MATERIALS STANDARDS AND SPECIFICATIONS

1. Introduction

A standard is a document, definition, or reference artifact intended for general use by as large a body as possible; a specification, which involves similar technical content and similar format, usually is limited in both its intended applicability and its users.

Standards have been a part of technology since building began, both at a scale that exceeded the capabilities of an individual, and for a market other than the immediate family. Standardization minimizes disadvantageous diversity, assures acceptability of products, and facilitates technical communication. There are many attributes of materials that are subject to standardization, eg, composition, physical properties, dimensions, finish, and processing. Implicit to the realization of standards is the availability of test methods and appropriate calibration techniques. Apart from physical or artifactual standards, written or paper standards also must be considered, ie, their generation, promulgation, and interrelationships.

The International Organization for Standardization (ISO) defines a *standard* as the result of the standardization process: "the process of formulating and applying rules for an orderly approach to a specific activity for the benefit and with the cooperation of all concerned and in particular for the promotion of optimum overall economy taking due account of functional conditions and safety requirements" (1). The ISO defines a specification as "a concise statement of a set of requirements to be satisfied by a product, a material, or a process, indicating, whenever appropriate, the procedure by means of which it may be determined whether the requirements given are satisfied. Notes. (*1*) A specification may be a standard, a part of a standard, or independent of a standard. (*2*) As far as practicable, it is desired that the requirements are expressed numerically in terms of appropriate units, together with their limits." A specification may also be viewed as the technical aspects of the legal contract between the purchaser of the material, product, or service and the vendor of the same and defines what each may expect of the other. It involves concepts of units of measurement, terminology and symbolic representation, and attributes of the physical artifact, ie, quality, variety, and interchangeability and may be regarded as a document intended primarily for use in procurement that clearly and accurately describes the essential technical requirements for items, materials, or services, including the procedures by which it will be determined that the requirements have been met (2).

2. Standards

2.1. Objectives and Types.

The objectives of standardization are economy of production by way of economies of scale in output, optimization of varieties in input material, and improved managerial control; assurance of quality; improvement of interchangeability; facilitation of technical communication; enhancement of innovation and technological progress; and promotion of the safety of persons, goods, and the environment. The likely consequences of choosing a material that is not standard, other than in exceptional circumstances, are that the selected special would be unusually costly; require an elaborate new specification; be available from few sources; be lacking documentation for many ancillary properties other than that for which it was chosen; be unfamiliar to others, eg, purchasers, vendors, production workers, maintenance personnel, etc; and contribute to the proliferation of stocked varieties and thus exacerbate problems of recycling, mistaken identity, increased purchasing costs, etc.

Physical or artifactual standards are used for comparison, calibration, etc, eg, the national standards of mass, length, and time maintained by the National Institute of Standards and Technology (NIST) or the standard reference materials (SRMs) collected and distributed by NIST. Choice of the standard is determined by the property it is supposed to define, its ease of measurement, its stability with time, and other factors (see FINE CHEMICALS, PRODUCTION).

Paper or documentary standards are written articulations of the goals, quality levels, dimensions, or other parameter levels that the standards-setting body seeks to establish. *Value standards* are a subset of paper standards and usually relate directly to society and include social, legal, political, and to a lesser extent, economic and technical factors. Such standards usually result from federal, state, or local legislation.

Regulatory standards most frequently derive from value standards but also may arise on an *ad hoc* or consensus basis. These include industry regulations or codes that are self-imposed; consensus regulatory standards that are produced by voluntary organizations in response to an expressed governmental need, especially where well-defined engineering practices or highly technical issues are involved; and mandatory regulatory standards that are developed entirely by government agencies. Examples of regulatory standards from the materials field include safety regulations, eg, those of the OSHA; clean air and water laws of the U.S. EPA; or rulings related to exposure to radioactive substances. Regulatory standards may be deliberately set in advance of the state of the art in the relevant technology, eg, fuel efficiency of automobiles, in contrast to the other types of standards (see REGULATORY AGENCIES, SURVEY).

Voluntary standards are especially prevalent in the United States and are generated by various consortia of government and industry, producers and consumers, technical societies and trade associations, general interest groups, academia, and individuals. These standards are voluntary in their manner of generation and in that they are intended for voluntary use. Nonetheless, some standards of voluntary origin have been adopted by governmental bodies and are mandatory in certain contexts. Voluntary standards include those which are recommended but which may be subject to some interpretation and those conventions as to units, definitions, etc, that are established by custom.

Product standards may stipulate performance characteristics, dimensions, quality factors, methods of measurement, and tolerances; and safety, health, and environmental protection specifications. These are introduced principally to provide for interchangeability and reduction of variety. The latter procedure is referred to as rationalization of the product offering, ie, designation of sizes, ratings, etc, for the attribute range covered and the steps within the range. The designated steps may follow a modular format or a preferred number sequence.

Public and private standards also may be distinguished. Public standards include those produced by government bodies and those published by other organizations but promoted for general use, eg, the ASTM standards. Private standards are issued by a private company for its own interests and generally are not available to parties other than its vendors, customers, and subcontractors.

Consensus standards are the key to the voluntary standards system because acceptance and use of such standards follow directly from the need for them and from the involvement in their development of all those who share that need. Consensus standards must be produced by a body selected, organized, and conducted in accordance with due process procedures. All parties or stakeholders are involved in the development of the standard and substantial agreement is reached according to the judgment of a properly constituted review board. Other aspects of due process involve proper issuance of notices, record keeping, balloting, and attention to minority opinion.

2.2. Generation, Administration, and Implementation. The development of a good standard is a lengthy and involved process, whether for a private organization, a nation, or an international body. The generic aspects of the development of a standard are shown in Figure 1. Once the need for a standard has been determined, information relevant to the subject must be gathered from many sources, eg, libraries and specialists' knowledge, field surveys, and laboratory results. Multidisciplinary and multifunctional teams must digest this information, array and analyze options, achieve an effective compromise in the balanced best interests of all concerned, and participate in the resolution of issues and criticisms arising from the reviews and appeals process. Among its functions, the administrative arm of the pertinent standards organization sets policy, allocates resources, establishes priorities, supervises reviews and appeals procedures, and interacts with organizations external to itself. The affected entities usually comprise a large, diverse, and overlapping group of interests, ie, economic sectors: industry, government, business, construction, chemicals, energy, etc; functions: planning, development, design, production, maintenance, etc; and organizations and groups of individuals: manufacturers, consumers, unions, investors, distributors, etc. No standard can be fully effective in meeting its objectives unless attention is paid to the implementation function which includes promulgation, education, enforcement of compliance, and technical assistance. Usually in the choice of a standard for a given purpose, the more encompassing the population to which the standard applies, ie, from the private level to the trade association or professional society to the national level or to the international level, the more effective and the less costly the application of the standard. Finally it must be recognized that standardization is a highly dynamic process. It cannot function without continued feedback from all affected parties and it must provide for constant review and adaptation to changing circumstances, improved knowledge, and control. Intended or inadvertent application of standards can impose trade barriers which should be minimized (4). The impact of acquisition reform by the DoD on specifications and standards has been reviewed (5).

2.3. Standard Reference Materials. An important development in the United States, relative to standardization in the chemical field, was the establishment by NIST of standard reference materials (SRMs), originally called standard samples (6). The objective of this program is to provide materials that may be used to calibrate measurement systems and to provide a central basis for uniformity and accuracy of measurement. SRMs are well-characterized, homogeneous, stable materials or simple artifacts with specific properties that have been measured and certified by NIST. Their use with standardized, well-characterized test methods enables the transfer, accuracy, and establishment of measurement traceability throughout large, multilaboratory measurement networks. Progress to date has been summarized by Rasberry (7). More than 1300 materials are included, eg, metals and alloys, ores, cements, phosphors, organics, biological materials, glasses, liquids, gases, radioactive substances, and specialty materials (8). The standards are classified as standards of certified chemical composition, standards of certified physical properties, and engineering-type standards. Although most of these are provided with certified numerical characterizations of the compositions or physical properties for which they were established, some others are included even where provision of numerical data is not feasible or certification is not useful. These latter materials do, however, provide assurance of identity among all samples of the designation and permit standardization of test procedures and referral of physical or chemical data on unknown materials to a known or common basis.

Shifts in the nature of the materials included in the SRM inventory have occurred. In the compositional SRMs, increased attention is paid to trace-organic analysis for environmentally, clinically, or nutritionally important substances; to trace-element analysis in new high technology materials, eg, alloys, plastics, and semiconductors; and for bulk analyses in the field of recycled, nuclear, and fibrous materials (see TRACE AND RESIDUE ANALYSIS). Concern not just for certification of the total concentration of individual elements but for the levels of various chemical states of those species is expected. With regard to the development of physical property SRMs, density standards, dimensional standards at the micrometer and submicrometer level, and materials relative to standardization of optical properties should be among the more active areas. Developments in SRMs for engineering properties should include materials suitable for nondestructive evaluation (qv), evaluation of durability, standardizing computer and electronic components, and workplace hazard monitoring.

