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U.S. METRIC STUDY INTERIM REPORT

ENGINEERING STANDARDS

U.S. METRIC STUDY

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U.S. METRIC SUBSTUDY REPORTS

The results of substudies of the U.S. Metric Study, while being evaluated for the preparation of a comprehensive report to the Congress, are being published in the interim as a series of NBS Special Publications. The titles of the individual reports are listed below.

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U.S. METRIC STUDY INTERIM REPORT

ENGINEERING STANDARDS

Eleventh in a series of reports prepared for the Congress

U.S. METRIC STUDY
Daniel V. De Simone, Director

National Bureau of Standards
Special Publication 345-11

UNITED STATES DEPARTMENT OF COMMERCE
Maurice H. Stans, *Secretary*
NATIONAL BUREAU OF STANDARDS
Lewis M. Branscomb, *Director*

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LETTER OF TRANSMITTAL

THE HONORABLE PRESIDENT OF THE SENATE
THE HONORABLE SPEAKER OF THE HOUSE OF REPRESENTATIVES

SIRS:

I have the honor to present the eleventh in the series of interim reports stemming from the U.S. Metric Study, prepared by the National Bureau of Standards.

This Study was authorized by Public Law 90-472 to reduce the many uncertainties concerning the metric issue and to provide a better basis upon which the Congress may evaluate and resolve it.

I shall make a final report to the Congress on this Study in August 1971. In the meantime, the data and opinions contained in this interim report are being evaluated by the Study team at the National Bureau of Standards. My final report to you will reflect this evaluation.

Respectfully submitted,

Maurice H. Stans

Secretary of Commerce

Enclosure

LETTER OF TRANSMITTAL

Honorable Maurice H. Stans
Secretary of Commerce

Dear Mr. Secretary:

I have the honor to transmit to you another interim report of the U.S. Metric Study, which is being conducted at the National Bureau of Standards at your request and in accordance with the Metric Study Act of 1968.

The Study is exploring the subjects assigned to it with great care. We have tried to reach every relevant sector of the society to elicit their views on the metric issue and their estimates of the costs and benefits called for in the Metric Study Act. Moreover, all of these sectors were given an opportunity to testify in the extensive series of Metric Study Conferences that were held last year.

On the basis of all that we have been able to learn from these conferences, as well as the numerous surveys and investigations, a final report will be made to you before August 1971 for your evaluation and decision as to any recommendations that you may wish to make to the Congress.

The attached interim report includes data and other opinions that are still being evaluated by us to determine their relationship and significance to all of the other information that has been elicited by the Study. All of these evaluations will be reflected in the final report.

Sincerely,

Lewis M. Branscomb

Lewis M. Branscomb, *Director*
National Bureau of Standards

Enclosure

FOREWORD

This report concerns the relationship of measurement units to engineering standards. Although it is addressed primarily to the issues posed by Section 3 of the Metric Study Act (Public Law 90-472), it is of necessity related also to international standards, a subject covered by a previous report.

Reports covering other substudies of the U.S. Metric Study are listed on the inside front cover. All of these, including this report, are under evaluation. Hence, they are published without prejudice to the comprehensive report on the entire U.S. Metric Study, which will be sent to the Congress by the Secretary of Commerce in August of 1971.

This report was prepared by a Metric Study task force, headed by Dr. Robert D. Stiehler and including Mr. Gustave Shapiro, Mr. Robert J. Klein, Mr. Harry Stoub, Mr. Arthur G. Strang, and Mr. Theodore R. Young, all of the National Bureau of Standards.

We are grateful to Mr. Frank Masterson and Mr. R. B. Belford, President and Technical Director, respectively, of the Industrial Fasteners Institute, for permission to include their first progress report on "A Study to Develop an Optimum Metric Fastener System." Their report, which appears as Appendix V of this volume, illustrates the manner in which innovations in engineering standards can be achieved.

In this as in all aspects of the U.S. Metric Study, the program has benefited from the independent judgment and thoughtful counsel of its advisory panel and the many other organizations, groups, and committees that have participated in the Study.

