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Recommended Practice

Recommended Environments for Standards Laboratories

ISA-RP52.1 — Recommended Environments for Standards Laboratories

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Preface

(This Preface is included for informational purposes and is not a part of Recommended Practice RP52.1).

This Recommended Practice has been prepared as a part of the service of ISA toward a goal of uniformity in the field of instrumentation. To be of real value this document should not be static, but should be subjected to periodic review. Toward this end the Society welcomes all comments and criticisms, and asks that they be addressed to the Standards and Practices Board Secretary, ISA, 67 Alexander Drive, P.O. Box 12277, Research Triangle Park, North Carolina 27709, e-mail: standards@isa.org.

This standards and practices project began with Task Force No.1 on Environmental Standards as organized by the Measurement Standards Division in 1959. A report was published in the February 1961 issue of the ISA Journal, entitled "Recommended Environments for Standards Laboratories." In 1962 the Measurement Standards Instrumentation Division organized the F-6 Environmental Committee. The Committee's report was published in the October 1964 issue of ISA Transactions, entitled "Recommended Environments for Standards Laboratories."

The present committee, known as the RP 52 Committee on Recommended Environments for Standards Laboratories, was organized by the Metrology Division in 1966. This committee conducted a panel discussion meeting at the 23rd Annual ISA Conference (1968) in New York City. The purpose was to review the 1964 Recommendations and to elicit new information from the audience on experience gained from environmental control of standards laboratories.

From a resume of this panel discussion it was possible for the committee members to formulate a revision of the 1964 Recommendations in light of new information. As an additional step, a re-edited version of the panel discussion was sent to 29 members of the National Conference of Standards Laboratories (NCSL) in order to gain further information. Selection for this survey was made from among the total membership in NCSL on the basis of extended experience with operation of a standards laboratory where environmental control was a factor of concern and interest. From responses of a portion of the 29 members selected, it was possible for the committee to have additional information at hand as an aid in revising the 1964 Recommendations. The result of this somewhat lengthy process of revision is found below.

The ISA Standards and Practices Department is aware of the growing need for attention to the metric system of units in general, and the International System of Units (SI) in particular, in the preparation of instrumentation standards. The Department is further aware of the benefits to USA users of ISA Standards of incorporating suitable references to the SI (and the metric system) in their business and professional dealings with other countries. Towards this end this Department will endeavor to introduce SI and SI-acceptable metric units in all new and revised standards to the greatest extent possible. *The ASTM Metric Practice Guide*, which has been published by the American National Standards Institute as ANSI Z210.1, (ASTM E380-76) will be the reference guide for definitions, symbols, abbreviations and conversion factors.

The ISA Standards Committee on Recommended Environments for Standards Laboratories, RP 52, operates within the ISA Standards and Practices Department, Whitney B. Miller, Vice-President. The persons listed below serve as members of this committee.

NAME	COMPANY
W. F. Snyder, Chairman	National Bureau of Standards
A. C. Bentley	U. S. Army Metrology and Calibration Center, Redstone Arsenal
A. Bruno	Franklin Institute Research Laboratories
C. D. Koop	Autonetics Division, Rockwell International
J. D. Mitchell	Autonetics Division, Rockwell International
T. M. Morrow	Morco Associates
R. B. Smock	U. S. Army Metrology and Calibration Center, Redstone Arsenal

To those who contributed to the panel discussion meeting at the 23rd Annual ISA Conference (1968) in New York City, and to certain members of the National Conference of Standards Laboratories who contributed comments in the revised Recommendations, their assistance in the formulation of this revision is gratefully acknowledged.

In addition to the RP 52 committee members, the following have served as a Board of Review for this Recommendation.

NAME	COMPANY
J. A. Aikens	Naval Air Propulsion Test Center
L. R. Becht	Western Standards Laboratory, Naval Air Rework Facility
J. M. Belanger	Hydro-Quebec
P. Bliss	Pratt and Whitney Aircraft Company
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W. N. Johnston, Jr.	Intelcom Rad Tech.
P. S. Lederer	National Bureau of Standards
R. G. Marvin	Dow Chemical Company
A. P. McCauley, Jr.	Glidden-Durkee Division SCM Corporation
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W. W. Moles	General Electric Company
A. R. Parsons	Honeywell Inc.
W. A. Schmitt	Hughes Helicopters
D. B. Sharp	IBM Corporation
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A. J. Woodington	Convair Aerospace Division, General Dynamics

This Recommended Practice was Approved by the ISA Standards and Practices Board in June, 1975.

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A. T. Upfold	Polysar Ltd.
K. A. Whitman	Allied Chemical Corporation

Contents

1 Purpose

The measured value assigned to a standard or measurement instrument has the essential qualification that the assigned value was valid at the specific time and under the specific conditions of the calibration. No assurance is made regarding the future value or the value under different conditions. If the device is physically stable with time, and if a sufficient history is compiled under environmental conditions that are compatible with the previous calibration, the confidence level of the assigned value increases. If the specific conditions of measurements are not repeated when the device is again calibrated, any variables introduced can create substantial uncertainty. With this fact in mind, it is obvious that there is a need for knowing and maintaining the environmental factors associated with the various types of measurement standards and instruments. Aside from the necessity of securing repeatable measurements, environmental controls help to reduce the number of tedious corrections necessary in making measurements that are affected by adverse environments.

2 Scope

The usual concept that working standards are less accurate than reference standards and that the environmental requirements are less demanding is the basis on which these recommendations are made. The same concept carries over, in general, in differentiating between Type I and Type II laboratories. It should be emphasized that these recommendations are intended to apply to Echelon II laboratories only (see Section 3). Moreover, these recommendations serve primarily as guidelines to the design, construction, and operation of standards laboratories and, thus, serve as recommended practices and are not to be construed as mandatory requirements. In many cases satisfactory repeatability of calibrations can be obtained even though the environment does not comply fully with these recommendations.

3 Definitions

Echelon I: The National Bureau of Standards. This echelon has custody of the national standards and calibrates lower-level standards by comparison with them.

Echelon II: All levels between Echelon I and Echelon III. Typical agencies included in this echelon are the standards laboratories of industrial concerns, universities, the Department of Defense, and commercial calibration laboratories. In some cases Echelon II is divided into two levels. *The standards used in the upper level (Type I) are calibrated by comparison with standards of Echelon I.* In general, the standards in the lower level (Type II) are used to calibrate standards in Echelon III.