Standard reference materials provide a necessary but insufficient means for achieving accuracy and measurement compatibility on a national or international scale. Good test methods, good laboratory practices, well-qualified personnel, and proper intralaboratory and interlaboratory quality assurance procedures are equally important. A systems approach to measurement compatibility is illustrated in Figure 2. The function of each level is to transfer accuracy to the level below and to help provide traceability to the level above. Thus traversing the hierarchy from bottom to top increases accuracy at the expense of measurement efficiency.

Analytical standards imply the existence of a reference material and a recommended test method. Analytical standards other than for fine chemicals and for the NIST series of SRMs have been reviewed (9). Another sphere of activity in analytical standards is the geochemical reference standards maintained by the U.S. Geological Survey and by analogous groups in France, Canada, Japan, South Africa, and Germany (10).

2.4. Chronological Standards. Chronological standards are needed for an extremely diverse range of fields, eg, astrophysics, anthropology, archaeology, geology, oceanography, and art. The techniques employed for dating materials include dendrochronology, thermoluminescence, obsidian hydration, varve deposition, paleomagnetic reversal, fission tracks, racemization of amino acids, and a variety of techniques related to the presence or decay of radioactive species, eg, 14C, 10Be, 18O, and various decay products of the U and Th series. Because the time periods of interest range from decades to millions of years and the available materials may be limited, no one technique presents a general solution. Some progress has been made on age standardization and calibration through the efforts of the Sub-Commission on Geochronology of the International Union of Geological Sciences (11). Establishment of a physical bank of chronological standards that are analogous to those standards set by NIST and the U.S. Geological Survey for compositional and physical properties would greatly benefit a broad range of scientific and cultural communities.

2.5. Standard Reference Data. In addition to standard reference materials, the materials scientist or engineer frequently requires access to standard reference data. Such information helps to identify an unknown material, describe a structure, calibrate an apparatus, test a theory, or draft a new standard specification. Data are defined as that subset of scientific or technical information that can be represented by numbers, graphs, models, or symbols. The term, standard reference data, implies a data set or collection that has passed some screening and evaluation by a competent body and warrants the body's imprimatur and promotion. Such a data set may be generated expressly for this purpose by especially careful measurements made on a standard reference material or other well-characterized material, eg, the series of standard x-ray diffraction patterns generated by NIST. In some cases, a reference data set may not represent a specific set of real experimental observations but a recommended, consistent set of stated reliability that is synthesized from limited, fragmentary, and conflicting literature data by review, analysis, adjustment, and interpolation. NIST has provided a site (12) giving access to 92 NIST databases, related articles, and links to standard reference materials. A journal specifically devoted to recording techniques for evaluating data and archiving the results of such evaluation is the *Journal of Physical and Chemical Reference Data,* jointly sponsored by NIST, the American Chemical Society, and the American Institute of Physics. The biennial proceedings of the international conferences run by the Committee on Data (CODATA) of the International Council of Scientific Unions (ICSU) also contain many contributions on data evaluation and standard reference data. Two recent references review available materials data sources, both on the internet (13) and in print (14), but these cover other data types as well as standard reference data.

2.6. Standards for Nondestructive Evaluation. Nondestructive evaluation (NDE) standards are important in materials engineering for evaluating the structure, properties, and integrity of materials and fabricated products. Such standards apply to test methods, artifactual standards for test calibration, and comparative graphical or pictorial references. These standards may be used as inspection guides, to define terms describing defects, to describe and recommend test methods, for qualification and certification of individuals and laboratories working in the NDE field, and to specify materials and apparatus used in NDE testing. NDE standards have been reviewed with regard to what standards are available, what are satisfactory, what are lacking, and what need improvement (15). Other references include useful compilations of standards and specifications in NDE (16–20) (see NONDESTRUCTIVE EVALUATION).

2.7. Traceability. Traceability is a concept that dates back to the Convention du Metre in 1875. Measurements are traceable to designated standards if scientifically rigorous evidence is produced on a continuing basis to show that the measurement process is producing data for which the total measurement uncertainty is quantified relative to national or other designated standards through an unbroken chain of comparisons (21,22). The intent of traceability is to assure an accuracy level sufficient for the need of the product or service. Although calibration is an important factor, measurement traceability also requires consideration of measurement uncertainty that arises from random error, ie, variability within the laboratory, and from systematic error of that laboratory relative to the reference standard. Although the ultimate metrological standards are those of mass, length, and time, maintained at NIST and related to those defined by international standardizing bodies (23), there are literally thousands of derived units, for only a fraction of which primary reference standards are maintained.

Traceability also is used by materials engineers for the identification of the origin of a material. This attribution often is necessary where knowledge of composition, structure, or processing history is inadequate to assure the properties required in service. Thus critical components of industrial equipment may have to be related to the particular heat of the steel that is used in the equipment apart from having to meet the specification. The geographical derivation of certain ores and minerals often is specified where analytical measurements are inadequate, and much recycled material can be used only if traceability to the original form can be established.

2.8. Basic Standards for Chemical Technology. There are many numerical values that are standards in chemical technology. A brief review of a few basic and general ones is given herein. Numerical data and definitions quoted are taken from References (24–29) (see UNITS AND CONVERSION FACTORS) and are expressed in the International System of Units (SI). A comprehensive guide for the application of SI has been published by ASTM (30).

Atomic Weight. As of this writing (ca 2005), the definition of atomic weights is as follows: "An atomic weight (relative atomic mass) of an element from a specified source is the ratio of the average mass per atom of the element to 1/12 of the mass of 12C" in its nuclear and electronic ground sate (31). The atomic weights of the elements as of 2001 are given in Ref. 32.

Temperature. Temperature is the measurement of the average kinetic energy, resulting from heat agitation, of the molecules of a body. The most widely used scale is the Celsius scale for which the freezing and boiling points of water are used as defining points. The ice point is the temperature at which macroscopic ice crystals are in equilibrium with pure liquid water under air that is saturated with moisture at standard atmospheric pressure (101.325 kPa). One degree on the Celsius scale is 1.0% of the range between the melting and boiling points of water. The unit of thermodynamic temperature is the Kelvin, defined as

1/273.16 of the thermodynamic temperature of the triple point of water. The relation of the Kelvin and Celsius scales is defined by the International Temperature Scale of 1990 (33,34). The international temperature scale between and 962°C is based on a number of defining fixed points, use of a standard platinum resistance thermometer, and the following formula for the resistance, R, as a function of temperature, t, above 0°C,

$$Rt = R0[1 + At + Bt2 + Ct3]$$

where A, B, and C are arbitrary constants (see TEMPERATURE MESUREMENT).

Pressure. Standard atmospheric pressure is defined to be the force exerted by a column of mercury 760-mm high at 0°C. This corresponds to 0.101325 MPa (14.695 psi). Reference or fixed points for pressure calibration exist (35,36) and are analogous to the temperature standards cited. These points are based on phase changes or resistance jumps in selected materials. For the highest pressures, the most reliable technique is the correlation of the wavelength shift, $\Delta\lambda$ with pressure of the ruby, $R1$, fluorescence line and is determined by simultaneous specific volume measurements on cubic metals correlated with isothermal equations of state which are derived from shockwave measurements (37). This calibration extends from 6100 GPa (0.061 Mbar) and may be represented by the following:

$$P = \frac{1904}{5}\left\{\left[\frac{\lambda_o + \Delta\lambda}{\lambda_o}\right]^5 - 1\right\}$$

where λ_o is the wavelength measured at 100 kPa (1 bar) and P is in units of GPa (see PRESSURE MEASUREMENT).

Length. One meter is defined as the length of path traveled by light in a vacuum during a time interval of 1/299,792,458 of a second (38).

Mass. The unit of mass is the kilogram and is the mass of a particular cylinder of Pt-Ir alloy which is preserved in France by the International Bureau of Weights and Measures.

Time. The unit of time in the International System of units is the second: "the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the fundamental state of the atom of cesium-133" (38). This definition is experimentally indistinguishable from the ephemeris-second which is based on the earth's motion. In the U.S. this unit is measured by a cesium fountain atomic clock, NIST-F1, developed at the Time and Frequency Division of NIST's Physics Laboratory at Boulder, Colo. (39). The uncertainty of the NIST-F1 is less than 1×10^{-25}, so that this clock will neither gain nor lose a second in more than 30 million years.

