceeds 45°"

4) Where missile barriers adequate, air blasts may cause

a) Failure of shield

b) Ear damage

c) Self inflected injury from involuntary or irrational reaction to blast

d) Flash fire

5) Secondary line of defense

a) Safety spectacles worn regardless of shielding and barricades

b) Permanently flame retardant - treated clothing

c) Shirts buttoned

d) Lab. aprons, coats, jackets etc. used.

e) Gloves (gauntlet) used

6) Materials

a) Steel plate

b) Laminated safety glass

c) Chemically treated; single thickness, laminated

7) Types: Portable, fixed, sliding types

E Comparative Useage

1 Asbestos for protection against heat and flame

2 Leather and rubber for mechanical protection

a Can serve as reservoir

3 Rubber, plastic and coated fabrics protection against liquids, fumes, dusts

4 Hand protection - neoprene and P.V.C. coated fabrics (gloves)

5 Equipment must be selected in relation to type of exposure

6 Consider chemical concentration and temperature range

F Attitudes toward protective equipment

1 Management often fails

a Foreman often over zealous and show others "how to do it"

b Foreman eats alpha particle dust - readioactive materials not dangerous

2 Employees

a Requires constant encouragement and training

b Causes discomfort with resistance

c Not a cure all - need daily bathing, clean under garments, etc.

d Accidents happen to "other" fellows

e More resistance with increased complexity of protective device

f Advising "why" increases acceptance

3 Added considerations

a Proper fit and freedom to work essential

b Allow finger dexterity

c Does not induce hazards

d Maintenance of equipment

REFERENCES

1 National Research Council. Committee on Design, Construction and Equipment of Laboratories. "Laboratory Design", Coleman, H.S. Reinhold Publishing Co. New York, 1962.

2 National Research Council. Committee on Design, Construction and Equipment. "Laboratory Planning for Chemistry and Chemical Engineering". Lewis, H.F., Editor. Reinhold Publishing Co., New York. 1962.

3 Chemical Rubber Company. "Handbook of Laboratory Safety". Steere, N.V., Editor. Chemical Rubber Company. Cleveland, 1967.

4 Guy, K. Laboratory Organization and Administration, St. Martins Press. New York, 1962.

5 Manufacturing Chemists Association, Inc. "Guide for Safety in the Chemical Laboratory" Washington, D.C., 1954.

6 Pieters, H.A. "Safety in the Chemical Laboratory" Academic Press. New York. 1951.

7 Fawcett, H.H., Wood, W.S. "Safety and Accident Prevention in Chemical Operations" Interscience Publish. New York. 1965.

8 National Safety Council "Accident Prevention Manual for Industrial Operations" Fifth Edition. National Safety Council. Chicago.

PERSONAL PROTECTIVE EQUIPMENT: RESPIRATORY SYSTEM

I PERSONAL PROTECTIVE DEVICES

Personal protective devices have one serious weakness, that is, they do nothing to reduce or eliminate the hazard. They merely set up a defense against it and any failure of this defense means immediate exposure to the hazard. The fact that many protective devices can be or can become ineffective without the knowledge of the wearer is particularly serious.

Standards and specifications for personal protective equipment have been developed as the result of extensive research and testing. Excellent equipment in great variety is commercially available.

Despite its general availability and relatively low cost, however, protective equipment should not supersede the elimination of the hazard. Employees who are not adequately safety-minded are constantly tempted to rely chiefly on personal protective equipment, whereas, these devices are intended for emergency or temporary use only. Respirators, in particular, are frequently resorted to instead of eliminating the air contaminants.

These devices may be divided into four groups: 1) respirators; 2) goggles and face shields; 3) protective clothing; and 4) protective creams and lotions. The safety department, especially in larger plants, is generally responsible for the issuance, maintenance, and educational program of these devices. In many instances, however, the industrial hygienist is asked to advise and make recommendations concerning the choice and use of the protective equipment. For this reason he must be familiar with, and know the limitations of, these items.

II RESPIRATORY PROTECTIVE DEVICES

All respirators have two drawbacks in common: they are more or less uncomfortable to wear and they reduce the worker's efficiency. If the lessened efficiency could be measured in terms of cost, it would probably show that substantial expenditures to eliminate the hazard often are justified.

To insure the effectiveness of respiratory protective devices, the U. S. Bureau of Mines tests and approves such equipment. Only those devices approved by the Bureau of Mines should be used, since such approval is authoritative assurance of their effectiveness, when used under the specified conditions. Lists of approved devices may be obtained upon request from the Bureau of Mines, Washington 25, D. C.

It is important that the type of respiratory equipment used be correct for the hazard involved. Deaths and near deaths have occurred because of dependence in deadly atmospheres on respiratory protective equipment not suited to the hazard. Examples are the use of filter-type respiratory respirators in an atmosphere containing carbon monoxide, or an all-purpose canister type when there is an oxygen deficiency.

A In the event a hazard cannot be eliminated or reduction of the hazard is impracticable, an orderly procedure should be followed, including at least the following steps:

1 Identify the substance or substances against which protection is necessary.

2 Obtain full knowledge of the hazards that each such substance offers and its significant properties.

3 Determine the conditions of the exposure that will be involved.

4 Determine what, if any personal characteristics and capabilities are essential to the safe use of the protective devices and procedures required.