Echelon III: The level at which measuring instruments are calibrated prior to use by the user. Typical agencies in this level are the production line test departments and service departments of instrument manufacturers, and the repair and calibration facilities of instrument users. In general, the standards in this echelon will have been calibrated against standards in Echelon II.

4 Recommended practices

4.1 Acoustic noise

Applicable Laboratory: All laboratories.

Requirements:

Types I and II: The maximum level for noise is 45 decibels as measured on a sound level meter using the A or 40-dB weighting network.

4.2 Dust particle count

4.2.1 Applicable Laboratory: Dimensional, Optical, and Micromass.

Requirements:

Type I: Less than 4×10^5 particles larger than 1 µm per cubic metre of room volume. Less than 2×10^6 particles larger than 0.5 µm per cubic metre. No particles larger than 50 µm.

Type II: Less than 7×10^6 particles larger than 1 µm per cubic metre. Less than 4×10^7 particles larger than 0.5 µm per cubic metre. No particles larger than 50 µm.

4.2.2 Applicable Laboratory: All other types.

Requirements:

Type I and Type II: Less than 7×10^6 particles larger than 1 µm per cubic metre. Less than 4×10^7 particles larger than 0.5 µm per cubic metre. No particles larger than 50 µm.

4.3 Electrical and magnetic fields (shielding)

4.3.1 Applicable Laboratory: Pressure-Vacuum, Force, Acceleration, Dimensional, Optical, and Flow.

Requirements:

Types I and II: No special requirements except for electronic measuring instrument which should be shielded locally and guarded by self-shielding or small screened enclosures.

4.3.2 Applicable Laboratory: Temperature, dc, Low-Frequency, High-Frequency, and Microwave.

Requirements:

Types I and II: 100 µV/m, maximum radiation field strength, dc ground bus to ground, less than 2 Ω resistance, ac ground to ground, less than 5 Ω resistance.

4.4 Laboratory air pressure

Applicable Laboratory: All types.

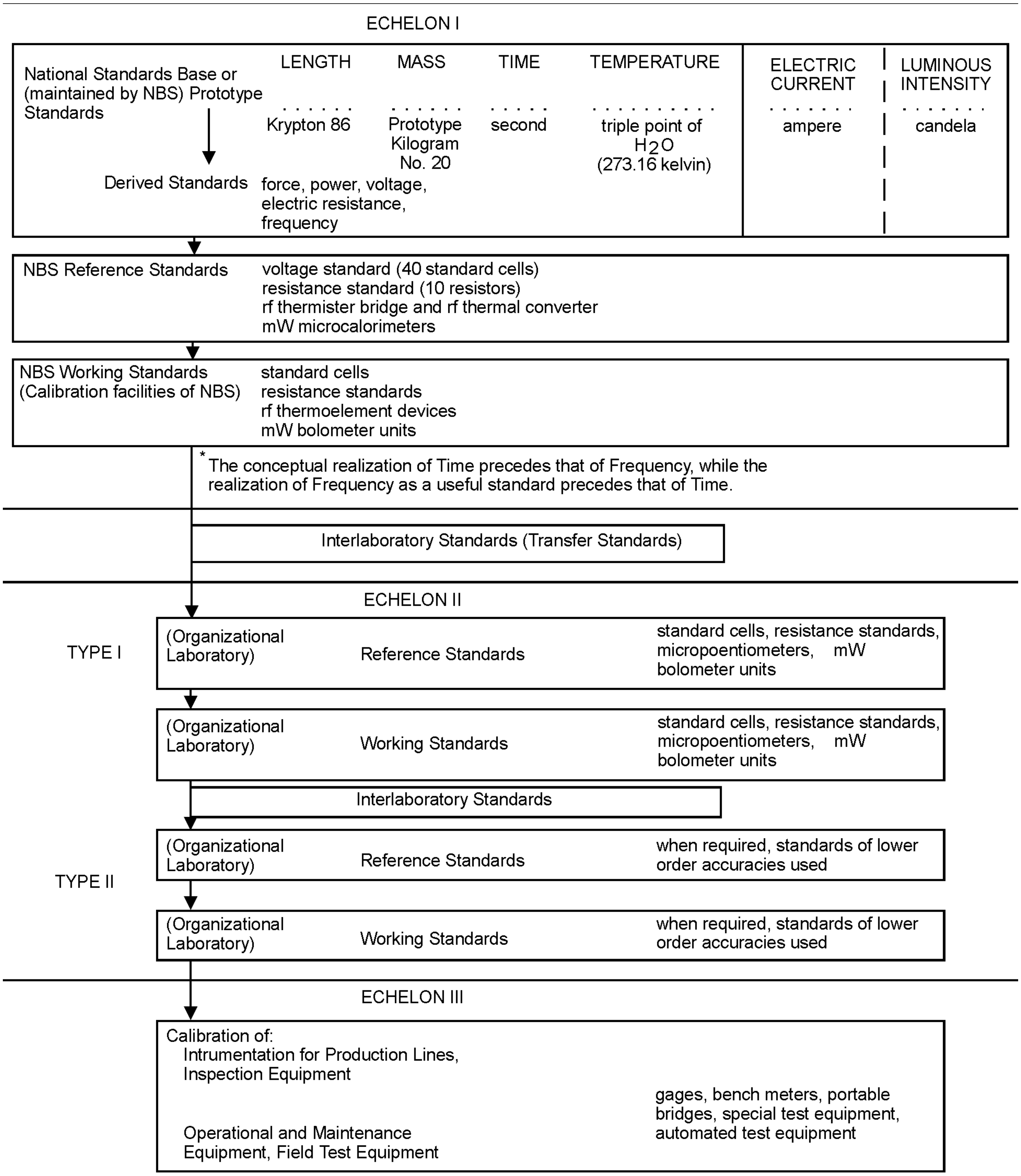
Requirements:

Types I and II: Maintain positive pressure of 10 pascals (newtons per square metre), (0.1 millibar), (0.05 inch of water) in the laboratory.

4.5 Lighting

Applicable Laboratory: All types.

An echelon of standards in a measurement system*



*See Chapter 2 p. 8; also, “An Echelon of Standards,” Chapter 2 pp. 10-13, of *Basic Electronic Instrument Handbook*, Clyde F. Coombs, Jr., Editor, McGraw-Hill Book Co., New York, 1972.

Requirements:

Types I and II: 1000 lux (lumens per square metre), (approx. 100-foot candles) at bench level or reading surface.

4.6 Relative humidity

4.6.1 Applicable Laboratory: Dimensional

Requirements:

Types I and II: 45%, maximum relative humidity, (around a regulated temperature of 20°C.)