Standard Cell Potential. A large class of chemical reactions are characterized by the transfer of protons or electrons. Substances losing electrons in a reaction are said to be oxidized, those gaining electrons are said to be reduced. Many such reactions can be carried out in a galvanic cell which forms a natural basis for the concept of the half-cell, ie, the overall cell is conceptually the sum of two half-cells, one corresponding to each electrode. The half-cell potential measures the tendency of one reaction, eg, oxidation, to proceed at its electrode; the other half-cell of the pair measures the corresponding tendency for reduction to proceed at the other electrode. Measurable cell potentials are the sum of the two half-cell potentials. Standard cell potentials refer to the tendency of reactants in their standard state to form products in their standard states. The standard conditions are 1 M concentration for solutions, 101.325 kPa (1 atm) for gases, and for solids, their most stable form at 25°C. Since half-cell potentials cannot be measured directly, numerical values are obtained by assigning the hydrogen gas–hydrogen ion half-reaction the half-cell potential of zero V. Thus, by a series of comparisons referred directly or indirectly to the standard hydrogen electrode, values for the strength of a number of oxidants or reductants can be obtained (40), and standard reduction potentials can be calculated from established values (see BATTERIES, INTRODUCTION; ELECTROCHEMICAL PROCESSING, INTRODUCTION).

Standard cell potentials are meaningful only when these are calibrated against an emf scale. To achieve an absolute value of emf, electrical quantities must be referred to the basic metric system of mechanical units. If the current unit, A, and the resistance unit, W, can be defined, then the volt may be defined by Ohm's law as the voltage drop across a resistor of one standard ohm when passing one standard ampere of current. In the ohm measurement, a resistance is compared to the reactance of an inductor or capacitor at a known frequency. This reactance is calculated from the measured dimensions and can be expressed in terms of the meter and second. The ampere determination measures the force between two interacting coils where these carry the test current. The force between the coils is opposed by the force of gravity acting on a known mass; hence, the ampere can be defined in terms of the meter, kilogram, and second. Such a means of establishing a reference voltage is inconvenient for frequent use and reference is therefore usually made to a previously calibrated standard cell.

Ideally a standard cell is constructed simply and is characterized by a high constancy of emf, a low temperature coefficient of emf, and an emf close to one volt. The Weston cell, which uses a standard cadmium sulfate electrolyte and electrodes of cadmium amalgam and a paste of mercury and mercurous sulfate, essentially meets these conditions. The voltage of the cell is 1.0183 V at 20°C. The a-c Josephson effect, which relates the frequency of a superconducting oscillator to the potential difference between two superconducting components, is used by NIST to maintain the unit of emf. The definition of the volt, however, remains as the W/A derivation described.

Concentration. The basis unit of concentration in chemistry is the mole which is the amount of substance that contains as many entities, eg, atoms, molecules, ions, electrons, protons, etc, as there are atoms in 12 g of 12C, ie, Avogadro's number. Solution concentrations are expressed on either a weight or volume basis. Molality is the concentration of a solution in terms of the number of moles of solute per kilogram of solvent. Molarity is the concentration of a solution in terms of the number of moles of solute per liter of solution.

A particular concentration measure of acidity of aqueous solutions is pH which usually is regarded as the common logarithm of the reciprocal of the hydrogen-ion concentration (see HYDROGEN-ION ACTIVITY). More precisely, the potential difference of the hydrogen electrode in normal acid and in normal alkali solution (V at 25°C) is divided into 14 equal parts or pH units; each pH unit is 0.0591 V. Operationally, pH is defined by

$$\mathrm{pH} = \mathrm{pH(soln)} + E/K \text{ where } E \text{ is the emf of the cell:}$$

$$\mathrm{H_2|solution\ of\ unknown\ pH||saturated\ KCl||solution\ of\ known\ pH|H_2}$$

and $K = 2.303RT/F$, where R is the gas constant, 8.314 J/(mol·K) (1.987 cal/(mol·K)), T is the temperature in Kelvin, and F is the value of the Faraday, 9.64853×10^4 C/mol. pH usually is equated to the negative logarithm of the hydrogen-ion activity (qv), although there are differences between these two quantities outside the pH range 4.0–9.2:

$$-\log qH + mH+ = \mathrm{pH} + 0.014(\mathrm{pH}\ 9.2) \text{ for pH } 9.2$$
$$-\log qH + mH+ = \mathrm{pH} + 0.009\ (4.0\ \mathrm{pH}) \text{ for pH } 4.0$$

Energy. The SI unit of energy is the joule which is the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of the force. The newton is that force which, when applied to a body having a mass of one kilogram, accelerates that body one meter per second squared.

3. Specifications

3.1. Objectives and Types. A specification establishes assurance of the fitness of a material, product, process, or service for use. Such fitness usually encompasses safety and efficiency in use as well as technical performance. Material specifications may be classified as to whether they are applied to the material, the process by which it is made, or the performance or use that is expected of it. Product or design specifications are not relevant to materials. Within a company, the specification is the means by which engineering conveys to purchasing what requirements it has for the material to be supplied to manufacturing. It has its greatest utility prior to and at the time of purchase. Yet a properly written and dated specification with accompanying certificates of test, heat, or lot numbers, vendor identification, and other details pertinent to the actual material procurement constitutes an important archival document. Material specification records provide information regarding a proven successful material that can be used in a new product. Such records also are useful in the rebuilding of components and as defense evidence in a liability suit.

3.2. Content. Although formats of materials specifications may vary according to the need, the principal elements are title, statement of scope, requirements, quality assurance provisions, applicable reference documents, and preparations for delivery, notes, and definitions. The scope statement comprises a brief description of the material, possibly its intended area of application, and categorization of the material by type, subclass, and quality grade. Requirements may include chemical composition, physical properties, processing history, dimensions and tolerances, and/or finish. Quality assurance factors are test methods and equipment including precision; accuracy and repeatability; sampling procedures; inspection procedures, ie, acceptance and rejection criteria; and test certification. Reference documents may include citation of well-established specifications, codes and standards, definitions and abbreviations, drawings, tolerance tables, and test methods. Preparations for delivery are the instructions for packing, marking, shipping mode, and unit quantity of material in the shipment. The notes section is intended for explanations, safety precautions, and other details not covered elsewhere. Definitions are specifications of terms in the document which differ from common usage.

3.3. Strategy and Implementation. Great reliance used to be placed on compositional specifications for materials, and improvements in materials control were sought by increasing the number of elements specified and by decreasing the allowable latitude, eg, maximum, minimum, or range, in their concentration. However, the approach is fallible: the purchaser assumes enough knowledge about materials behavior to completely and unerringly associate the needed properties with composition; analyses must be made by purchaser, vendor, or both for each element specified; and the purchaser bears responsibility for materials failures when compositional requirements have been met. Property requirements alone or in combination with a less exacting compositional specification usually is a more effective approach. For example, the engineer may specify a certain class of low alloy steel and call for a particular hardenability but leave the vendor considerable latitude in determining composition to achieve the desired result.

The most effective specification is that which accomplishes the desired result with the fewest requirements. Properties and performance should be emphasized rather than how the objectives are to be achieved. Excessive demonstration of erudition on the part of the writer or failure to recognize the usually considerable processing expertise held by the vendor results in a lengthy and overly detailed document that generally is counterproductive. Redundancy may lead to technical inconsistency. A requirement that cannot be assessed by a prescribed test method or quantitative inspection technique never should be included in the specifications. Wherever possible, tests should be easy to perform and highly correlatable with service performance. Tests that indicate service life are especially useful. Standard test references, eg, ASTM methods, are the most desirable, and those that are needed should be selected carefully and the numbers of such references should be minimized. To eliminate unnecessary review activity by the would-be complier, the description of a standard test should not be paraphrased or condensed unless the original test is referenced.

Effective specification control often can be established other than through requirements placed on the end use material, ie, the specification may bear on the raw materials, the process used to produce the material, or ancillary materials used in its processing. Related but supplementary techniques are approved vendor lists, accredited testing laboratories, and preproduction acceptance tests.

4. Economic Aspects

A proper assessment of the costs and benefits associated with standardization depends on having suitable baseline data with which to make a comparison. Several surveys have shown typical dollar returns for the investment in standardization in the range of 5:1–8:1 with occasional claims made for a ratio as high as 50:1.

Savings include reduced costs of materials and parts procurement; savings in production and drafting practice; reduction in engineering time, eg, design, testing, quality control, and documentation; and reduction in maintenance, field service, and in-warranty repairs. In most companies a small number of individuals are authorized to write checks on the company's funds, but a large number of people are permitted to specify materials, parts, processes, services, etc, which just as definitely commit company resources. Furthermore, actions involving specification and standard setting frequently lack adequate control and may not be monitored regularly. Thus awareness, appreciation, and involvement of top management in any industrial standardization program are essential to its success.

The DOD estimates conservatively that materials and process specifications represent almost 1% of the total hardware acquisition costs. The operation of a single ASTM committee dealing with engine coolants has been estimated at over $150,000/yr (2). Costs of generation of a single company specification range from a few hundred to several thousand dollars. The total annual U.S. cost for material and process specifications is greater than $300 million. Because these costs can be so large, it is imperative to ensure that monies are not spent unwisely in the specification and standardization field. Although there are justifiable instances for "specials" or documents intended to fill the needs of an individual company or other institution, savings are usually realized by adopting a standard already established by an organization at a higher hierarchical level, ie, a trade association, or national or international standard.