5 Determine what facilities are needed for maintenance.

6 From these considerations, select the type respirator which will provide protection.

B Respiratory Protective Devices Are of Three Types:

1 Air purifying - which removes the contaminant from the air as it is inhaled by filtering or by chemical absorption, adsorption, or catalytic action.

2 Air supplying - which supplies respirable air from a compressor, hand or electrically operated blower, or a cylinder of compressed air.

Reprinted by Division of Training, NIOSH.

3 Self contained breathing apparatus-which supplies air or oxygen from a tank carried by the wearer, or by a chemical reaction producing oxygen from the moisture in the wearer's exhaled breath.

The correct use of all types of respiratory protective equipment requires careful attention to many details and the unfailing observance of rules for safe procedure. Full details of types approved by the U. S. Bureau of Mines should be obtained from the manufacturers.

No matter how well a respiratory protective device is designed and made, unless it is properly cared for and maintained in good condition, it may fail to give protection. Planning after determing the need for the equipment should provide for careful and unfailing maintenance. This includes inspection, repairs, replacement of used filters, cleaning, and sterilization.

C Since a respirator is uncomfortable when worn for extended periods, personnel must realize fully the need of the protection or they will not wear respirators faithfully. Important factors in getting full employee cooperation in this respect are:

1 Recourse to respiratory protective equipment only after every effort has been made to eliminate the hazard.

2 Explaining the situation fully to the workmen involved.

3 Careful fitting of respirators.

4 Adequate provisions for maintenance and cleanliness.

5 Careful instruction as to use.

6 Intelligent, fully informed supervisors.

7 Sterilization of equipment before reissue.

A more detailed discussion of respiratory protective devices can be found in the Manual of Respiratory Protective Devices, published in 1963 by a joint AIHA-ACGIH Committee.

PERSONAL PROTECTIVE DEVICES

Selected References

1 Burgess, W. A.: Personal Protective Devices. Included as a topic, pages 319-343, in "Industrial Hygiene Highlights," edited by L. V. Cralley, L. J. Cralley and G. D. Clayton, copyright by Industrial Hygiene Foundation of America, Incorporated, 1968.

2 Lundin, A. M.: Respiratory Protective Equipment. Chapter 13, pages 481-506, in "Fundamentals of Industrial Hygiene, edited by J. B. Olishifski and Frank E. McElroy, National Safety Council, 1971.

3 Patty, F. A.: Respirators and Respiratory Protective Devices, Chapter XI, pages 343-355, in "Industrial Hygiene and Toxicology, Volume 1, 2nd Edition, Interscience 1967.

4 National Safety Council: <u>National Safety News</u> (The March issues usually feature personal protective devices. Review other issues as well.)

5 Personal Protective Equipment, Chapter 38, pages 1142-1204, in "Accident Prevention Manual for Industrial Operations," edited by F. E. McElroy, 6th Edition, National Safety Council, 1969.

6 "Respiratory Protective Devices Manual" published by American Industrial Hygiene Association and American Conference of Governmental Industrial Hygienists, 1963.

7 American National Standard Practices for Respiratory Protection" sponsored by U.S. Department of the Interior, Bureau of Mines, ANSI Z 88.2-1969, American National Standards Institute, New York, 1969.

8 "Respiratory Protective Devices; Tests for Permissibility; Fees." Department of the Interior, Bureau of Mines. Federal Register, Volume 37, Number 59, p . 6244-71, March 25, 1972.

MANUFACTURERS OF PROTECTIVE MATERIALS

I PROTECTIVE CLOTHING

American Optical Corporation, 14 Mechanic St., Southbridge, Mass. 01550.

Mine Safety Appliances Co., 201 N. Braddock Ave., Pittsburgh, Pa. 15208.

Safety Clothing & Equipment Co., Div. Safety First Industries, Inc., Cleveland, Ohio 44103.

United States Safety Service Co., 1535 Walnut, Kansas City, Mo. 64108.

II PROTECTIVE SLEEVES AND APRONS

American Optical Corp., 14 Mechanic St., Southbridge, Mass. 01550.

Goodyear Tire & Rubber Company, 1144 Market, Akron, Ohio 44305.

Mine Safety Appliances Co., 201 N. Braddock Ave., Pittsburgh, Pa. 15208.

Standard Safety Equipment Co., 431 N. Quentin Rd., Palatine, Ill. 60067.

Surety Rubber Co., North High St., Carrollton, Ohio 44615.

West Chemical Products, Inc., 42-16 West St., Long Island City, New York 11101.

III INDUSTRIAL RUBBER GLOVES AND SYNTHETIC RUBBER GLOVES

Edmont-Wilson, 3119 Walnut St., Coshocton, Ohio 43812.

Pioneer Rubber Co., Tiffin Road, Willard, Ohio 44890.

Surety Rubber Company, North High St., Carrollton, Ohio 44615.

IV INDUSTRIAL CLEANSERS

Dameron Enterprises, Inc., 7635 National Turnpike, Louisville, Ky. 40214.

Sugar Beet Products, P.O. Box 1387, Saginaw, Mich. 48605.

United States Borax & Chemical Corp., 3075 Wilshire Boulevard, Los Angeles, Calif. 90005.

West Chemical Products, Inc., Long Island City, New York 11101.