4.6.2 Applicable Laboratory: All other than Dimensional

Requirements:

Type I: 35-55% around a regulated temperature of 23°C.

Type II: 20-55% around a regulated temperature of 23°C.

4.7 Temperature

4.7.1 Applicable Laboratory: Dimensional and Optical

Requirements:

Type I: 20 ±0.3°C.

20 ±0.1°C at gaging point

Type II: 20 ±1°C.

20 ±0.3°C at gaging point

4.7.2 Applicable Laboratory: Temperature, Acceleration, dc, Low-Frequency, and Pressure-Vacuum.

Requirements:

Type I: 23 ±1°C.

Type II: 23 ±1.5°C.

4.7.3 Applicable Laboratory: Flow, Force, High-Frequency, and Microwave.

Requirements:

Type I: 23 ±1.5°C.

Type II: 23 ±1.5°C.

4.8 Vibration

4.8.1 Applicable Laboratory: Dimensional, Optical, Pressure-Vacuum, Acceleration, Force, and Mass.

Requirements:

Types I and II: 0.25 micrometer, (250 nm), (10 micro-inches) maximum displacement amplitude from 0.1 Hz to 30 Hz, 0.001g maximum from 30 Hz to 200 Hz.

4.8.2 Applicable Laboratory: Temperature, Flow, dc, Low-Frequency, High-Frequency, and Microwave.

Requirements:

Types I and II: No specific requirements.

4.9 Voltage regulation

4.9.1 Applicable Laboratory: All types employing electronic measuring instruments.

Requirements:

Types I and II: Maximum change from average voltage less than 0.1%, with consideration of holding transients at a minimum. Total rms value of all harmonics should not exceed 5% of the rms value of the fundamental from no load to full load of regulator.

5 Appendix

Comments and reference material

5.1 Acoustic noise

5.1.1 Much has been written on both the objective and subjective observations of acoustic noise and the effect of noise on humans. With increased knowledge, there is concern about exposure to high sound levels that may be injurious to people. Although no harmful effects of a lasting nature occur from distracting noises at the sound levels of common experience, these noises can be psychologically harmful without the subject being aware of the effect. Such considerations must be kept in mind in the design of laboratories.

Because there is little information in the literature on noise level surveys in specialized laboratory areas, the best criteria that can be advanced are the noise levels commonly experienced for private offices. It is reasonable to expect that operations in a standards laboratory should be carried out in an environment that is as conducive to concentration and freedom from distracting noises as one would find in an executive office with quiet surroundings.

There is a considerable amount of information available on office environments in the literature. Because of more refined methods of measurement, there has been a trend in recent years to recommend even lower noise levels. In the earlier years of measurement and evaluation, the noise tolerance usually specified for a private office was that it should be no greater than 45 dB measured on a sound level meter.

The acceptable noise level for private offices is 40 to 45 dB, (1)(8) as measured on a sound level meter using the A, or 40-dB weighting network. Extensive investigations have indicated that the problems of noise measurement and the evaluation of loudness and annoyance are considerably more complex than they appeared to be forty years ago. New methods of measurement techniques have been developed with more complex methods of evaluation. Investigators in this area have been Stevens,(3, 4) Beranek,(2, 5) Kryter,(6) also Zwicker and others. For an evaluation and references to these investigations see Corliss and Winzer,(7) Young,(8) and Ohme.(9) Peterson and Gross(10) have consolidated much of this information into a handbook. In view of the complexity of loudness evaluation, it recommended that noise measurement in laboratory areas be made by the relatively simple sound level meter technique using the A or 40-dB weighting network. The measurement should be made with a meter that meets the ANSI SI.4-1971 American National Standards Specification for Sound Level Meters.

The size of the room, degree of sound absorption, the noise produced by the air conditioning system as well as by the laboratory equipment, and the number of people in the area, will be determining factors for sound levels under working conditions. The sound level can be high, on occasion, due to normal work activity and noise from laboratory and office equipment. Attainment of a low sound level will come mainly from a relatively low noise level of the general environment and, to a considerable degree, can be partially achieved by sound-insulated walls, floors, and ceilings. The use of sound absorption materials on interior surfaces is recommended to obtain more pleasant surroundings by reducing reverberation effects and the harsh effects of highly reflecting surfaces. It is very important to select a material that does not shed particles for use as a sound absorber in the laboratory area.

5.1.2 Reference material

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4) Stevens, S. S., "Calculating Loudness," *Noise Control*, Vol. 3, No. 5, pp. 11-22, September 1957.

5) Beranek, Leo L., "Revised Criteria for Noise in Buildings," *Noise Control*, Vol. 3, No. 1, pp. 19-27, January 1957.

6) Kryter, Karl D., *The Effects of Noise on Man,* Academic Press, New York, 1970.

7) Corliss, Edith L. R. and George E. Winzer, "Study of Methods for Estimating Loudness,"*J. Acoust. Soc. Am.* Vol. 38, No. 3, pp. 424-428, September 1965.

8) Young, Robert W., "Single-Number Criteria for Room Noise," *J. Acoust. Soc. Am.* Vol. 36, No. 2, pp. 289-295, February 1967.

9) Ohme, Wolfgang E., "Loudness Evaluation," *Hewlett-Packard J.* Vol. 19, No. 3, pp. 2-11, November 1967.

10) Peterson, A. P. G. and E. E. Gross, *Handbook of Noise Measurement*, General Radio Company, West Concord, Mass. 7th Edition, 1972.

11) See Chapter 12, "Sound and Vibration," ASHRAE Guide and Data Book - Systems, American Society of Heating, Refrigeration and Air Conditioning Engineers, New York, 1970.

5.2 Dust particle count

5.2.1 A judgement of how much dust can be tolerated is not easy to determine on a quantitative basis. Recommendations are based mainly on good housekeeping considerations. This is the best single practice to avoid the adverse effects caused by dusty environments. In low-frequency measurements, dust accumulation on insulating or conducting surfaces can influence measurements. Many standard laboratory instruments utilize exposed contact construction making repeated cleaning necessary in a dust-laden area. The dust contamination of oil baths required in standards laboratory measurements must be considered. Dust can promote rust and corrosion and contaminate standard samples and measurements involving fluids in flow measurements. In open-air systems utilizing mercury reservoirs or columns, dust can increase errors in pressure-vacuum measurements. The use of mechanical and/or electrostatic traps and filters can help regulate dust. Dust control is also important in laboratories where dead-weight testers are used. The accuracy of a dead-weight gage can be reduced due to airborne particles, such as skin flakes, clothing fibers, and hair.