The ideal specification regards only those properties required to assure satisfactory performance in the intended application and properties that are quantitative and measurable in a defined test. Excessively stringent requirements not only involve direct costs for compliance and test verification, but also constitute indirect costs by restricting the sources of the material. Reducing the margin between the specification and the production target increases the risk that an acceptable product is unjustly rejected because the test procedure gives results that vary from laboratory to laboratory. A particularly effective approach is to recognize within a specification or related set of specifications the different levels of quality or reliability required in different applications. Thus the U.S. military recognizes class A, class B, and class S design allowables where, on the A basis $\geq$99% of values are above the designated level with a 95% confidence; on the B basis $\geq$90% are above with a 95% confidence; and on the S basis, a value is expected which exceeds the specified minimum (41).

From the customer's point of view, there is an optimal level of standardization. Increased standardization lowers costs but restricts choice. Furthermore, if a single minimal performance product standard is rigorously invoked in an industry, competition in a free market ultimately may lead the manufacturer of a superior product to save costs by lowering his product quality to the level of the standard, thus denying other values to the customer. Again, excessive standardization, especially as applied to design or how the product performance is to be achieved, effectively can limit technological innovation.

5. Legal Aspects

The increasing incidence of class action suits over faulty performance, the trend toward personal accountability and liability, and the increasing role of consumerism have all affected standardization. Improvement in the technical quality of standards, the involvement of all of the possible stakeholders in standards creation, and endorsement by larger standardizing bodies help to minimize the legal exposure of the individual engineer or company. A particular embodiment of these attitudes is the certification label, ie, a symbol or mark on the product indicating that it has been produced according to the standards of a particular organization. The Underwriters Laboratories seal on electrical equipment is a familiar indication that the safety features of the product in question have met the exacting standards of that group. Similarly, the symbol of the International Wool Secretariat on a fabric attests to the fiber content and quality of that material, and the American Petroleum Institute (API) monogram on piping, fittings, chain, motor-oil cans, and other products carries analogous significance.

Antitrust laws sometimes have been invoked in opposition to the collaborative activities of individual companies or private associations, eg, ASTM, in the development of specifications and standards. Although such activities should not constitute restraint of trade, they must be conducted so that the charge can be refuted. Therefore all features of due process proceedings must be observed. Actions aimed at strengthening the voluntary standards system have begun (42). A recommended national standards policy has been generated by an advisory committee that was initiated by, but is independent of, the ANSI. ANSI's activities and accomplishments in the 2001–2003 period have been summarized by Hurwitz (43). The Federal Office of Management and Budget has issued a circular establishing a uniform policy for federal participation and the use of voluntary standards (44,45). In general, the circular calls for federal agency participation in the development, production, and coordination of voluntary standards and encourages the use, whenever possible, of applicable voluntary standards in federal procurement. As a result, more internal government standards in agencies, such as the Department of Defense and General Services Administration, are being canceled than are being created. Almost 5000 industry standards have been adopted by DOD, a number that is certain to increase.

6. Education

Seminars, workshops, and short courses sponsored by professional societies and trade associations provide the needed training in materials standards and specifications. Familiarization with sources of information in the field, how to prepare specifications and standards, how to tailor requirements for cost effectiveness, and the cross-referencing and correlation of specifications and standards are covered.

7. Trends and Outlook

7.1. International Standards. International trade is increasing rapidly in volume, in complexity, and in its significance to individual national economies. Thus the move toward more extensive adoption of international standards as well as cross-referencing of equivalent national specifications is understandable. Historically, international trade was comprised principally of raw materials sold by undeveloped countries to industrialized countries in exchange for manufactured products. This is no longer so. Today's U.S.-designed car may be equipped with a German engine and French tires, and be built in part from Japanese steel and Dutch plastics. This composite implies a need for materials standardization accepted on an international level.

International standardization began formally in 1904 with the formation of the International Electrotechnical Commission (IEC) and involves the national committees of more than 40 member nations who represent their countries' interests in electrical engineering, electronics, and nuclear energy. In 1947, the International Organization for Standardization (ISO) was formed to review standardization activities in fields other than electrical. ISO is comprised of more than 80 member countries. Both organizations are autonomous, but maintain a coordinating committee to answer jurisdictional questions. Both are located in the same building in Geneva, Switzerland. The activities of the IEC and ISO have increased many fold over the years. The United States is represented in ISO by ANSI and in IEC by a U.S. National Committee that is a part of ANSI. Although the two organizations are dominant in drafting documentary standards, the influence and activities of other international organizations are substantial. Among these are IUPAC, NATO, and Comit Europ en de Normalisation (CEN), the European Economic Community (EEC), and the Pan American Standards Commission (COPANT). The CEN is supported by the separate national standards authorities, and its influence has been much strengthened following the 1992 adoption of a European Common Market by the EEC. Another organization, the Committee on Data (CODATA) of the International Council of Scientific Unions, should also be mentioned. CODATA concentrates its attention on the evaluation of data and the methodology of compilation, presentation, manipulation, and dissemination of data in all fields of science and technology. Much of its work consists of appraisal of standard data and standards for presentation of data. Some of the recent activities related to materials have been reported (46).

The problems of existing materials designation systems and the need for schemes to demonstrate equivalencies (or the lack thereof) have been discussed (13,47–49). A comprehensive international standard for materials designations is highly desirable, but may only be realizable for such new classes of materials as advanced ceramics, overview (qv) (50). The General Agreement on Tariffs and Trade (GATT Code) was succeeded in 1995 by the World Trade Organization

(WTO), which aims to minimize the hazard of the intentional or unintentional use of standards as technical barriers to trade as recently reviewed (51).

The role of the U.S. government in international standardization activities has been examined by a special ASTM task force (52). The addresses of these organizations or their subsidiary standards groups are as follows.

International Bureau of Weights and Measures (BIPM), Pavillon de Breteuil, F-92310, Sevres, France.

International Electrotechnical Commission (IEC), 3 rue de Varembe, CH-1211, Geneve 20 Switzerland.

International Organization for Standardization (ISO), 1 rue de Varembe, CH-1211, Geneve 20 Switzerland.

North Atlantic Treaty Organization (NATO) Headquarters, Blvd. Leopold III, 1110 Brussels, Belgium.

VAMAS (Versailles Project on Advanced Materials and Standards). Lists of standards produced, current and completed projects are available at the VAMAS Internet site or contact Dr. Martin Rides, VAMAS Secretary, National Physical Laboratory, Queens Road, Teddington, Middlesex, TW 11 0LW.

NSSN (a national resource for global standards) c/o ANSI, 25 West 43rd St., New York, N.Y. 10036.

European Committee for Standardization (CEN),36 rue de Stassart, B-1050, Brussels, Belgium.

European Economic Community (EEC), 200 rue de la Loi, 1049 Brussels, Belgium.

COPANT (Pan-American Standards Commission), Avenue Pte. Roque Soenz Pena 501, 7 Piso OF 716, Buenos Aires, Argentina.

CODATA, 51 Boulevard de Montmorency, 75016 Paris, France.

International Union for Pure and Applied Chemistry (IUPAC), P.O. Box 13757, Research Triangle Park, N.C. 27709-3757. Among its publications in the standards field are:

A. D. McNaught and A. Wilkinson, eds, *Compendium of Chemical Terminology*, 2nd ed., 1997; G. J. Leigh, H. A. Favre, and W. V. Metanowski, *Principles of Chemical Nomenclature (A Guide to IUPAC Resources)*, Blackwell Science, 1998; G. J. Leigh, *Nomenclature of Inorganic Chemistry–The Red Book*, Blackwell Science, 1990; J. A. McCleverty, and N. G. Connelly, *Nomenclature of Inorganic Chemistry, II, Recommendations 2000*, The Royal Society of Chemistry, 2001.

Increased requirements for quality and reliability in all products, especially for those of high dollar value and in components of highly integrated technological systems, has led to the formation and broad adoption of the ISO 9000 series of international quality standards for products and services. ISO 9000, which has now been adopted by over 50 countries (53), is actually a series of five integrated standards developed during the 1980s to provide uniform, worldwide quality assurance requirements. ISO 9000 is the road map to the series and also defines key terms; ISO 9001 relates to design and servicing; ISO 9002 to production and installation; ISO 9003 to final inspection and testing; and finally ISO 9004 provides guidance on implementing these standards. As of this writing (ca 2005), there is a trend toward use of third-party registrars to certify that ISO

9000 requirements for a quality system have indeed been implemented and documented.

7.2. National Standards, Worldwide. Most countries have a national standards organization that both leads the standardization activities in that country and acts within its own country as sales agent and information center for the other national standardizing bodies. In the United States, the ANSI performs that function. The organizations for the leading industrial countries of the world are as follows.