VI WATERLESS HAND CLEANERS

Dameron Enterprises, Inc., 7635 National Turnpike, Louisville, Ky. 40214.

Dow Chemical Company, Midland, Mich. 48640.

Sugar Beet Products, P.O. Box 1387, Saginaw, Mich., 48605.

VII PROTECTIVE OINTMENTS & CREAMS

Armar-Stone Laboratories, Inc., 601 E. Kensington Rd., Mt. Prospect, Ill. 60656.

Ayerst Laboratories, 685 Third Ave., New York, N.Y. 10017.

Dome Laboratories, Div. Miles Laboratories, Inc., West Haven, Conn. 06516.

E.I. DuPont de Nemours & Co., 1007 Market Street, Wilmington, Del. 19898.

Mine Safety Appliances Co., 201 N. Braddock, Ave., Pittsburgh, Pa. 15208.

West Chemical Products, Inc., 42-16 West St., Long Island City, N.Y. 11101.

SAFETY PROGRAM EVALUATION

I INTRODUCTION

- A Safety v. Industrial Hygiene
- B Safety Programs
  - 1 Institutes
  - 2 Colleges
  - 3 NIOSH
- C Development of Safety Program
  - 1 Breakdown of program
  - 2 Accident investigation breakdown

II MANAGEMENT BACKING

- A Function of Safety Engineer
  - 1 Buffer for management
  - 2 Obtain new knowledge
  - 3 Indoctrinate management
    - a Obtain backing
- B True Cost of Accidents
  - 1 Insured costs - Medical, Compensation
  - 2 Uninsured costs
  - 3 Iceberg

III MEASUREMENT OF SAFETY PROGRAMS

- A Accident Frequency Rate
  - 1 Formula
- C Advantages of Use
- D Disadvantages of Use
- E Measurement of Control
  - 1 Advantages of use
  - 2 Measurement method
    - a Accident investigation

IV PROFILE OF ACCIDENT INVESTIGATION PROGRAM

- A Basic Activity Level
  - 1 All injuries investigated
    - a Loss time injuries 25%
    - b Injuries reported to insurance company 25%
    - c Doctors' cases 25%
    - d First aid cases 25%
  - 2 Properly designed investigation form utilized
    - a Existence of form, total accident oriented 50%
    - b Adequacy of form, essential parts 50%
  - 3 Special announcement for major injuries
    - a Distributed to all key management 50%
    - b Posted in plant within 24 hours 50%
- B Intermediate Activity Level
  - 1 Executive management involvement

Prepared by Charles A. Rizzo, Safety Engineer, Division of Training, NIOSH, 2/73.

		a	Participation in investigation	50%
		b	Participation in follow-up	50%
	2		Simplified rating system	
		a	System used for revealing the percentage of accidents investigated	50%
		b	System reduced to writing	50%
	3		Formal supervisory training	
		a	Classroom instruction minimum of 2 hours each 3 years	60%
		b	Adequacy of training materials and test administered	40%
C			Advanced Activity Level	
	1		All accidents investigated	
		a	All property damage accidents investigated	80%
		b	Adequacy of written program	20%
	2		Qualitative rating system	
		a	System to evaluate quality of investigations	50%
		b	Adequate use of ratings	50%
	3		Remedial follow-up system	
		a	All major accidents checked	50%
		b	Random sampling of all other accidents	50%

SAFETY PROGRAM BREAKDOWN

MANAGEMENT INVOLVEMENT
ACCIDENT INVESTIGATION
FACILITY INSPECTION
POLICIES - STANDARDS
GROUP MEETINGS
PERSONAL PROTECTION
SUPERVISORY TRAINING
GENERAL PROMOTION
HIRING AND SELECTION
REFERENCE LIBRARY
EMERGENCY CARE
RECORDS - STATISTICS
PERSONAL COMMUNICATIONS
ACCIDENT ANALYSIS
FIRE LOSS CONTROL
ENVIRONMENTAL HEALTH
PRODUCTS LIABILITY
ENGINEERING CONTROL
JOB ANALYSIS
JOB OBSERVATION
SKILL TRAINING
OFF-THE-JOB SAFETY
ECONOMICS APPLICATION
INCIDENT RECALL
INCIDENT ANALYSIS
BIOMECHANIC APPLICATION
"SAFETY PROFITS EVERYONE"

SUPERVISOR'S ACCIDENT INVESTIGATION REPORT

COMPANY OR BRANCH	DEPARTMENT		
EXACT LOCATION	DATE OF OCCURRENCE	TIME ☐ AM ☐ PM	DATE REPORTED

PERSONAL INJURY		**PROPERTY DAMAGE**	
INJURED'S NAME		PROPERTY DAMAGED	
OCCUPATION	INJURED PART OF BODY	ESTIMATED COSTS $	ACTUAL COSTS
NATURE OF INJURY		NATURE OF DAMAGE	
OBJECT/EQUIPMENT/SUBSTANCE/INFLICTING INJURY		OBJECT/EQUIPMENT/SUBSTANCE/INFLICTING DAMAGE	
PERSON WITH MOST CONTROL OF OBJECT/EQUIPMENT/SUBSTANCE		PERSON WITH MOST CONTROL OF OBJECT/EQUIPMENT/SUBSTANCE	

DESCRIPTION

DESCRIBE CLEARLY HOW THE ACCIDENT OCCURRED: ATTACH ACCIDENT DIAGRAM FOR ALL MOTOR VEHICLE ACCIDENTS.