Filters for incoming air can be constructed of oil-coated glass fibers or fine metallic ribbon that can be cleaned and re-oiled(1) or disposed of periodically. High Efficiency Particulate Air (HEPA) filter units are used to clean rooms and for other applications where a high degree of filter efficiency is required or desirable.(2) In low-humidity areas, washing the incoming air to add moisture will tend to reduce the dust content. Pressurization of the laboratory environment will reduce the entry of dust-laden air (see Laboratory Air Pressure section).

5.2.2 Numerous methods of dust monitoring or dust counting, are described in the literature, some relatively simple, others relatively complex and with automatic readout. One of the least expensive is the dry-slide technique.[3] In this method, a projection microscope enlarges the contents of a glass slide which has been exposed to the air in a particular area of the laboratory for a definite period of time. The operator counts the number of particles in random sample fields of a gridded screen and measures their size on the projection microscope graticule. A slightly more complex and expensive procedure for particle size 5 μm and larger involves microscope counting of particles collected on a membrane filter through which a known volume of air has been drawn. The procedure is required in Federal Standard No. 209[4] and detailed operating techniques for sampling in clean rooms and other areas are available in ASTM-F-25[5] and SAE-ARP-743[6]. A Department of Army Technical Bulletin[7] specifies a modified program similar to that specified in references (5) and (6) which is considered suitable for use in calibration laboratories equivalent to Echelon II, Type II. This program gives some measure of assurance that housekeeping, filter maintenance, etc., is adequate without the costly and time consuming daily routine of clean-room monitoring.

The design criteria of a Class II clean room as outlined in Air Force T.O. 00-25-203 and the operating criteria of a Class II clean room as outlined in Air Force T.O. 33-1-14 specify dust counts. The latter, published in December 1962, states that a maximum of 85×10^3 particles between 0.3 and 10 μm and a maximum of 15×10^3 particles larger than 10 μm per cubic foot will be tolerated. The new superseding D.O.D. statement, MIL-C-45622A, paragraph 3.2.2. says that measuring and test equipment and measurement standards shall be calibrated and used in an environment controlled to the extent necessary to assure continued measurements of required accuracy giving due consideration to temperature, humidity, vibration, cleanliness, and other controllable factors affecting precise measurement.

5.2.3 Comments on air freshness

There do not seem to be any specific or well-recognized recommendations on the subject of air freshness. The matter lies in the realm of psychological effects, and therefore tends to preclude any universal agreement. There is some material on this subject in the chapter on "Physiological Principles" in the ASHRAE Handbook of Fundamentals published by the American Society of Heating, Refrigeration, and Airconditioning Engineers. Certain phases of the problem are also discussed in the chapter on "Air Contaminants and Odors." It should be understood that specifications for air circulation tend toward minimum rather than adequate requirements. One study shows a range of 10 to 30 cfm per person as a minimum requirement. Factors, such as: volume of the room, number of people in the room, and the amount of traffic, influence the requirements for fresh air.

In an unpublished report of the National Bureau of Standards it is stated, "At Boulder, where there is a wide range of temperature, both annual and diurnal, provision is made to economize the operation. Within the range of 65° to 75°F, there is a full intake of fresh air circulated throughout the building. The fresh air intake gradually is decreased to 20% as the outside air falls to 5°F, below which the air intake remains constant at 20%. As the outside air increases to 80°F, the air intake is decreased rapidly to 20% and remains there for any higher temperatures." In terms of complete building air changes, the 20% intake is equivalent to approximately 1.5 air changes per hour. At 100% intake, there are approximately 7.5 changes per hour.

Certain measurement areas at the Boulder Laboratories have an ample supply of fresh air, especially during periods within a certain temperature range of fairly dry outside air. This achievement is a by-product of increasing the efficiency of the air conditioning system.

5.2.4 Reference material

1) Snyder, W. F., "Environmental Control of Electric Calibration Laboratories," 15th Annual Meeting of the American Ordnance Association, Standards and Metrology Division; Redstone Arsenal, Alabama, January 1960.

2) High Efficiency Particulate Filter Units, Inspection, Storage, Handling, Installation; U.S. Atomic Energy Commission, Division of Technical Information, Bulletin No. TID-7013.

3) Marsh, R. C., W. J. Whitefield, and I. M. Kodel, "Dry Slide Technique," *Air Engineering,* Vol. 4, No. 4, pp. 44-53, April 1962.

4) *Clean Room and Work Station Requirements, Controlled Environment*, Federal Standard 209, (revision a, August 10, 1966; revision b, April 24, 1973).

5) Sizing and Counting Airborne Particulate Contamination in Clean Rooms and Other Dust-Controlled Areas Designed for Electronic and Similar Applications, ASTM-F-25.

6) Procedure for Determination of Particulate Contamination of Air in Dust Controlled Spaces by the Particle Count Method, SAE-ARP-743.

7) TB 750-117, Department of the Army Technical Bulletin, "Procedure for Establishment and Control of Army Calibration Laboratory Environment (Secondary Reference Level)", 17 July 1970, including Change 1, 24 November 1970.

8) Avery, R. H., "The Meaning of Clean Rooms," *Air Engineering*, Vol. 1, No. 2-3, pp. 29-32, May 1959, and pp. 28-31, 51, June 1959.

9) *ASHRAE Handbook of Fundamentals*, American Society of Heating, Refrigerating, and Air-conditioning Engineers, New York, 1966.

5.3 Electrical and magnetic fields (shielding)

5.3.1 Laboratories: pressure-vacuum, force, acceleration, dimensional, optical, and flow

Shielding to eliminate stray radio frequency energy is important when working with vacuum gages which include thermocouples and electronic amplifiers. Errors as high as 30% can result from improper shielding of a thermocouple gage. Adequate shielding may be achieved by enclosing the instrument in a metallic case with metallic sheathing on line cords and probes. Normal shielding precautions should also be observed between an accelerometer and a cathode follower or similar coupling circuit and throughout the shaker and electronic readout equipment. To shield an entire laboratory is an expensive undertaking for the utilization afforded here.

5.3.2 Laboratories: temperature, dc, low-frequency, high-frequency, microwave

In laboratory environments where electronic measurement equipment is used that is susceptible to interference from radiated electromagnetic energy, sufficient shielding and filtering should be used for the laboratory area to reduce the average field strength within the immediate area of the instrumentation to less than 100 μV/m. For conducted electromagnetic energy, the measured open-circuit voltage should be no greater than 100 μV.