Australia: SAA, AS, Standards Association of Australia, 80–86 Arthur Street, North Sidney, NSW 2060.

Austria: ON, ONORM, Oesterreichlisches Normungsinstitut, Leopoldsgasse 4, A-1021 Wein 2.

Belgium: IBN, Institut Belge de Normalisation, 29 Avenue de la Brabanconne B-1040, Bruxelles 4.

Brazil: ABNT, NB, EB, Associacao Brasileira de Normas Tecnicas, Caixa Postal 1680, Rio de Janeiro.

Canada: CSA, Standards Council of Canada, 270 Albert St., Suite 200, Ottawa, ON KIP 6N7.

China: China Association for Standardization, PO Box 820, Beijing, People's Republic of China.

Czech Republic: Czech Standars Institure, Biskupsky dvur 5 110 02, Praha 1, Czech Republic.

Denmark: DS, Dansk Standardiseringsraad, Aurehjvej 12, DK-29000, Hellerup.

Finland: SFS, Suomen Standardisoimisliitto, Box 205 SF-00121, Helsinki 12.

France: AFNOR, NF, Association Francaise de Normalisation, Tour Europe, Cedex 7, 92080 Paris-La Defense.

Germany: DIN, Deutsches Institut fur Normung, 4-10 Burggrafenstrasse, D-1000 Berlin 30.

India: ISI, IS, Indian Standards Institution, Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002.

Iran: Institute of Standards and Industrial Research of Iran, Ministry of Industries and Mines, PO Box 2937, Tehran.

Ireland: IIRS, I.S., Institute for Industrial Research and Standards, Blasnevin House, Ballymun Road, Dublin-9.

Israel: SII, Standards Institution of Israel, 42 University Street, Tel Aviv 69977.

Italy: UNI, Ente Nazionale Italiano de Unificazione, Piazza Armando Diaz 2, 120123 Milano.

Japan: JISC, JIS, Japanese Industrial Standards Committee, Agency of Industrial Science and Technology, Ministry of International Trade and Industry, 1-3-1 Kusumigaseki Chiyoda-Ku, Tokyo 100.

Mexico: DGN, Diraccion General de Normas, Tuxpan No. 2, Mexico 7 DF.

Netherlands: NNI, Nederlands Normalisatie-instituut, Polakweg, 5 Rijswijk (ZH)-2280.

Poland: Polski Komitet Normalizacji Miar i Jakosci, Ul. Elektoraina 2, 00-139 Warszawa.

Romania: Institutul Roman de Standardizare, Casuta Postala 63-87, Bucarest 1.

Russia: GOST, Gosudarstvennyj Komitet Standartov, Leninsky Prospekt 9b, Moskva 11 7049.

Slovakia: Slovak Standards Institute, P.O. Box 246, Karloveska 63, SK-840 00, Bratislava 4, Slovakia.

Spain: Instituto Nacional de Racionalizacion y Normalizacion, Aurbano 46, Madrid 10.

Sweden: SIS, Standardiseringskommission i Sverige, Tegnergatan 11, Box 3295, Stockholm S 10366.

United Kingdom: BSI, BS, British Standards Institution, 2 Park Street, London W1 A 2BS, England.

7.3. New Areas for Standardization. Increasing concern over the environment and safety issues has led to new standards for exposure of organisms to materials, noise, and electromagnetic radiation (see ENVIRONMENTAL IMPACT; INDUUSTRIAL HYGIENE; TOXICOLOGY). The decreasing availability of natural resources forces industry to make use of leaner ores and apply materials that are in short supply more frugally (see MINERALS RECOVERY AND PROCESSING). This usage is expected to result in new analytical standards and compositional specifications. The use of specifications in coping with problems of residual and additive elements in both virgin and recycled materials has been reviewed (54) (see RECYCLING, INTRODUCTION).

7.4. Computerization. The computerization of all aspects of industry and commerce, from management to engineering and manufacturing, and from purchasing to sales, has made it vital to standardize the ways materials information is incorporated into machine-readable systems (see COMPUTER-AIDED DESIGN AND MANUFACTURING (CAD/CAM); COMPUTER-AIDED CHEMICAL ENGINEERING). The designation of materials, the recording of properties, as well as auxiliary information, can all be computerized. More than a dozen standards in this area have been developed by ASTM's Committee E49 who have also prepared a guide to the building of materials (qv) (55). A particularly important issue is standardization to assist the exchange of digital information. One aspect of this facilitation is the development of a standardized hypertext mark-up language, MatML (56). Internationally, work toward the goal of standardization in materials informatics is carried out under the aegis of ISO-STEP (standard for the exchange of product data). STEP, known formally as ISO 10303, covers all aspects of information needed to describe manufactured products including shape, product configuration, and process description. Materials are covered in Part 45 which treats material structure, properties, and measurement conditions in such a way that the information is fully integratable with other parts of the STEP standard. Implementation for materials awaits the development of particular application protocols (APs), eg, composite part design or polymer testing. The STEP model has been more fully described (57,58). Status is available from the ISO-STEP secretariat at NIST.

Another standardization matter relative to computerization of materials information is that of terminology (14,59) (see NOMENCLATURE). Full terminological standardization is not expected to be realized until later in the twenty-first century, but the hazards of lack of such standardization are exacerbated in computerized systems.

7.5. Nonlaboratory Environments. New technology such as that of fusion energy (qv) introduces demands for standards and specifications of increased quality. Extension of temperature and pressure capabilities in the laboratory and factory demand new accepted standards of calibration. Pressure equipment in the GPa range and the tokamak nuclear fusion apparatus having operating temperatures of 10^6 °C dictate the need, but the state of the art of standards in these fields is far behind such values. Micro-miniaturization (nano-technology) of the active components of electronic equipment and the ability to detect material in picogram quantities requires updated standards for purity, smoothness, and compositional measurement as well as dimensional definition within tens of nanometers. Standards and specifications work is expected to affect the biomaterials field, eg, regarding laboratory-created microorganisms (see GENETIC ENGINEERING—PROCEDURES).

Environments deviating significantly from that of the laboratory, a selection of which is presented in Table 1, yet in which all the usual engineering functions must be performed, also pose problems and opportunities for material standards. Sensors (qv) must measure the attributes of these environments, construction materials must withstand the exposure regimes, and performance criteria must be specified.

7.6. Units. The SI system of units and conversion factors (qv) has been formally adopted worldwide, with the exception of Brunei, Burma, Yemen, and the United States. The participation of the United States in the metrication movement is evident by the passage of the Metric Acts of 1866 and 1975 and the subsequent establishment of the American National Metric Council (private) and the U.S. Metric Board (public) to plan, coordinate, monitor, and encourage the conversion process.

8. Sources of Specifications and Standards

There are many hundreds of standards-making bodies in the United States. These comprise branches of state and federal government, trade associations, professional and technical societies, consumer groups, and institutions in the safety and insurance fields. The products of their efforts are heterogeneous, reflecting parochial concerns and different ways of standards development. However, by evolution, blending, and accreditation by higher level bodies, many standards originally developed for private purposes eventually become de facto, if not official, national standards. Individuals seeking access to U.S. standards and specifications are referred to the directory by Toth (61). Selected organizations, principally from these sources, whose work is especially relevant to chemistry and chemical technology are listed below (see INFORMATION RETRIEVAL).

8.1. General Sources. American National Standards Institute (ANSI) 25 West 43rd Street New York, N.Y. 10036 ANSI, previously the American

Standards Association and the United States of America Standards Institute, is the coordinator of the U.S. Federal National Standards System and Acts by assisting participants in the voluntary system to reach agreement on standards needs and priorities, arranging for competent organizations to undertake standards development work, providing fair and effective procedures for standards development, and resolving conflicts and preventing duplication of effort.

Most of the standards-writing organizations in the United States are members of ANSI and submit the standards that they develop to the Institute for verification of evidence of consensus and approval as American National Standards. There are ca 11,000 ANSI-approved standards, and these cover all types of materials from abrasives (qv) to zirconium as well as virtually every other field and discipline. Presently, ANSI adopts the standard number of the developing organization, eg, ASTM. ANSI also manages and coordinates participation of the U.S. voluntary-standards community in the work of nongovernmental international standards organizations and serves as a clearinghouse and information center for American National Standards and international standards.

The American Society for Testing and Materials (ASTM) 100 Barr Harbor Dr., P.O. Box C700, West Conshohocken, Pa. 19428-2959 The ASTM *Annual Book of ASTM Standards* contains all up-to-date formally approved (ca 12,000) ASTM standard specifications, test methods, classifications, definitions, practices, and related materials, eg, proposals. These are arranged in 15 sections plus an index volume as follows.