ANALYSIS

WHAT ACTS, FAILURES TO ACT AND/OR CONDITIONS CONTRIBUTED MOST DIRECTLY TO THIS ACCIDENT?

WHAT ARE THE BASIC OR FUNDAMENTAL REASONS FOR THE EXISTENCE OF THESE ACTS AND/OR CONDITIONS?

LOSS SEVERITY POTENTIAL

☐ Major ☐ Serious ☐ Minor

PROBABLE RECURRENCE RATE

☐ Frequent ☐ Occasional ☐ Rare

PREVENTION

WHAT ACTION HAS OR WILL BE TAKEN TO PREVENT RECURRENCE? PLACE X BY ITEMS COMPLETED.

INVESTIGATED BY	DATE	REVIEWED BY	DATE

MAJOR ACCIDENT LOSS
ANNOUNCEMENT

☐ PERSONAL INJURY ☒ PROPERTY DAMAGE

N. E. corner building A	Maintenance Department	2-20-69 4 P.M.
Location	*Department & Division*	*Date and Time of Accident*

APPARENT NATURE AND EXTENT OF INJURY-DAMAGE TO PERSONS OR PROPERTY (INCLUDE COSTS WHEN DAMAGE IS INVOLVED)

Crack in boring main mill frame caused operation shut down. Repair work will require 2 turns. Total damage costs estimated at $1700.

PERSONAL INFORMATION

Crane operator age 20 - 3 months job experience.

BRIEF DESCRIPTION OF ACCIDENT

The South crane in building A was moving a hamper of refuse suspended by a four way pan chains North over the large boring mill. One side of the pan bumped the east corner of the mill causing one of the four hooks to dislodge. As the crane continued to move a short distance north, the hanging pan hooked the main mill frame and caused it to crack before the crane movement was stopped.

APPARENT CAUSES

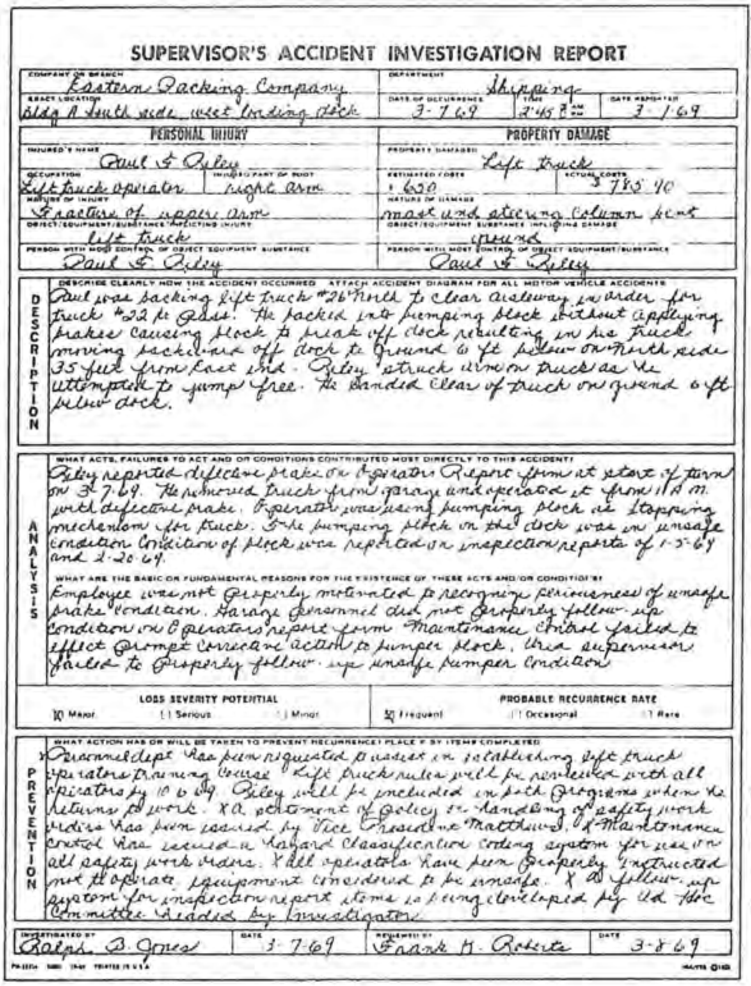
Crane operator apparently forgot safe procedure to move all loads down shop over stock pile on South side of shop. Ground man failed to observe unsafe crane movement in time to whistle warning to operator.

Carl T. Blanding	Blake A. Carlson
Immediate Supervisor	*Department Head*

SAFETY PROFITS EVERYONE THE FAMILY THE EMPLOYEE THE COMPANY

PH-1265 1M 10-69 Printed in U.S.A.