This simplified expression of the maximum tolerable radio frequency interference (RFI) is not dependent on frequency, nor is the importance of bandwidth in the measurement of broadband interference considered. The simplification assumes that the frequency sensitivity of the laboratory electronic equipment for wanted information must be of the same, or greater, order of magnitude as that for unwanted interference, and that deleterious effects of broad-band interference are no different than those of continuous-wave interference. A combination of cable shielding, instrument shielding, and room shielding may be required in order to minimize spurious signals. It is good planning to include such details prior to the construction of a laboratory.

Electrical shielding with metals of good conductivity will usually suffice. Unless the requirement is for measurement on sensitive receivers and similar equipment, it is not necessary to shield a room to a 100 dB attenuation if cables and instruments are well shielded themselves. Single sheets of metallic foil will give 60 dB attenuation if properly installed.

Proper grounding is important, but it must be remembered that grounding is a relative matter. All objects are in electrical relation to a given ground reference; the lowest possible impedance to the reference should be achieved for all frequencies concerned. The possibility of circulating currents and coupling of grounding circuits must be minimized. Problems have occurred in the grounding of vans when used in a dry, sandy desert. The White Sands Missile Range has experienced this problem.

Since a convenient water table does not always exist, the solution is quite involved and sometimes uncertain. The former NBS Central Radio Propagation Laboratory encountered a similar problem when placing transmitters on rocky mountain peaks. Even with a good water table it is best to have a grid of conductors or a large metallic sheet buried in the ground, rather than to have a few rods driven into the soil. High-gain, low-level ac and dc amplifiers and null detectors require an interference-free environment for reliable operation. Where ferromagnetic weights are used in the vicinity of magnetic fields, shielding precautions should be taken, although magnetic shielding is rarely necessary in comparison with attenuation of electrical fields.

Corollary requirements to any effective degree of shielding are those of filtering of electrical circuits leading into an enclosure, proper sealing around pipes and conduits at their entrance into the enclosure, effective shielding of doors, shielding of air intakes and exhaust ducts, and the shielding of fluorescent fixtures. All of these sources of electrical noise and of leakage, in combination, must be lower in level than the background level obtained by attenuation in the enclosure shielding. Otherwise there is a loss of effectiveness in the overall shielding.

There are few references in the literature that state ambient background levels for shielded enclosures in units of radiated field strength. Shielded enclosure characteristics are usually expressed by their ability to attenuate a signal from either inside or outside the enclosure. This factor is often called the "shielding effectiveness" and carries the unit of decibels. Military specifications sometimes give maximum radiation limits for an electronic device in terms of radiated field strength. Typical examples are MIL-I-16910A, MIL-I-10379A, and MIL-I-11748B. None of these specifications discusses shielded enclosures. The only known reference which pertains directly to shielded enclosures and gives values in terms other than decibels is a Russian interference specification, "Norms for Maximum Admissible Industrial Interference," by A. Zharow.[(5)] In the section pertaining to shielded enclosures the author writes, "The radio interference field level in it (screen room) due to sources outside it (shall) not exceed 2 µV." This specification covers a frequency range of 0.15 to 400 MHz.

In 1964 the effect of electromagnetic fields upon electrical measurements was studied.[(16)] This study, made at fixed frequencies from 10 Hz to 1 GHz, showed that none of the instruments tested was susceptible to field strengths of up to 1000 µV/m.

A difficulty is often encountered in the measurement of very low intensity radiated fields. Commercial field strength receivers will not accurately measure fields of the order of 1 µV. Most electromagnetic fields within a shielded enclosure will not be of sufficient magnitude that a commercial field strength meter can measure them. The chief limiting factor is the internal noise of the receiver.

5.3.3 Reference material

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2) Miedzinski, J., "Electromagnetic Screening, Theory, and Practice," *Technical Report MT 135*, British Electrical and Allied Research Association, 1959.

3) Benedict, D. L., "Elimination of Radio Interference by Shielding and the Design of Shielded Rooms," *Final Report Project 336*, U.S. Navy Bureau of Yards and Docks, Contract No. NOy22272, Stanford Research Institute, August 1962.

4) Lintov, S. A. and G. P. Gusev, "Screened Measuring Compartments," *Measurement Techniques*, No. 5, pp. 577-581, September-October 1958.

5) Zharow, A., "Norms for Maximum Admissible Industrial Interference," available from the Armed Services Technical Information Agency (ASTIA), Document No. AD-286596.

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11) Sachs, H., H. G. Tobin, and W. Benjamin, "Evaluation of Conductive Glass in Fluorescent Light Shielding Applications." *Proceedings of the Sixth Conference on Radio Interference Reduction and Electronic Compatibility*, Chicago, October 1960, p. 281.

12) Kall, A. R., and F. Kugler, "The Shielded Test Cells of the Titan ICBM Test Facility," *Proceedings of the Sixth Conference on Radio Interference Reduction and Electronic Compatibility*, Chicago, October 1960, p. 295.

13) *Handbook on Radio Frequency Interference* (four volumes), Frederick Research Corporation, Wheaton, Maryland, 1962.

14) "Bibliography on Radio Frequency Interference," *IRE Transactions on Radio Frequency Interference*, February 1962, Vol. RFI-4, No. 1.

15) Borden, C. C., "Shielded Rooms for Electronic Equipment", *Architectural Forum*, Vol. 130, No. 3, pp. 195-196, September1961.

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5.4 Laboratory air pressure

5.4.1 To eliminate the infiltration of dust-laden outside air through doors or air locks to the laboratory, it is advantageous to maintain a positive pressure differential between the laboratory and adjoining or outside areas. As little as 10 pascals (newtons per square metre), (0.1 millibar), (0.05 inch of water) pressure differential will normally afford a sufficient outward velocity of air from the laboratory when a door is opened. When a laboratory complex consists of several adjoining rooms, or rooms within a room, it is not uncommon to adjust air flows by staging pressure differentials so that rooms where cleanliness is most critical will have higher pressures than adjoining laboratory spaces. When this is done it may not be practical to maintain the recommended differential between each laboratory room. The exact level of differential pressure required depends on the air movement outside the laboratory. Barostats are frequently used to help maintain the differential as doors are opened and closed. Periodic checks should be made to assure that an adequate differential pressure is maintained. An inexpensive inclined tube manometer can be permanently installed to give a continuous indication of the differential pressure. Observations with an air-velocity meter in an open door could serve as a means of establishing direction and magnitude of airflow (and pressure difference). Special precautions and precise ambient pressure measurements may need to be taken in laboratories where precision pressure and vacuum measurements are being made.