Daniel V. De Simone, *Director*
U.S. Metric Study

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

Public Law 90-472[1] approved on August 9, 1968 authorized the Secretary of Commerce to make a study to determine the advantages and disadvantages of increased use of the metric system in the United States. The Congress in passing this law recognized the close relationship between engineering standards and measurement units and authorized a study to determine the feasibility of retaining and promoting international use of dimensional and other engineering standards based on the customary measurement units of the United States. Section 3 of this act is specifically directed to this issue and states:

> In conducting the studies and developing the recommendations required in this Act, the Secretary shall give full consideration to the advantages, disadvantages, and problems associated with possible changes in either the system of measurement units or the related dimensional and engineering standards currently used in the United States, and specifically shall—
>
> (1) investigate the extent to which substantial changes in the size, shape, and design of important industrial products would be necessary to realize the benefits which might result from general use of metric units of measurement in the United States;
>
> (2) investigate the extent to which uniform and accepted engineering standards based on the metric system of measurement units are in use in each of the fields under study and compare the extent to such use and the utility and degree of sophistication of such metric standards with those in use in the United States; and

[1] See app. 1 for the full text of this law.

(3) recommend specific means of meeting the practical difficulties and costs in those areas of the economy where any recommended change in the system of measurement units and related dimensional and engineering standards would raise significant practical difficulties or entail significant costs of conversion.

The last part of section 3, Public Law 90-472, dealing with the difficulties and costs of conversion is not within the scope of this report. Costs of conversion are considered in the report on the Manufacturing Industry, SP345-4. The cost of issuing engineering standards based on metric measurement units would be largely absorbed during the regular revision of the present standards. Metric dimensional specifications for standard parts and products would be largely based on national and international standards used in other countries. The cost of development of new standards incorporating latest knowledge and technological capabilities would be mainly the cost of technological improvement. On the other hand, revision of engineering standards in a crash program solely to incorporate metric measurement units could cost many millions of dollars. However, a crash program has not been considered since it is neither necessary nor feasible.

Since the passage of Public Law 90-472, the increasing worldwide use of the metric system, which was the primary concern leading to its passage, has now encompassed virtually all countries of the entire world. The one notable exception to this worldwide trend is the United States. Concomitant with the expansion in metrication has been an acceleration in the internationalization of engineering standards on which the quality, uniformity and compatibility of products are based. Engineering standards have served as a keystone in our domestic industrial development, as they have in other industrialized nations. These developments and the coupling of engineering standards with product certification in Europe were presented in NBS SP345-1 on International Standards. The aspects of SP345-1 relating to engineering standards have been included in this report.

This survey was limited to nine representative groups of engineering standards, comprising roughly one-third of some 400 recommendations issued by the International Electrotechnical Commission (IEC) and 1200 recommendations issued by the International Organization for Standardization (ISO) through 1969. It consisted of a comparison of over 500 IEC and ISO Recommendations with corresponding national standards of the U.S. and six other countries. This number is less than 1 percent of the estimated 60,000 standards issued by private and government organizations in the U.S. and voluntarily used as national standards. Nevertheless, a study of these groups indicated trends in voluntary standardization and the surge toward international standardization that has occurred in recent years. Company standards have not been studied since they are proprietary in nature and are affected only to the extent that they depend on national or international standards.

The role of measurement units depends upon the category of the standard; that is, dimensional specification, quality specification, method of test, or descriptive standard. A survey of ISO Recommendations issued through

1969 indicates that about 25 percent are dimensional specifications, about 15 percent are quality standards, about 45 percent are methods of test, and about 15 percent are descriptive standards. *Measurement units are important in dimensional specifications since sizes are usually simple multiples or submultiples of the customary measurement unit employed in a particular country.* Measurement units in quality specifications and methods of test are not critical since the units serve only as a language. Differences in actual requirements among quality specifications result from differences in engineering practices and *not* from the measurement units. Measurement units are not involved in descriptive standards. Nevertheless, the extent of incompatibility among corresponding national descriptive standards appear to be as great as among other categories. *Thus, it is the engineering practice rather than the measurement units that determines compatibility or incompatibility of most standards. The importance of measurement units is their role in developing the engineering practice.*

National standards in most countries are issued by a single standardization organization. In the U.S., voluntary standards used throughout the country and effectively national standards are issued by about 400 organizations, exclusive of individual companies which have proprietary standards for their products. In addition, about 6,000 local governments issue building codes and regulations which may or may not be in agreement. Fragmentation and lack of central responsibility have led to duplication of effort and confusion. Only a small portion of U.S. standards are coordinated by the American National Standards Institute (ANSI) which represents the U.S. in IEC and ISO. Participation of other organizations in ISO is through ANSI. However, many products being standardized by ISO are not included in the present scope of ANSI or its member organizations. Private voluntary groups in the U.S. issue about 20,000 standards, exclusive of company and government standards, but very few standards for consumer goods are among them.