A SUGGESTED TECHNIQUE FOR MEASURING THE QUANTITY AND QUALITY OF ACCIDENT INVESTIGATIONS



SUPERVISOR'S ACCIDENT INVESTIGATION REPORT

COMPANY OR BRANCH: Eastern Packing Company
DEPARTMENT: Shipping
EXACT LOCATION: Bldg A South side west loading dock
DATE OF OCCURRENCE: 3-7-69
TIME: 2:45 P.M.
DATE REPORTED: 3-7-69

PERSONAL INJURY	PROPERTY DAMAGE
INJURED'S NAME: Paul F. Riley	PROPERTY DAMAGED: Lift truck
OCCUPATION: Lift truck operator INJURED PART OF BODY: right arm	ESTIMATED COSTS: $650 ACTUAL COSTS: $785.40
NATURE OF INJURY: Fracture of upper arm	NATURE OF DAMAGE: mast and steering column bent
OBJECT/EQUIPMENT/SUBSTANCE INFLICTING INJURY: lift truck	OBJECT/EQUIPMENT/SUBSTANCE INFLICTING DAMAGE: ground
PERSON WITH MOST CONTROL OF OBJECT/EQUIPMENT/SUBSTANCE: Paul F. Riley	PERSON WITH MOST CONTROL OF OBJECT/EQUIPMENT/SUBSTANCE: Paul F. Riley

DESCRIPTION

DESCRIBE CLEARLY HOW THE ACCIDENT OCCURRED   ATTACH ACCIDENT DIAGRAM FOR ALL MOTOR VEHICLE ACCIDENTS

Paul was backing lift truck #26 North to clear aisleway in order for truck #22 to pass. He backed into bumping block without applying brakes causing block to break off dock resulting in his truck moving backwards off dock to ground 6 ft below on North side 35 feet from East end. Riley struck arm on truck as he attempted to jump free. He landed clear of truck on ground 6 ft below dock.

ANALYSIS

WHAT ACTS, FAILURES TO ACT AND OR CONDITIONS CONTRIBUTED MOST DIRECTLY TO THIS ACCIDENT?

Riley reported defective brake on Operators Report form at start of turn on 3-7-69. He removed truck from garage and operated it from 11 A.M. with defective brake. Operator was using bumping block as stopping mechanism for truck. The bumping block on the dock was in unsafe condition. Condition of block was reported on inspection reports of 1-5-69 and 2-20-69.

WHAT ARE THE BASIC OR FUNDAMENTAL REASONS FOR THE EXISTENCE OF THESE ACTS AND/OR CONDITIONS?

Employee was not properly motivated to recognize seriousness of unsafe brake condition. Garage personnel did not properly follow-up condition on Operators report form. Maintenance Control failed to effect prompt corrective action to bumper block. Area supervisor failed to properly follow-up unsafe bumper condition

LOSS SEVERITY POTENTIAL: ☒ Major ☐ Serious ☐ Minor

PROBABLE RECURRENCE RATE: ☒ Frequent ☐ Occasional ☐ Rare

PREVENTION

WHAT ACTION HAS OR WILL BE TAKEN TO PREVENT RECURRENCE? PLACE ✓ BY ITEMS COMPLETED

x Personnel dept has been requested to assist in establishing lift truck operators training course. Lift truck rules will be reviewed with all operators by 10-6-69. Riley will be included in both programs when he returns to work. x A statement of policy on handling of safety work orders has been issued by Vice President Matthews. x Maintenance control has issued a hazard classification coding system for use on all safety work orders. x All operators have been properly instructed not to operate equipment considered to be unsafe. x A follow-up system for inspection report items is being developed by Ad Hoc Committee headed by Investigator.

INVESTIGATED BY: Ralph B. Jones	DATE: 3-7-69	REVIEWED BY: Frank H. Roberts	DATE: 3-8-69

Accuracy and Completeness
10 points max.

Clear, Adequate Step-By-Step Description
15 points max.

Thorough Cause Analysis
15 points max.

Evaluation
5 points max.

Adequacy and Timeliness of Action
30 points max.

Proper Signatures
5 points max.

Submission of Report Prior to Rating Cut-Off Time
Automatic 5 points

Submission of Report within 24 hours
15 points max. - 5 points deducted for each day late.

NOTE: All points should be prorated depending on compliance with the requirements.

ACCIDENT INVESTIGATION

BASIC ACTIVITY LEVEL	V.F.	% EFFECTIVE	TOTAL
1. All Injuries Investigated	50		
2. Properly Designed Investigation Form Utilized	30		
3. Special Announcement For Major Injuries	20		
INTERMEDIATE ACTIVITY LEVEL			
1. Executive Management Involvement	40		
2. Simplified Rating System	30		
3. Formal Supervisory Training	30		
ADVANCED ACTIVITY LEVEL			
1. Total Down Grading Incidents Investigated	40		
2. Qualitative Rating System	30		
3. Remedial Follow Up System	30		

LEGAL ASPECTS OF THE OCCUPATIONAL SAFETY AND HEALTH ACT

I. INTRODUCTION

NOTES

A. Occupational Safety and Health Act signed into law on December 29, 1970.

B. Purposes:

1. To assure safe and healthful working conditions for the nation's working men and women; and,

2. To preserve human resources.

C. Major Responsibilities and Authorities Delegated to the Department of Labor:

1. To promulgate, modify and improve mandatory occupational safety and health standards;

2. Authorized to enter factories;

3. To prescribe regulations for maintaining accurate records;

4. To develop and maintain statistics on occupational safety and health;

5. To establish and supervise programs for the education and training of employee and employer personnel: and,

6. To make grants to states.

D. Major Responsibilities and Authorities Delegated to the Department of Health, Education, and Welfare

1. To conduct, directly or by grants or contracts, research, experiments or demonstrations relevant to occupational safety and health;

Prepared by Robert B. Weidner, Attorney -- PE, Division of Training, NIOSH, 3/75-SL(580). 3/75-IHE(551).