Exception to the above practice is the case of a laboratory area where calibrations are performed on nuclear standards. A negative pressure should be maintained to avoid dispersion of radioactive dust and gases.

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5.5 Lighting

5.5.1 The "general" specification of 1000 lux (lumens per square metre), (approx. 100-foot candles), at bench level or reading surface is considered to be a sound representation for all types of metrology laboratory functions. Probably the most significant consideration that must be taken into account is the *other laboratory and/or equipment conditions and configurations that can cause degradation in over-all measurement performance*.

Consideration must be given to the effect on the values of the equipment and standards under different lighting conditions. Changes may occur in the measured values of passive standards which can be directly related to changing levels of radiation from incandescent lights and the color of the instruments.

The effect of radiation on the control point of the laboratory thermostat is an important consideration for the same reasons indicated above. It was observed that turning the laboratory lights out at night in a laboratory using a silver-colored thermostat caused the temperature level of the laboratory to change by as much as 2.2°C.

There is also the effect of a sudden change in heat load which causes a transient change in temperature as the air conditioning system adjusts to the gain or loss in a load. Fluorescent lamp ballasts deliver nearly as much heat load to a system as incandescent lamps.

In specifying the lighting value at bench level, the effect of increased utilization of the individual or "high rise" console type of equipment should possibly be considered from the view point of reflective surfaces, console portability (on wheels) and the use on different locations within the laboratory or in different laboratories.

Another aspect that should be considered is variable intensity lighting. In some laboratories a number of different measurements may have to be performed under one light source. It would be advantageous if this light source intensity could be varied. For example, the lighting requirement to read a meter might be 125 footcandles while at another time on the same bench an oscilloscope would require only 30 foot-candles of illumination.

The single most important consideration when planning a lighting specification is *not a static number* (XXX foot candle at bench level) that is normally quoted. The laboratory function layout, types of equipment to be used, etc., become important. The user of a recommended practice must develop an awareness of all the other vitally essential characteristics pertinent to a "general" specification to effectively achieve the intended results.

Laboratory Design,(2) published in 1951, recommended an illumination of 323 lux 30 foot-candles (f-c) as being satisfactory for general laboratory work, and the same value is given to private offices. In 1956, the laboratories of the Electronic Calibration Center at NBS Boulder were designed with an illumination of 807 lux (75 f-c), using fluorescent lighting. Measurements indicated that the average value is between 807 and 861 lux (75 and 80 f-c) at a height of 940 mm (37 inches) above the floor level and is reasonably uniform over all benches and desks. Experience shows that this illumination suffices for most laboratory purposes. In localized areas where it is sometimes necessary to obtain greater illumination of instrument and vernier scales, auxiliary lighting from a nearby source is often employed. In the case of optical laboratories, the optimum of using a lower illumination level is advantageous.

The Third Edition of the *IES Lighting Handbook*,[3] published in 1966, gives recent information on levels of illumination that are recommended for many kinds of lighting. Of the hundreds of lighting situations listed, none relates specifically to that of a measurement laboratory. However, several are similar to the conditions of a physical measurements laboratory, and the values given can serve as a guide. These are as follows:

Hospitals, laboratories, close work	1076 lux (100 f-c)
Offices, ordinary desk work	1076 lux (100 f-c)
Testing, general	538 lux (50 f-c)
Testing, extra-fine instruments, scales, etc.	2152 lux (200 f-c)
Machine shops, medium bench and machine work	1076 lux (100 f-c)
Machine shops, fine bench and machine work	2152 lux (200 f-c)

The values of illumination were obtained with a combination of general lighting plus specialized supplementary lighting. Care should be taken to maintain the recommended brightness ratios as indicated below. These visual tasks generally involve the discrimination of fine detail for long periods of time under conditions of poor contrast. The design and installation of the combination system must provide not only a sufficient amount of light, but also the proper direction of light, diffusion, and eye protection. As far as possible, the design should eliminate direct and reflected glare as well as objectionable shadows.[4] To achieve a comfortable brightness balance in an office, it is desirable and practical to limit brightness ratios between areas of appreciable size as follows[4]:

3 to 1	between task and adjacent surroundings
10 to 1	between task and more remote darker surfaces
1 to 10	between task and more remote lighter surfaces
20 to 1	between light sources or windows and surfaces adjacent to them
40 to 1	anywhere within the normal field of view.

These ratios are recommended as maxima; reductions are generally beneficial.

In addition to the value of quantity of illumination, other factors that should be considered include the proper balance of brightness, control of direct and reflected glare, the reflectance of room surfaces, the proper balance of brightness ratios, and auxiliary lighting to do special jobs (such as reading verniers or fine scales).

An overall illumination of 1076 lux (100 f-c) plus supplementary lighting is in order for laboratory operations. This marked increase in recent years is possible because of the availability of efficient light sources. Due to much greater efficiency, fluorescent lighting has permitted much greater illumination without an attendant increase in heat load upon air conditioning equipment. Of course, fluorescent lighting increases the problems of interference, but this interference can be minimized by proper shielding.

Shielded illumination can be achieved by use of fluorescent lamps in a fixture that utilizes a glass diffuser with transmission cutoff characteristics in the near infrared region. This will eliminate the slight temperature rise at bench tops due to the absorption of reflection of infrared rays.

Air Force T.O. 33-1-14 states that ceiling and sidewalls to a distance of 0.9 m (3 feet) from the ceiling shall have a minimum reflection factor of 80%. The sidewalls below 0.9 m from the ceiling shall have a reflection factor of approximately 60%. It is also recommended that table tops be constructed of non-reflecting material.

5.5.2 Reference material

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7) Blackwell, H. R., "Further Validation Studies of Visual Task Evaluation," *Illuminating Engineering* Vol. 64, No. 9, pp. 627-641, September, 1969.

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5.6 Relative humidity

5.6.1 All laboratories

The narrow tolerances for relative humidity (RH) of the 1964 ISA Recommendations have been dropped. The effects of relative humidity at specific percentage values on standards and precision measurement equipment can be studied under locally controlled conditions or in laboratory areas that are designed for control of relative humidity and temperatures within narrow operating limits. The limits given below will minimize corrosion of dimensional standards static electricity, hygroscopic effects, and allow for optimum permissible comfort of laboratory personnel. Relative humidity requirements for laboratories that engage in measurements for materials such as paper, cloth, and other highly hygroscopic matter are considered beyond the scope of this recommended practice.