Section 1.	Iron and Steel Products (7 vols.)
Section 2.	Non-ferrous Metal Products (5 vols.)
Section 3.	Metals Test Methods and Analytical Practices (6 vols.)
Section 4.	Construction (10 vols.)
Section 5.	Petroleum Products, Lubricants, and Fossil Fuels (5 vols.)
Section 6.	Paints, Related Coatings, and Aromatics (4 vols.)
Section 7.	Textiles (2 vols.)
Section 8.	Plastics (4 vols.)
Section 9.	Rubber (2 vols.)
Section 10.	Electrical Insulation and Electronics (5 vols.)
Section 11.	Water and Environmental Technology (4 vols.)
Section 12.	Nuclear, Solar, and Geothermal Energy (2 vols.)
Section 13.	Medical Devices and Services (1 vol.)
Section 14.	General Methods and Instrumentation (3 vols.)
Section 15.	General Products, Chemical Specialties and End-use Products (1 vol.)
Index	(1 vol.)

Defense Logistics Agency, Defense Industrial Supply Center, 700 Robbins Avenue Philadelphia, Pa. 19111. Publishes *Department of Defense Index of Specifications and Standards*, a monthly with annual accumulations; available from Superintendent of Documents, GPO, Washington, D.C. 20402.

General Services Administration, Federal Supply Service, 18th and F Streets, Washington, D.C. 20406. Publishes *Index of Federal Specifications, Standards, and Commercial Item Descriptions* FTMR 101-29.

Global Engineering Documentation Services, Inc., 15 Inverness Way East, Englewood, Colo. 80112. An information broker, not an issuer of standards. The world's largest library of government, industry, and technical society specifications and standards, including obsolete documents dating from 1946. Publishes an annual *Directory of Engineering Documentation Sources*.

MTS Systems Corp. Box 24012, 14000 Technology Dr., Eden Prairie, Minn. 55344. Publishes *Standards Cross-Reference List* that includes standards issued by one agency but adopted and renumbered or redesignated by another agency, compiled and cross-referenced to aid in their location and identification.

National Institute of Standards and Technology (NIST), Standards Information Service, Gaithersburg, Md. 20899. Maintains a reference collection on standardization, engineering standards, specifications, test methods, recommended practices, and codes obtained from U.S., foreign, and international standards organizations. Publishes various indexes and directories; for example the *Directory of International and Regional Organizations Conducting Standards-Related Activities* (NIST SP 767), and *Standards Activities of Organizations in the United States* (NIST SP 806). Copies are not available from NIST but from NTIS or Global Engineering.

National Standards Association, Inc., 5161 River Road, Bethesda, Md. 20816. Maintains a standards and specifications database for online searching of government and industry standards, specifications, and related documents (see DATABASES).

National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22161. A for-profit organization, spun off from the federal government, that acts as an archiving and distribution agency for public sale of technical information emanating from a wide variety of government agencies and contractually supported technical programs, as well as for some foreign technical reports and other analyses prepared by national and local government agencies, their contractors, or grantees. A bibliographic database of >1.4 million titles is maintained.

Visual Search Microfilm Files (VSMF), Information Handling Services, 15 Inverness Way East, Englewood, Colo. 80150. VSMF carries government specifications, ASTM, AMS, and many other specifications and standards. Copies of these may be obtained on an individual basis or broad categories of this service may be obtained on a subscription basis.

8.2. Materials. *Abrasives*:

Abrasives Engineering Society, 144 Moore Road, Butler, Pa. 16001.

Biochemical Compounds:

National Research Council Committee on Biological Chemistry, National Academy of Science, Washington, D.C. 20418. *Specifications and Criteria for Biochemical Compounds*

Carbides:

Cemented Carbide Producers Association, 30,200 Ddetroit Road, Cleveland, Ohio 44145. Accredited Standards Comm. B212 covers standard shapes, sizes, grades, and designations and defect classification.

Castings:

Investment Casting Institute, 1336 Summit Ave., Montvale, N.J. 07645-1720.

North American Die Casting Association, 241 Holbrook Dr., Wheeling, Ill. 60090-5809.

American Foundrymen's Society, 1695 Penny Lane, Schaumburg, Ill. 60173-4555.

Steel Founders Society of America, 780 McArdle Dr., Unit G, Crystal Lake, Ill. 60014.

Cement and Concrete:

Cement Statistical and Technical Association, Malmo, Sweden.

American Concrete Institute, 38,800 Country Club Dr., Farmington Hills, Mich. 48331.

Ceramic Tile:

Methods and Materials Standards Association, c/o H. B. Fuller Co., 315 South Hicks Road, Palatine, Ill. 60067.

Chemicals:

Chemical Manufacturers Association, 2501 M Street, NW, Washington, D.C. 20037. *Manual of Standard and Recommended Practice* for chemicals, containers, tank car unloading, and related procedures.

Chemical Specialties Manufacturers Association, 1001 Connecticut Avenue, NW, Washington, D.C. 20036. *Standard Reference Testing Materials* for insecticides (see INSECTICIDES), cleaning products, sanitizers, brake fluids, corrosion inhibitors (see CORROSION AND CORROSION CONTROL), antifreezes, polishes, and floor waxes.

Color:

Color Association of the United States, 315 East 39th Street, New York, N.Y. 10018. Color standards for fabrics, paints, wallpaper, plastics, floor coverings, automotive and aeronautical materials, china, chemicals, dyestuffs, cosmetics, etc.

American Association of Textile Chemists and Colorists, P.O. Box 12215, Research Triangle Park, N.C. 27709

Inter-Society Color Council, U.S. Army Natick R&D Center, Att: STRNC-ITC Natick, Mass. 01760.

Friction Materials:

Friction Materials Standards Institute, 23 Woodland Rd, Suite B-3, Madison, Conn. 06443.

Leather:

Leather Industries of America, 1900 L Street, NW, Washington, D.C. 20036.

American Leather Chemists Association 1314 50th St., Suite 103, Lubboock, Texas 79412. Chemical and physical test methods for leather (qv).

Metals and Alloys:

Aluminum Association, 900 19th Street, NW, Washington, D.C. 20006. Standards for wrought and cast aluminum and aluminum alloy products, including composition, temper designation, dimensional tolerance, etc.

Society of Automotive Engineers (SAE), 400 Commonwealth Drive, Warrendale, Pa. 15096. *SAE Handbook,* an annual compilation of more than 500 SAE standards, recommended practices, and information reports on ferrous and nonferrous metals, nonmetallic materials, threads, fasteners, common parts, electrical equipment and lighting for motor vehicles and farm equipment, power-plant components and accessories, passenger cars, trucks, buses, tractor and earthmoving equipment, and marine equipment. *AMS Index,* a listing of more than 1000 SAE Aerospace Material Specifications (AMS) on tolerances; quality control and process; nonmetallics; aluminum, magnesium, copper, titanium, and miscellaneous nonferrous alloys; wrought carbon steels; special-purpose ferrous alloys; wrought low alloy steels; corrosion- and heat-resistant steels and alloys; cast-iron and low alloy steels; accessories, fabricated parts, and assemblies; special property materials; refractory and reactive materials.

Copper Development Association, 260 Madison Ave., New York, N.Y. 10018. Standards for wrought and cast copper and copper alloy products; a standards handbook is published with tolerances, alloy data, terminology, engineering data, processing characteristics, sources and specifications cross-indexes for six coppers and 87 copper-based alloys that are recognized as standards.

Tin Research Institute, 1353 Perry Street, Columbus, Ohio 43201.

Zinc Institute, 292 Madison Avenue, New York, N.Y. 10017.

Lead Industries Association, 13 Main Street, Sparta, N.J. 07871.

American Iron and Steel Institute, 1140 Conecticut Ave., Suite 705, Washington, D.C. 20036. Standards for steel compositions, steel products, manufacturing tolerances, inspection methods, etc.

Ferroalloys Association, 900 2nd St. NE, Suite 39, Washington, D.C. 20002.

Metal Powder Industries Federation, 105 College Road East, Princeton, N.J. 08540.

National Mining Association, Suite 500 East, 1001 Constitution Avenue, NW, Washington, D.C. 20001.

Silver Institute, 1200 G Street, NW Suite 800, Washington, D.C. 20005.

Paper:

Technical Association of the Pulp and Paper Industry (TAPPI), 15 Technology Parkway South, Norcross, Ga. 30092. *TAPPI Standards* and *TAPPI Yearbook* cover all aspects of pulp (qv) and Paper (qv) testing and associated standards.

American Paper Institute, 1250 constitution Ave, NW, Suite 210, Washington, D.C. 20036-2603.

Physical standards, sizes, gauges, definitions of paper and paperboard.

Petroleum Products:

American Petroleum Institute, 1220 L Street, NW, Washington, D.C. 20005. Fosters development of standards, codes, and safe practices in petroleum industries and publishes the same in its journals and reference publications.

Plastics:

Society of the Plastics Industry, 1667 K St., NW, Suite 1000, Washington, D.C. 20006.