NOTES

2. To develop criteria for dealing with toxic materials and harmful physical agents;

3. To make toxicity determinations on request by employer or employee groups;

4. To publish an annual listing of all known toxic substances;

5. To conduct directly, or by grants and contracts, educational programs aimed at providing an adequate supply of qualified personnel; and,

6. To establish a National Institute for Occupational Safety and Health.

E. Established a 12-member National Advisory Committee on Occupational Safety and Health.

F. Established an Occupational Safety and Health Review Commission which will adjudicate disputes.

G. Established a National Commission of State Workmen's Compensation Laws to make a study and evaluation of such laws.

H. Scope of the Act

1. Pertains to every employer EXCEPT United States and State or political subdivisions of the State.

2. Covers every workplace EXCEPT for working conditions with respect to which other Federal agencies and specified (e.g., AEC contract) state agencies, exercise statutory authority to prescribe or enforce standards or regulations affecting occupational safety and health.

3. Federal and state employees are covered under the Act by reason of Executive Order 11612, Section 4 (B)(1).

II. DUTIES

A. The General Duty Clause

1. ". . . . to furnish to each of his employees employment and a

place of employment which are free from recognized hazards that are causing or likely to cause death or serious physical harm to his employee."

NOTES

B. Occupational Safety and Health Standards — Two Types:

1. "General Standards" which are applicable to all employers are contained in Title 29, Code of Federal Regulations, Part 1910, and

2. "Particular Standards" which are applicable to specific industries such as the Safety and Health Regulations for Construction which are contained in Title 29, Code of Federal Regulations, Part 1518.

III. INSPECTIONS

A. The Act contains a general prohibition against giving advance notice of inspection, except in limited circumstances:

1. In cases of apparent imminent danger to enable the employer to abate the danger as quickly as possible;

2. In circumstances where the inspection can most effectively be conducted after regular business hours or where special preparations are necessary for an inspection;

3. Where necessary to assure the presence of representatives of the employer and employees or the appropriate personnel needed to aid in the inspection; and,

4. In other circumstances where the Area Director determines that the giving of advance notice would enhance the probability of an effective and thorough inspection.

B. Extent of Inspections

1. The Act authorizes inspectors to enter without delay at reasonable times where work is performed

NOTES

by employees of an employer and to conduct investigations during regular working hours at other reasonable times within reasonable limits and in a reasonable manner.

2. The Act also authorizes the inspection of all pertinent conditions, including structures, machines, apparatuses, devices, equipment and materials therein, and to question privately any employer, owner, operator, agent or employee.

C. The Act permits the employer and A representative authorized by his employer to accompany the inspector during the inspection of the workplace.

D. Initiation of Inspection

1. Any employee who believes that a violation of a job safety or health standard exists which threatens physical harm, or who believes that an imminent danger situation exists, may request an inspection.

2. Inspections may be initiated by the Department of Labor for the purpose of enforcing standards promulgated under the Act.

E. Priorities have been given by OSHA for each category of inspection activity, in the following order of importance:

1. Imminent danger

   a. The Act defines imminent danger as "any conditions or practices in any place of employment which are such that a danger exists which could reasonably be expected to cause death or serious physical harm immediately or before the imminence of such danger can be eliminated through the enforcement procedures otherwise provided by this Act."

   b. Normally, a health hazard would not constitute an imminent danger, except in extreme situations, such as the presence of high concentrations of airborne toxic substances which are an immediate threat to the lives or health of employees.

NOTES

2. Catastrophe and fatality situations
    a. Employers must notify the Department of Labor in the event of any catastrophe or fatality.
3. Investigation of complaints
    a. The Act gives employees the right to file a complaint. These complaints are given priority in inspections.
4. OSHA's Target Industry Program and Target Health Program
    a. The purpose of these programs is to concentrate efforts on the industries with the highest recorded injury - frequency rate and those substances selected for initial action.
5. Inspections conducted on a random basis
    a. These are given the lowest priority.

F. Duties of Compliance Safety and Health Officer

1. Primary aim - the enforcement of standards issued under the Act.
2. Secondary goals are to ascertain whether the employer has:
    a. Posted the notice informing employees of their rights and obligations under the Act;
    b. Complied with the record-keeping requirements under the Act;
    c. Given advance notice to authorized representatives of employees, if such notice is requested.
3. At the end of the inspection, the Official is required to conduct a closing conference with the employer.

NOTES

a. The purpose of this conference is to advise the employer of all conditions and practices disclosed during the inspection which may constitute safety or health violations.

b. Officers are directed to also indicate, where possible, the applicable section or sections of the standards which may have been violated.

IV. CITATIONS

A. Types

1. "Citation for Serious Violation" – OSHA Form–2A: issued by Area Director when investigation reveals a serious violation.
2. "Citation" – OSHA Form-2: issued by Area Director when investigation reveals a non-serious violation.
3. "De Minimis Notice" – Form-2B: issued by Area Director when investigation reveals a de minimis violation.