5.6.2 Dimensional laboratories

Forty-five per cent, maximum, is recommended for dimensional laboratories mainly to prevent corrosion.[1,2,3] A one-degree change in temperature can cause 3.5% change in RH near 20°C and 45% RH.[4,5] Forty-five per cent is recommended, also, because of a particular problem that has been observed in humidity control systems. This problem is the failure of the reheat cycle of the system which can cause the system to generate a humidity approaching 90%. The value 45% gives time to shut off the spray pump portion of the system and generally keeps the humidity well below the critical oxidizing humidity of 60%.

It is a recognized fact that steel will corrode at a fairly low humidity, if it is subjected to: perspiration from fingertips, corrosive vapors, certain atmospheric gases, or contaminated dust. If the boundary surfaces of a room are not near temperature equilibrium with the bulk of the room air, moisture may condense on cool surfaces even at low relative humidities. The answer to such a rust problem is adequate insulation to bring all surfaces into temperature equilibrium. This also accomplishes the desired feature of controlling radiation from objects within the room when the surface boundaries are warmer than the bulk of the room air.

Factual data on corrosion have come as a consequence of the quest for information on humidity. Corrosion of iron and steel has been a primary interest because ferrous materials are common and give rise to the more common corrosive problems. Corrosion of nonferrous metals, although almost universal, is usually unnoticed and is primarily protective in nature. When noticeable or destructive, it occurs under rather severe conditions, such as the presence of corrosive vapors or solutions.

Some early investigations provided the following information. To quote from Vernon,(1) "A fundamental change in the rate of rusting takes place at a critical humidity in the neighborhood of 65% saturation; this change is linked to the hygroscopicity of the rust." According to Vernon,(1,2,3) two types of corrosion films form on iron, a "primary" and a "secondary" film. The primary film, which is invisible and protective in nature like that on many non-ferrous metals, forms at low relative humidities and builds up slowly; then its growth tapers off with time. However, near the critical humidity of 65%, this protective film breaks down in the presence of gaseous and dust contaminants causing a very rapid growth of secondary film which is the observed rusting of iron. This is explained by a surface phenomenon in finely divided particles which act hygroscopically, i.e., taking up water from the air. If the critical humidity is reached, oxidation is greatly accelerated by contaminants, the protective or primary film breaks down, and rusting becomes quite visible. If there are no contaminants, either gaseous or in dust form, the primary film protects the iron almost indefinitely.

Even at 45% RH, it is necessary that iron parts be cleaned and coated by protective oil and grease.(6)

5.6.3 Laboratories other than dimensional

Since laboratories other than dimensional types are not all presented with the extensive corrosion problem, the greater and higher ranges (35 to 55% RH for Type I, and 20 to 55% for Type II are recommended to meet climatic, budgetary, and personnel requirements(7,8,9) of laboratories throughout the United States and, also, in the foreign operations of the Department of Defense. Localized changes in RH or compensation may be required in measurement areas when operating near the extremes of the ranges.

Laboratories which use iron and steel components (optical benches, proving rings, force machines, etc.) must be extra careful in applying corrosion prevention techniques.

Almer(10) has reported that hygroscopic materials in balances will cause changes in balance point with changes in RH. Changes vary extensively for each balance. Effect must be determined for the particular model. Changes in RH of less than 5% cause no appreciable change in most units.

Rosa(11) found that standard resistors increased in value during "wet" seasons of the year. He discovered that moisture caused shellac on wire to expand, stretching the manganin and thus causing increase in resistance. Dipping coils in paraffin permitted no change. Submerging in oil did not protect shellac because oil absorbed water and transmitted same to the coil. Redesign along the lines of the Thomas Ohm and development of new insulating materials and techniques have corrected this deficiency.(12,13) Newly designed standards using resistance coil elements should be checked against the effect of relative humidity.

For laboratories above 305 m (1000 feet) of elevation, the National Weather Service psychrometric tables should be consulted for possible effect of altitude on relative humidity.[14,15]

The American Society of Heating, Refrigeration, and Airconditioning Engineers has converted the psychrometric chart to the metric system. [16]

5.6.4 Reference material

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5.7 Temperature

5.7.1 All laboratories

From information gathered from a representative cross-section of standards laboratories personnel, the consensus is that performance requirements for low values of rate of change of temperature are not important and sometimes meaningless if the room temperature or the temperature at the measurement point remains within the rather narrow limits usually specified for standards laboratories. In consideration of this general viewpoint, the recommendation for rate of change of temperature has been deleted in this revision of the 1964 Recommendations.

The matter of the comfortable range of temperature for operation of a facility such as a standards laboratory is covered in the *ASHRAE Handbook of Fundamentals*.[12] Various factors are involved in addition to temperatures, such as relative humidity, movement of air, and degree of physical activity.

5.7.2 Dimensional and optical laboratories

A property which must be recognized when considering the accurate length of gages is the thermal expansion of the material.[1] A 25.4 mm (1 in.) steel gage increases in length about 0.003302 mm (0.000013 in.) for every Celsius degree rise in temperature. The temperature at which the actual length of the gage equals the nominal length must be specified; it is usually taken as 20°C or 68° F. At 25° C the length of a gage which is 1 in. at 20°C is about 25.401651 mm (1.000065 in.). If a gage is measured at the higher temperature, its length at the lower may be computed if the expansion coefficient is known.

If high precision is desired, it is not good policy to use expansion coefficients given in tables because measurements show that the expansion coefficients of steel may vary from 0.0000105 to 0.0000135 depending on the hardness and composition. This variation can cause the measurement of an unknown steel gage that agrees exactly with a standard at 25° C to differ from it by as much as 0.000508 mm (0.00002 in.) at 20° C. If the unknown piece that is being measured is brass, or some other material having an expansion coefficient that differs considerably from that of the standard, the effect of temperature change is still greater. From these considerations, it is evident that to measure or use gages with an accuracy in millionths of an inch, the coefficient of expansion of the materials must be known accurately and the temperature controlled and measured to at least 0.3° C.

5.7.3 Laboratories: temperature, acceleration, dc, low-frequency, and pressure-vacuum

Although some critical components can be placed within a constant temperature enclosure during measurement, close control of the laboratory temperature will enhance a bath control and will allow other measurements to be performed without temperature corrections. Some type of monitoring system capable of discerning differences as indicated by the recommendation should be provided at the measurement area. An important consideration for a Type I laboratory should be the temperature at which the transfer standards belonging to the laboratory are calibrated by NBS. The Type II laboratory performs measurements of a less critical nature and does not require as close control. One readily available reference that may be used in conjunction with this recommendation is an ASTM standard.[8]

The temperature requirement in acceleration calibrations depends, to a great extent, on the type, manufacturer, and model of accelerometer to be calibrated. Reference (9) gives extensive information on testing and calibration of accelerometers.