Refractories:

Refractories Institute, Centre City Tower, 650 Smithfield St., Suite 1160, Pittsburgh, Pa. 15222-3907.

Steam:

International Association for Properties of Steam, National Institute of Standards and Technology, Gaithersburg, Md. 20899.

Textiles:

International Bureau for Standardization of Man-made Fibers (BISFA), Avenue E, Van Nieuwenhuyse 4, B-1160, Brussels, Belgium.

Treating and Finishing:

Metal Treating Institute, 1550 Roberts Dr., Jacksonville, Fla. 32250-3222.

National Association of Metal Finishers, 3660 Maguire Blvd., Suite 250, Orlando, Fla. 32803.

Welding:

American Welding Society, P.O. Box 351040, 550 NW Le Jeune Road, Miami, Fla. 33135. *Codes, Standards and Specifications,* a complete set of codes, standards, and specifications published by the Society and continuously updated. Covers fundamentals, training, inspection and control, and process and industrial applications.

Wood:

American Lumber Standards Committee, Inc., P.O. Box 210, Germantown, Md. 20875-0210.

American Wood Preservers Bureau, P.O. Box 5283, Springfield, Va. 22150.

National Hardwood Lumber Association, P.O. Box 34518, Memphis, Tenn. 38184.

8.3. Equipment and Instrumentation Standards. Instrumentation Systems and Automation Society (ISA), 67 Alexander Drive, Research Triangle park, N.C. 27709. N.E. Battikles, ed., *Condensed Handbook of Measurement and Control*, ISA, 2nd ed., 2004. Instrumentation standards and recommended practices abstracted from those of 19 societies, the U.S. Government, the

Canadian Standards Association, and the British Standards Institute. Covers control instruments, including rotameters, annunciators, transducers, thermocouples, flow meters, and pneumatic systems (see FLOW MEASUREMENT).

American Institute of Chemical Engineers, 3 Park Avenue, New York, N.Y. 10016-5991. Standard testing procedures for plate distillation (qv) columns, evaporators, solids mixing equipment, other mixing equipment, centrifugal pumps (qv), dryers, absorbers, heat exchangers, etc (see EVAPORATION; MIXING AND BLENDING).

Management Control and Automation Association (formerly SAMA), P.O. Box 3698, Williamsburg, Va. 23187-3698. Standards for analytical instruments, laboratory apparatus, measurement and test instruments, nuclear instruments, optical instruments, process measurement and control, and scientific laboratory furniture and equipment (see ANALYTICAL METHODS, SURVEY).

8.4. Nuclear Standards. American Nuclear Society (ANS), 555 N. Kensington Avenue, La Grange Park, Ill. 60525.

American National Standards Institute, 25 West 43rd Street, New York, N.Y. 10036.

National Institute of Standards and Technology, W. I. Slattery, ed., *Index of U.S. Nuclear Standards*, National Bureau of Standards, (Special Pub. 483) Washington, D.C., 1977.

8.5. Safety Standards. The American Society of Mechanical Engineers (ASME), 3 park Ave., New York, N.Y. 10016. The ASME Boiler and Pressure Vessel Code, under the cognizance of the ASME Policy Board, Codes, and Standards, considers the interdependence of design procedures, material selection, fabrication procedures, inspection, and test methods that affect the safety of boilers, pressure vessels, and nuclear-plant components, whose failures could endanger the operators or the public (see NUCLEAR REACTORS, WASTE MANAGEMENT, INTRODUCTION). It does not cover other aspects of these topics that affect operation, maintenance, or nonhazardous deterioration.

American Insurance Association (AIA), 85 John Street, New York, N.Y. 10038. Compilation of industrial safety requirements based on codes and recommendations of the ANSI, the National Fire Protection Association (now part of AIA), the ASME, and several government agencies.

National Fire Protection Association, 470 Atlantic Avenue, Boston, Mass. 02210. *National Fire Codes,* issued in 11 volumes. One volume is devoted exclusively to hazardous chemicals, but most other volumes have some coverage of material hazards, use of materials in fire prevention or extinguishing, hazards in chemical processing, etc. More than 200 standards are described.

American Society of Safety Engineers, 1800 East Oakton St., Des Plaines, Ill. 60018.

American Public Health Association, 1015 18th Street, NW, Washington, D.C. 20036. *Standard Methods for Examination of Water and Wastewater,* 16th ed., 1985; *Methods of Air Sampling and Analysis,* 3rd ed., 1988.

National Safety Council, 444 North Michigan Avenue, Chicago, Ill. 60611. Industrial safety data sheets on materials and materials handling and safe operation of equipment and processes.

Underwriters Laboratories, 333 Pfingsten Road, Northbrook, Ill. 60062. *Standards for Safety* is a list of more than 200 standards that provide specifications and requirements for construction and performance under test and in actual use of a broad range of electrical apparatus and equipment, including household appliances, fire-extinguishing and fire protection devices and equipment, and many other nongenerally classifiable items, eg, ladders, sweeping compounds, waste cans, and roof jacks for trailer coaches.

Safety Standards, U.S. Department of Labor, GPO, Washington, D.C. 20402. Industrial safety hazards.

American Conference of Governmental Industrial Hygienists, P.O. Box 1937, Cincinnati, Ohio 45201. Practices, analytical methods, guides to codes and/or regulations, threshold limit values.

Factory Mutual Engineering Corp., 1151 Boston-Providence Turnpike, Norwood, Mass. 02062 Standards for safety equipment, safeguards for flammable liquids, gases, dusts, industrial ovens, dryers, and for protection of buildings from wind and other natural hazards.

Code of Federal Regulations, Title 49, Transportation, Parts 100 to 199, Superintendent of Documents, GPO, Washington, D.C. 20402. Safety regulations related to transportation of hazardous materials and pipeline safety.

Code of Federal Regulations, Title 29, Occupational Safety and Health, Superintendent of Documents, GPO, Washington, D.C. 20402. Safety regulations and standards issued by OSHA.

Code of Federal Regulations, Title 40, Environmental Protection Administration, Superintendent of Documents, GPO, Washington, D.C. 20402. Safety regulations and standards issued by the U.S. EPA.

Code of Federal Regulations, Title 21, Radiological Health, Superintendent of Documents GPO, Washington, D.C. 20402.

8.6. Weights and Measures. National Conference on Weights and Measures, c/o National Institute of Standards and Technology, Gaithersburg, Md. 20899.

National Conference on Standards Laboratories, c/o National Institute of Standards and Technology, Boulder, Colo. 80303.

U.S. Metric Association, Sugarload Star Route, Boulder, Colo. 80302.

U.S. Metric Board, 1815 N. Lynn Street, Arlington, Va. 22209.

American National Metric Council, 5410 Grosvenor Lane, Bethesda, Md. 20814.

International Bureau of Weights and Measures, Pavillion de Breteuil F-92310, Sevres, France.

9. Journals

ANSI Reporter and Standards Action, published by the American National Standards Institute. The monthly *ANSI Reporter* provides news of policy-level actions on standardization taken by ANSI, the international organizations to which it belongs, and the government. *Standards Action*, biweekly, lists for public review and comment standards proposed for ANSI approval. It also reports on final approval actions on standards, newly published American National

Standards, and proposed actions on national and international technical work. These two publications replace *The Magazine of Standards*, which ANSI, formerly The American Standards Association, discontinued in 1971.

ASTM Standardization News (formerly *Materials Research and Standards* and, earlier, *ASTM Bulletin*) American Society for Testing and Materials. A monthly bulletin which covers ASTM projects, national and international activities affecting ASTM, reports of new relevant technology, and ASTM letter ballots on proposed standards.

Professional Safety (J. of ASSE) American Society of Safety Engineers, 1800 East Oakton St., Des Plaines, Ill. 60018. A monthly that reviews safety standards.

Journal of Research of the National Institute of Standards and Technology The journal is published in four parts: (*1*) physics and chemistry, (*2*) mathematics and mathematical physics, (*3*) engineering and instrumentation, and (*4*) radio science.

Journal of Physical and Chemical Reference Data American Chemical Society, 1155 16th Street, NW, Washington, D.C. 20036: quarterly

Journal of Testing and Evaluation American Society for Testing and Materials. A bimonthly in which data derived from the testing and evaluation of materials, products, systems, and services of interest to the practicing engineer are presented. New techniques, new information on existing methods, and new data are emphasized. It aims to provide the basis for new and improved standard methods and to stimulate new ideas in testing.

Metrologia International Committee of Weights and Measures (BIPM) Pavillon de Breteuil, F-92312, Sevres, France Includes articles on scientific metrology worldwide, improvements in measuring techniques and standards, definitions of units, and the activities of various bodies created by the International Metric Convention.

Standards Engineering Standards Engineering Society, 13340 SW 96th Ave., Miami, Fla. 33176. A bimonthly in which general news and technical articles dealing with all aspects of standards and U.S. and foreign articles on standard materials and calibration and measurement standards are presented.