U.S. standards are generally not compatible with IEC and ISO Recommendations which many countries are adopting as their national standards. The notable exceptions are standards in a few industries where there has been active voluntary U.S. participation in the IEC or ISO technical committee. Interest in voluntary international standardization that existed early in the century markedly decreased after World War I. Interest was revived after World War II, but U.S. participation in ISO technical committees, subcommittees, and working groups had only reached the 50 percent level by 1970. As a result of indifference and lack of participation, U.S. practices have not been considered in many committees. *If U.S. practices are to be reflected in international recommendations, active participation on the drafting committees is essential.*

The 1,600 IEC and ISO Recommendations issued through 1969 is about 10 percent of the estimated 15 to 20 thousand required for international commerce. Recommendations are being issued at an increasing rate. With the increasing emphasis on international standardization, it is expected that most of the recommendations required will be drafted during the next 10 years. *The U.S. cannot afford to be absent from the negotiations in this criti-*

cal decade of standards development if U.S. practices and technology are to be reflected in emerging international standards.

Prior to 1967, the following measurement units were principally used in engineering standards of industrial nations:

Customary metric units
Imperial units
U.S. customary units

These units are not mutually exclusive since most Imperial and U.S. customary units are the same and some U.S. customary units are the same as customary metric units; for example, electrical units. Customary metric units are generally used in the U.S. for biological and chemical standards. The current trend is to use the International System of Units (SI). Both IEC and ISO now require SI units in all recommendations. Customary units may also be included if desired. *Future national standards which do not include SI units are not likely to receive due consideration in the development of international standards.* This trend has been recognized by the American Society for Testing Materials, American Society of Mechanical Engineers, Society of Automotive Engineers, and others. These organizations now require or recommend the inclusion of SI units in addition to customary units in the standards which they issue.

Dimensional specifications in different metric countries are incompatible as frequently as those in countries using the inch unit for measurement. *Thus, a change to metric units does not by itself make standards compatible.* The lack of compatibility among national standards of both metric and nonmetric countries is responsible for the current movement toward international standardization. A few dimensional specifications based on the inch and U.S. engineering practices are used internationally and have been incorporated in IEC and ISO Recommendations. Likewise, there are a few specifications based on metric units used throughout the world including the U.S. For most products, however, change in engineering practices and standards is required in both metric and nonmetric countries to achieve international standardization. *Thus, an opportunity is provided during such change to make a critical review of practices incorporated in standards that have continued because of tradition.* A metrication program can provide the psychological climate in the U.S. that is needed to effect a break from tradition and reflect in standards current knowledge and technological capabilities. *A metrication program could and should have as a by-product changes in engineering practices and standards which will conserve raw materials, improve the quality of products and reduce costs.* Such benefits can be achieved without a metrication program, but in many instances there is not sufficient incentive to change traditional practices. A metrication program can provide the incentive needed.

When different national standards are developed for new devices, products, or practices, the economic cost of subsequent international standardization may be prohibitive. For example, the same electrical measurement units are used throughout the world. However, the possibility of international standardization of the magnitudes of voltage and frequency for electrical equipment or of the practices in television communication used in different countries is remote. *In the future, standardization of new practices and technologies should start simultaneously at the national and international levels when standardization beyond the company level is essential.*

Finally, three questions were posed at the start of the survey. They may be answered as follows:

Q. To what extent are U.S. standards incompatible with international standards because of the differences in measurement units?

A. Only dimensional specifications comprising about 25 percent of engineering standards are incompatible because of measurement units. However, not all dimensional specifications are incompatible and more than a change in measurement units is required to make incompatible dimensional specifications compatible.

Q. Is it feasible to retain and promote U.S. standards without a change in our measurement units?

A. It is still possible, but it is becoming more and more difficult, to promote U.S. standards having only customary units. Promotion of U.S. standards internationally is greatly facilitated when the standard permits easy use in metric countries. Recent actions by several standardizing organizations to include measurement units of the International System of Units result from a recognition of this trend.