Accurate observations with mercury column instruments require accurate knowledge of the temperature at the measuring instrument because of the relatively large thermal expansion of mercury. A one-degree change in temperature at 25°C changes the density of mercury in a manometer column by 0.02%.

Thermal time lag in the instrument or system being measured and in the temperature-control system can lead to measurement problems. The method described in Reference (14) gives a procedure by which this measurement problem has been successfully met.

5.7.4 Laboratories: flow, force, high-frequency, and microwave

Proving rings are calibrated at 23°C; use at any other temperature requires corrections. From a cost accuracy standpoint, it does not seem feasible to recommend any other laboratory temperature.

5.7.5 Reference material

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5.8 Vibration

5.8.1 Laboratories: dimensional, optical, pressure-vacuum, acceleration, force, and mass

Vibration has been a factor to consider in all physical measurements. Balances used in mass laboratories are affected by vibrations. Users associated with the functions of micromass measurements, with the calibration of precision optical members,wedges, polygons, etc., and the calibration of precision manometers must be cognizant of specific problem areas and will probably find the "general" specification inadequate for their needs.

Measurements that have to be interpreted by the human eye or by photographic means also are affected by vibration. Since 12-16 Hz is the critical flicker frequency of the human eye, vibrations having frequencies below 12 Hz can be followed by the eye. Displacements having frequencies above 12 Hz cause blurring of interferometer fringe patterns. Since one fringe represents 10.7 microinches, displacement of 6 microinches could result in complete washout of the fringe pattern. A displacement 6 microinches at 12 Hz represents a vibration level of 4.4×10^{-4} g.

For a continuous vibration disturbance in Type 1 laboratories, Ferahian and Ward(5) recommend a maximum acceleration of 0.001g for frequencies above 100 Hz (see reference for details on choice of frequency), and a maximum displacement of one microinch for frequencies below 100 Hz, measurements being made at a base of the indicating instrument. For intermittent vibrations, such as from footsteps, they recommend a maximum acceleration of 0.01g.

It is felt that more emphasis should be placed both on relating vibration levels to the displacement and on g level. The sensitivity of instruments to vibration is enhanced in some cases by the direction of the disturbance, e.g., vertical movements for a precision balance should be less of a problem than horizontal motion while a planointerferometer is more sensitive to vertical motion.

The "general" specification providing a dual recommendation takes into consideration the most significant parameter for the frequency involved.

Most indicators are not designed to withstand continuous vibrations and should be protected by suitable cushioning of the mounting or by attaching the gage to a rigid support.

In reading mercury barometers, cathetometers are employed which should be equipped with levels and mounted on a cork, or sand-concrete platform, or other resilient mounting, to obtain high mechanical stability. To reduce vibration effects in reading instruments, the following precautions should be taken:

1) Locate the laboratory away from sources of vibration.

2) Whenever possible, use only equipment that is self-damped.

3) Use local methods to detune the resonant frequencies of instruments:

   a) by pneumatic suspensions.

   b) by seismographic mountings.

5.8.2 Laboratories: temperature, flow, dc, low-frequency, and microwave

Where there is much noise and vibration associated with certain tests, such as a large flow stand, isolation should be provided for the convenience of neighboring facilities. This precaution is for the benefit of both the user and other laboratory areas adjacent to the test area.

Vibration tolerance requirements differ so greatly that a single value, expressed in units of acceleration due to gravity, may not suffice. Moreover, some equipment will respond rather violently to vibration at its natural frequency which sometimes comes within the frequency range of a disturbing force or the brief effect of an impulse. In the case of an impulse, or shock disturbance, there are the complicating factors of amplitude, duration of pulse, and the waveshape.

In recent years, there has been a trend toward the use of electronic and oil-damped equipment of a type that is relatively immune to moderate vibration to replace galvanometers and other types of instruments that are sensitive to vibration and shock. In consequence, some of the problems with vibration have been partially corrected by technical advances in instrumentation.

It has been stated that in the use of pointer-type instruments, any environment producing a deviation equivalent to one-tenth of a scale division has exceeded the threshold of error determination.[6]

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5.9 Voltage regulation

5.9.1 The importance of voltage regulation (or, more properly, voltage stabilization - defined as stability of supply voltage with approximately constant load condition) should not be underestimated in performing precision measurements in standards laboratories. Much valuable time can be lost in the repeating of measurements that are not satisfactory because of a varying voltage in the power supply. Also, measurements may be made without the observer being aware that his measurements may be erroneous if the power supply voltage is beyond certain operating limits.

Today, many laboratory-type measurement instruments have built-in voltage regulators and their operation is relatively independent of power supply voltage within limits of ±10% of the design voltage. In contrast, former equipment required the use of a motor-generator type of voltage regulator or magnetic resonant transformer regulator, or a variety of other types of voltage regulators. Many of these have been replaced by the silicon controlled rectifier type (SCR) of voltage regulators. Only where a very high degree of voltage stabilization is required (better than 0.01%) or when the regulator is required to recover from transients within 50 to 100 microseconds, is it necessary to use specially designed electronic regulators in place of SCR regulators. With these electronic regulators it is possible to reduce the recovery period from transients to about 50 microseconds, and hold the magnitude of the transient at the output to approximately 0.05 that of the input voltage.

Operating characteristics(4) of high quality SCR voltage regulators will give the following performance, based upon unpublished measurements by the National Bureau of Standards:

1) Voltage stabilization approximately ±0.02% for 10% change in line voltage.

2) Voltage stabilization approximately ±0.002% for 2% change in line voltage.

3) Approximately 0.01% change in output voltage for change of load ranging from zero to full load.

4) Total harmonic output of output voltage from 2 to 3%.

5) Efficiency of 85 to 90% at full load, but decreasing at smaller loads.

6) Recovery time of the order of 0.1 second time from transients (1/ ϵ decay magnitude).

7) Magnitude of transients at output approximately same as at input.

5.9.2 Reference material

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Developing and promulgating technically sound consensus standards, recommended practices, and technical reports is one of ISA's primary goals. To achieve this goal the Standards and Practices Department relies on the technical expertise and efforts of volunteer committee members, chairmen, and reviewers.

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