10. Directories and Cross-References

A variety of directories and cross-references to standards and specifications are available worldwide (62–85).

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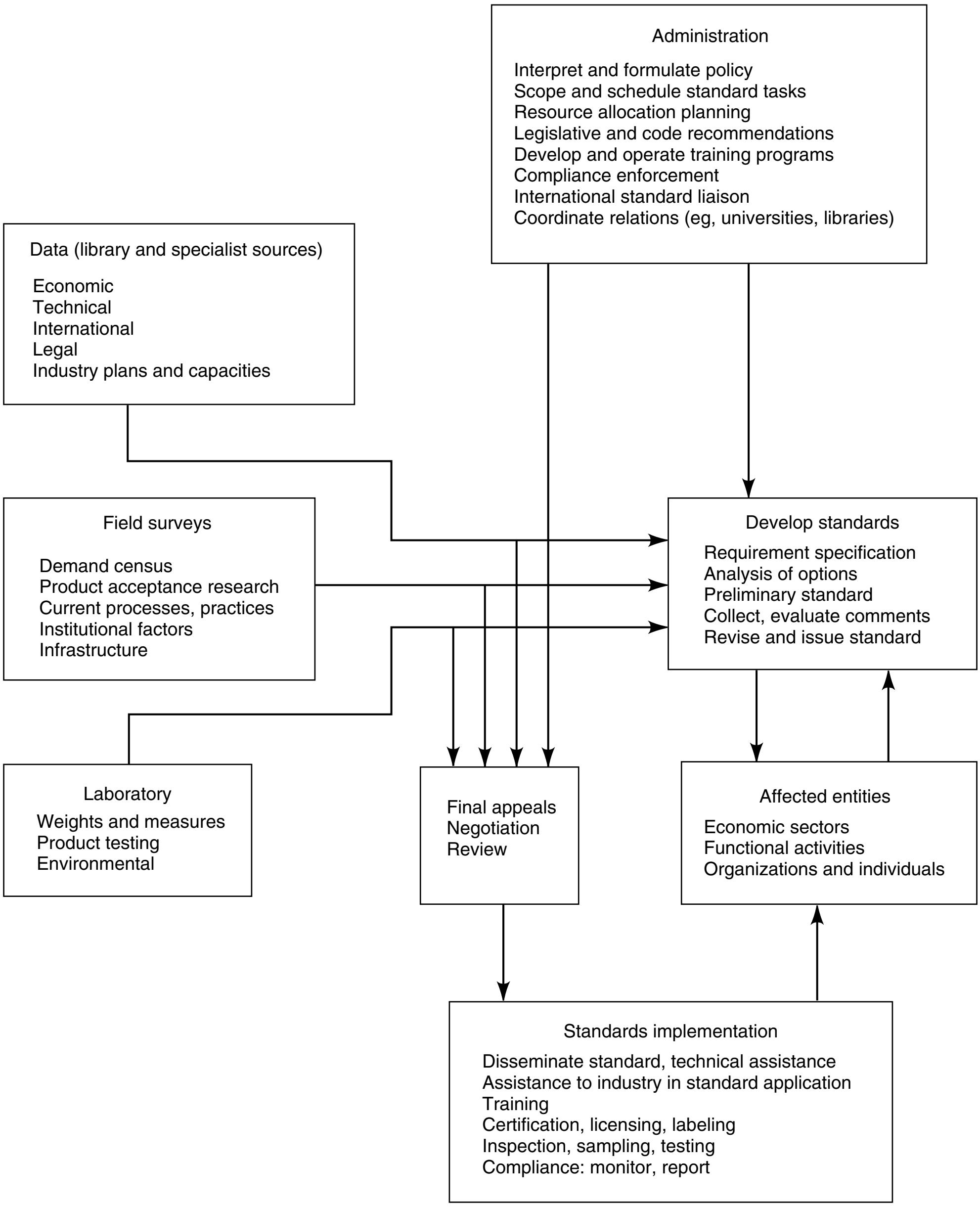

Fig. 1. Flow chart of the standardization process (3).

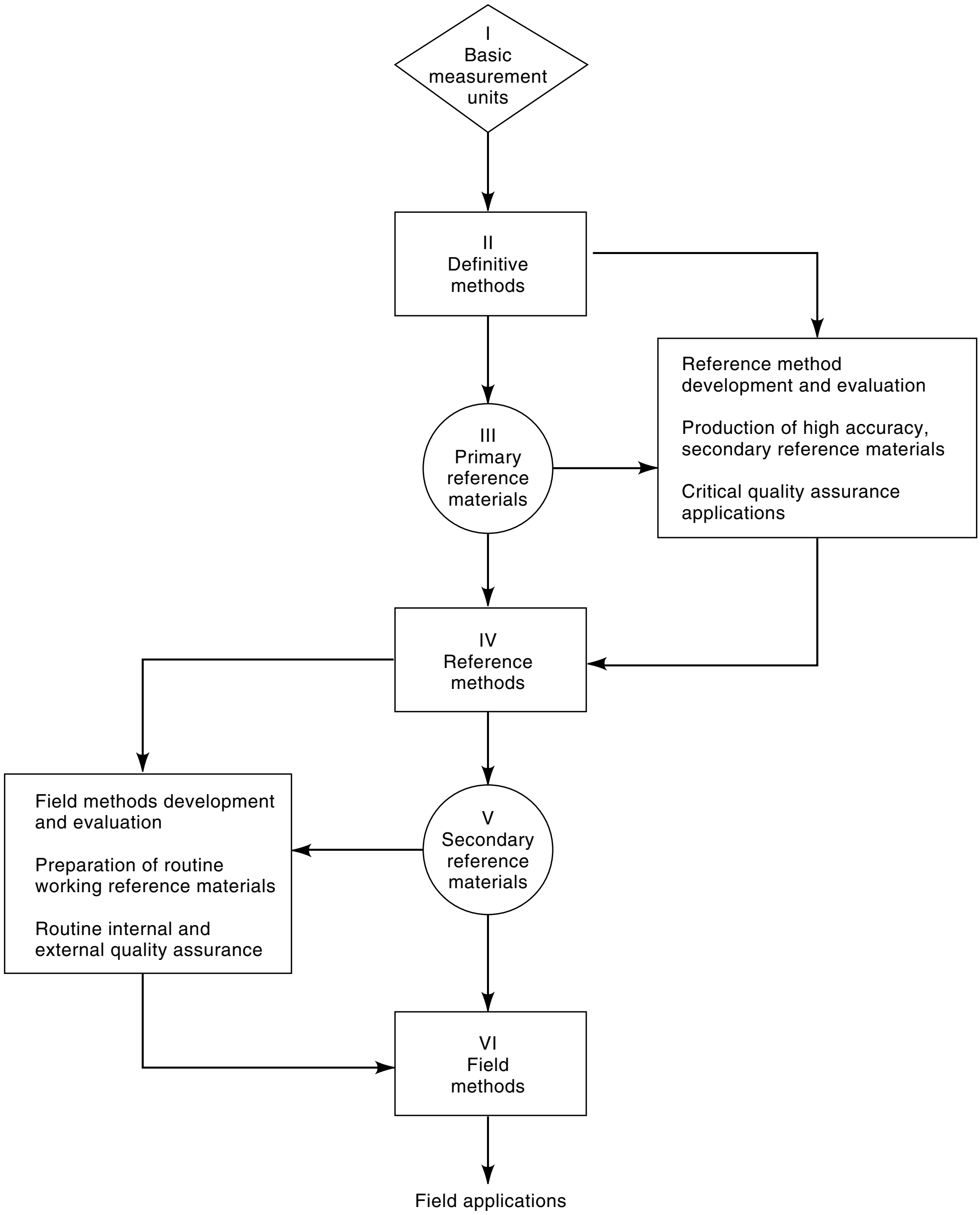

Fig. 2. Measurements standards hierarchy (6).

Table 1. **Characteristics of Various Environments**[a]

Space	Ocean	Human body	Nuclear reactor	Laboratory
extreme vacuum	high pressure	moist complex and diverse electrochemistry of various body fluids	high temperature	high temperature
radiation nonpenetrating penetrating	nearly constant temperature			high pressure
	saline water		neutron flux	high magnetic fields
			reactive coolants	
temperature ascent reentry ambient	silt and colloidal suspensions			plasmas
			radioactive sources	
	marine life			
	mechanical instability waves tides currents		high thermal flux	
lack of normal gravitational field		complex flexural behavior		
			inaccessibility	
micrometeorites		multicomponent composite, highly damped in the mechanical and electrical sense		
long-term missions	opaque to EM[b] radiation			
inaccessibility				
	inaccessibility			
		multielement constitution of body fluids gases wastes nutrients antibodies hormones enzymes reactive to foreign materials inaccessibility		

[a] Ref. 60.
[b] EM = electromagnetic.