Q. Is the nature of our measurement units a significant factor influencing U.S. effectiveness in international standards negotiation?

A. Yes. Efforts devoted to defending the use of U.S. customary units or to persuading the incorporation of dual units or sizes in international standards frequently makes negotiations on important features of U.S. practices ineffectual.

2. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

(1) Engineering standards and measurement units are separate but related items. (secs. 6 and 11)

(2) The compatibility or incompatibility of engineering standards in different countries depends primarily on the engineering practices rather than the measurement units; a change in units without a change in engineering practices will not resolve present incompatibilities among standards. (secs. 7, 8.5, and 14)

(3) Measurement units are important in engineering standards when a series of product sizes, such as screw threads, are based on simple multiples or submultiples of the customary measurement units employed in a particular country. On the other hand, sizes based on the same units are frequently not the same in different countries. (sec. 11.1)

(4) Dimensional specifications for standard products, in which measurements units are critical, comprise about one-fourth of engineering standards. (secs. 6 and 10)

(5) In most engineering standards, measurement units serve only as a language; descriptive standards generally do not include units. (secs. 6, 10, and 13)

(6) Many engineering standards in the U.S. employ customary metric units, particularly standards for biological and chemical materials. (secs. 13 and 17)

(7) In the U.S. and other countries and in international standardization, the current trend is to include or use the International System of Units (SI) in new and revised standards. (secs. 10 and 13)

(8) The International Electrotechnical Commission and the International Organization for Standardization are the two worldwide voluntary organizations concerned with standardization of engineering practices. (sec. 8.3)

(9) The U.S. through the American National Standards Institute participates in about 50 percent of the IEC and ISO groups developing international recommendations and standards. (sec. 8.4)

(10) The compatibility of U.S. standards with IEC and ISO Recommendations is related to the degree of U.S. participation in the group drafting the recommendations; but approval of an IEC or ISO Recommendation by ANSI does not necessarily imply compatibility with corresponding U.S. standards. (secs. 8.3, 8.4, and 17 to 24)

(11) U.S. standards that are or can be readily used in metric countries are more likely to receive due consideration in developing the IEC or ISO Recommendations. (secs. 13, 19, and 20)

(12) Some dimensional specifications based on the inch unit that are in use throughout the world are IEC or ISO Recommendations. (secs. 15.4, 23.2, 24.2, and 24.10)

(13) It is becoming increasingly more difficult to have inch-based dimensional specifications approved as IEC or ISO Recommendations. (secs. 10 and 11)

(14) The use of standard products whose dimensions are based on SI units is increasing within the U.S., particularly by companies manufacturing in several countries. (secs. 21.1, 24.7, and 24.15)

(15) Metrication without guidance can lead to a doubling in number of sizes and an economy burdened indefinitely with both inch-based and millimeter-based sizes. (secs. 24.7 and 24.15)

(16) Advantage should be taken in any increased usage of metric-based standard parts and products to effect through international standardization a reduction in the number of sizes and to incorporate latest knowledge and technology in establishing the international standards. (secs. 11.3, 23.3, 24.10, and 24.15)

(17) A by-product of conversion to metric-based parts and products can be conservation of materials and improved quality specifications, particularly in those instances where traditional practices have hindered change. (secs. 23.3 and 24.15)

(18) Currently, about 400 voluntary and government organizations issue engineering standards used throughout the U.S. which has resulted in duplication of effort and confusion; this uncoordinated system is not conducive to efficient functioning particularly at the international level. (sec. 8.2)

(19) There is an urgent need for review at both the domestic and international levels of the administrative process involved in the issuance of standards to handle the increasing rate of standards development. (sec. 9.3)

(20) The critical decade in international standardization has begun; failure to act promptly is likely to be detrimental to U.S. foreign trade of the future. (sec. 9.3)

(21) Standardization of new practices and technologies that require standardization beyond the company level should begin simultaneously at the

national and international levels if the prohibitive costs on international standardization after national practices are well established are to be avoided. (sec. 15.4)

2.2 RECOMMENDATIONS

The findings of this survey have led to the following recommendations:

(1) That the highest priority be given to reviewing and revising engineering standards in any metrication program, be it evolutionary, planned or mandatory.