B. Accompanying Forms

1. "Notification of Proposed Penalty" – Form-3: issued by Area Director with each citation, except a de minimis citation.
2. "Notification of Failure to Correct Violation and of Proposed Additional Penalty" – OSHA Form-3A: issued by Area Director if the violation found is after the second investigation and is for failure to correct a previous violation.

V. RECORDKEEPING, POSTING OF PERIODIC REPORTS

A. Recordable occupational injuries and illnesses are defined as occupational illnesses and injuries which result in fatalities, or non-fatal cases which result in loss of work

NOTES

days, transfer to another job, termination of employment, and illnesses and injuries which require medical treatment (other than first aid) or involve loss of consciousness or restriction in motion. This also includes any diagnosed occupational illnesses which are reported to the employer but are not classified as fatalities or lost work day cases.

B. Mandatory Reports

   1. Log of Occupational Injuries and Illnesses, OSHA Form-100.

      a. Must be entered as soon as practicable, but no later than 6 working days after receiving information that a recordable injury or illness has occurred.

      b. An equivalent may be used if it contains all the details provided in OSHA Form-100.

   2. Supplementary Record of Occupational Illnesses and Injuries, OSHA Form-101.

      a. Must be entered within 6 working days after receiving information that a recordable case has occurred.

   3. The Annual Summary, OSHA Form-102.

      a. Must be completed no later than January 31st of each year.

      b. Must be certified by the employer to be true and correct.

      c. Must be posted at each establishment no later than February 1st of each year and shall remain posted until March 1.

      d. Must be based on the information contained in the log of occupational injuries and illnesses for the particular establishment.

C. Small employers, defined in the regulations as those having seven or fewer employees, are exempt from almost all the record keeping and reporting requirements.

   1. The only time a small employer must maintain a log of occupational injuries and illnesses is if he is notified by the Bureau of Labor Statistics that he has

NOTES

been selected to take part in a statistical survey of occupational injuries and illnesses. In that event, the small employer would be required to maintain a log and to complete any survey forms he is sent.

2. The only other obligation in this area placed on small employers is to report promptly any accident involving death of an employee or hospitalization of five or more employees. In this requirement both small and large employers are treated alike.

VI. PENALTIES

The Act is penal in nature because it provides criminal sentences, criminal fines, and civil penalties to be assessed against an employer for violation of either the General Duty Clause or specific standards promulgated under the Act.

A. Types

1. Willful Violations Causing Death of an Employee.
2. Willful or Repeated Violations.
3. Serious Violations.
4. Nonserious or Other Violations.
5. De Minimis Violations.
6. Daily Penalties for Failure to Abate.
7. Failure to Post Notice of Employee Rights Under the Act.
8. Failure to Post Citations.
9. Failure to Report Employment Deaths.
10. Failure to Maintain Records.
11. Penalty for Giving False Information.
12. Penalties for Killing, Assaulting, or Hampering the Work of Enforcement Personnel.

VII. CONTEST OF CITATIONS AND PROPOSED PENALTIES

NOTES

A. Notice of Contest

1. An employer who receives a citation and proposed penalties has the right to contest either the citation or the proposed penalties, or both, to the Occupational Safety and Health Review Commission.

2. Must be filed within 15 working days from receipt of a citation and proposed penalty.

B. Hearing

1. Within 7 days of the receipt of the notice of contest, the Area Director must file with the Commission the notice of contest or modification of abatement and all citations, notifications of failure to correct violations.

2. Within 20 days of the receipt of the notice of contest, the Secretary of Labor files with the Commission a complaint against the employer. The employer will receive a copy of the complaint, as will the representative of the employees who have elected party status.

3. The employer <u>must</u> file an answer within 15 days after receipt of the complaint.

4. After the commission has received the employer's notice of contest from the Area Director, the Commission appoints a judge to conduct the hearing who has control over all proceedings, discovery, depositions, and production of documents in the case.

C. Review of the Final Order of the Commission

1. The employer or other party that has received an adverse order from the Commission has the right to have the Commission's order reviewed by the Court of Appeals.

NOTES

2. The review by the Court of Appeals is limited to only those questions of law or objections raised before the Commission.

VIII. VARIANCES

The Act provides that any affected employer may be granted a temporary variance from a standard, a permanent variance from a standard, or a variance, tolerance or exemption for any or all provisions of the Act.

A. Temporary Variance

1. The employer must establish that:
    - a. he is unable to comply with a standard by its effective date because of the unavailability of professional or technical personnel or of materials and equipment needed to come into compliance with the standard or because necessary construction or alteration of facilities cannot be completed by the effective date.
    - b. he is taking all available steps to safeguard his employees against the hazards covered by the standard, and
    - c. he has an effective program for coming into compliance with the standard as quickly as practicable.
2. The contents of the application for a temporary variance are set forth in detail in 29 C.F.R. Section 1905.10(b) (1972).

B. Permanent Variance

1. The employer must establish by a preponderance of evidence that the conditions, practices, means, methods, operations or processes used or proposed to be used by him will provide employment and a place of employment for his employees which are as safe and healthful as those which would prevail if he complied with the standard.

NOTES

2. The contents of the application for a variance are set forth in detail in 29 C.F.R. Section 1905.11(b)(1972).

C. Variances, Tolerances, and Exemptions from the Act

1. Any employer may request a variance, tolerance or exemption from the Act if it is to avoid serious impairment of the national defense.

2. The contents of the application are set forth in detail in 29 C.F.R. Section 1905.12(b)(1972).

D. Hearings and Interim Orders

1. When the employer files an application with the Assistant Secretary for a temporary variance, permanent variance or a variance, tolerance or exemption from the Act, the request will be referred to a hearing examiner who shall preside over the hearing and conduct and control all proceedings.

2. Based upon the evidence presented, the hearing examiner will make his decision, which shall become final 20 days after service thereof, unless exceptions are filed.

3. If exceptions are filed the record and transcript are transmitted to the Assistant Secretary, who shall rule on the exceptions and the rule or order of the hearing examiner.

4. ONLY the decision of the Assistant Secretary may be appealed and reviewed by the Court of Appeals.

IX. SIGNIFICANT DECISIONS

A. Occupational Safety and Review Commission

1. Scope of Review

a. Florida East Coast Properties, Inc. v. Secretary of Labor, OSAHRC Doc. No. 2354 - commission cannot review validity of citation when notice of contest is only as to penalty and such notices do not tell the running of the abatement period.

2. Proof of Violation

NOTES

   a. Portland Stevedoring Company v. Secretary of Labor, OSAHRC Doc. No. 1129 – no job safety violation where no evidence of employer exposure to alleged hazard.

   b. Crescent Wharf and Warehouse Company, OSAHRC Doc. No. 1 – it need not be proved that there is a substantial probability that an accident will occur from the violative condition, proof is required only where there is a substantial probability that the consequences of an accident resulting from the condition will be death or serious physical harm.

3. Penalties

   a. Nacirema Operating Company, Inc. v. Secretary of Labor, OSAHRC Doc. No. 4 – formula for determining penalties.

   b. General Meat Company v. Secretary of Labor, OSAHRC Doc. No. 250 – relatively minor monetary penalties of low gravity do not effectuate purposes of the Act (compliance in obtaining safe and healthful workplaces).

4. Abatement

   a. Forrest Lumber Company v. Secretary of Labor, OSAHRC Doc. No. 2343 – circumstances beyond employer's control prevented abatement within prescribed period ergo no additional penalties for failure to abate.

   b. Kesler and Sons Construction Company v. Secretary of Labor, OSAHRC Doc. No. 306 – Secretary cannot establish abatement date shorter than 15 working day period allowed for employer notice of contest, nor can Secretary issue failure to abate citation within the 15 day period.

NOTES

- c. Orvin Millwork Company v. Secretary of Labor, OSAHRC Doc. No. 1056 – In a hearing on failure to abate citation, subsequent to initial citation having become a final order, an employer may challenge existence of original violation.

5. Isolated Instance Rule

    - a. Standard Glass v. Secretary of Labor, OSAHRC Doc. No. 259 – employer not responsible for isolated and unauthorized actions by employees which violate OSHA requirements.

B. Judicial Decisions

1. Standards

    - a. Industrial Union Department AFL-CIO et al. v. Hodgson No. 72 – 1713 (D.C. Cir. decided, April 15, 1973) – standard of judicial review as to policy decision aspect of standards promulgation is whether the Secretary acted arbitrarity or capriciously; feasibility considerations include economic matters, NIOSH criteria document NOT conclusive in determining ultimately what the standard requires; decision to delay requirements for lower fiber limit exposure reasonable.

2. Application of Standards

    - a. Ryder Truck, Inc. v. Brennan, 497 F. 2d 230 (5th Cir., 1974) – while conceding that the Secretary's personal protective equipment standard is not perfect, the Court held that inherent in the standard is the "reasonable man" test; the standard was held not to be unconstitutionally vague.

    - b. Brennan v. Occupational Safety and Health Review Commission and Gerosa, Inc., 491 F. 2d 1340 (2d Cir., 1973) – In reversing the Commission's vacation of a citation for failure to designate an employee to inspect a crane, the Court held that the Secretary's interpretation was better calculated than the Commission's to achieve the congressional purpose of accident prevention.

NOTES

- c. Brennan v. Southern Contractors Service and Occupational Safety and Health Review Commission, 492 F. 2d 498 (8th Cir., 1974) - in reversing the Commission's decision the Court upheld the Secretary's interpretation of a safety net or other devices standard: ". . . . . the promulgator's interpretation is controlling as it is one of several reasonable interpretations, although it may not appear as reasonable as some other."

3. General Duty Clause (Sec. 5 (a)(1)) Violations

    - a. Brennan v. Occupational Safety and Health and Review Commission and Vy Lactos Laboratories, Inc., 494 F. 2d 460 (8th Cir., 1973) - recognized hazards include those within employer's actual knowledge as well as knowledge of the industry.

    - b. American Smelting and Refining Co. v. Occupational Safety and Health Review Commission, United Steelworker's of America Local 461, and Brennan, No. 73 - 1721 (8th Cir. decided July 15, 1974) - recognized hazards are not restricted to hazards discoverable only by the senses; "Where hazards are recognized but not detectable by the senses, common sense and prudence demand that instrumentation be utilized."

☆U. S. GOVERNMENT PRINTING OFFICE: 1982/560-975