(2) That international standardization be fostered in order to achieve the greatest economic benefit.

(3) That advantage be taken in any metrication program to effect through international standardization a reduction in number of product sizes, conservation of materials, and an improvement of product quality, by incorporating latest knowledge and technology, particularly in those instances where traditional practices have hindered change.

(4) That the use of SI units, either alone or with customary units, in all U.S. standards be promoted in order to foster their acceptance internationally and that standards be drafted in such form to permit easy use in metric countries.

(5) That standardization of new practices and technologies which require standardization beyond the company level, begin at the international level in order to avoid the prohibitive cost of international standardization after national practices are well established.

(6) That, except for the inclusion of SI units, no change in domestic standards be made when the cost of implementing the change would be prohibitive compared to the benefits, such as in the case of the standard for railway gage of existing railroads.

(7) That special attention be given to the administrative process of standardization in order to assure adequate U.S. participation in groups drafting standards at the international level, and to the development and issuance of national standards required by the consumer, industry, and government.

3. PURPOSE OF STANDARDS SURVEY

The intimate relationship between measurement units and engineering standards was recognized by the Congress in drafting Public Law 90-472 by the following provisions in sections 1 and 3, respectively:

"That the Secretary of Commerce is hereby authorized . . . to study the feasibility of retaining and promoting by international use of dimensional and other engineering standards based on the customary measurement units of the United States . . . ."

"In conducting the studies and developing the recommendations required in this act, the Secretary shall give full consideration to the advantages, disadvantages, and problems associated with possible changes in either the system of measurement units or the related dimensional and engineering standards currently used in the United States . . . ."

As a consequence of these provisions, a Standards Survey was included as one part of the overall Metric Study initiated under Public Law 90-472 to provide answers to the following questions:

(1) To what extent are U.S. standards incompatible with international standards because of the differences in measurement units?

(2) Is it feasible to retain and promote U.S. standards internationally without a change in our measurement units?

(3) Is the nature of our measurement units a significant factor influencing U.S. effectiveness in international standards negotiations?

In order to obtain meaningful answers to these questions, it was important to determine the role of measurement units in engineering standards.

4. SCOPE OF STANDARDS SURVEY

The many thousands of engineering standards in existence in the United States and in other countries and the limited financial resources available to conduct the Survey made a limitation in the scope necessary. Therefore, the Survey was restricted to the international recommendations issued by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), the two voluntary standardization organizations that have worldwide membership. These recommendations are indicative of current trends toward harmonization of national standards.

Even a comparison of the approximately 1,200 ISO Recommendations and 400 IEC Recommendations with national standards of various countries was too great a task with the available resources. Accordingly, the Survey was further restricted to the following nine groups of standards:

- Steel
- Nonferrous metals
- Plastics
- Rubber
- Pipe and tubing
- Antifriction bearings
- Threaded fasteners
- Electrical and electronic components and equipment
- Building construction and materials

These nine groups are representative of standards for basic engineering materials, components, and products. Conclusions and recommendations in this report are based on a survey of engineering standards in these nine groups.

This report does not attempt to assess the cost of conversion or to study means of meeting the practical difficulties and costs involved in converting manufacture to engineering standards based on metric measurement units mentioned in item (3) of section 3 of Public Law 90-472. Other reports deal with costs involved in conversion, particularly SP345-4 on the Manufacturing Industry. Cost of issuing engineering standards based on metric measurement units would be largely absorbed during the regular revision of the present standards. Metric dimensional specifications for standard parts and products would be largely based on national and international standards used in other countries. The cost of development of new standards incorporating latest knowledge and technological capabilities would be mainly the cost of technological improvement. A crash program solely to incorporate metric measurement units in engineering standards would cost many millions of dollars. Such a program is not feasible and therefore is not considered as an alternative in the U.S. Metric Study.

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5. DEFINITIONS

5.1 ENGINEERING PRACTICE

A way in which things are made or done technically, such as in characterizing, constructing, describing, designing, dimensioning, drawing, inspecting, manufacturing, measuring, prescribing, sampling, servicing, testing, or using a product, or a thing made to have prescribed attributes.

5.2 ENGINEERING STANDARD

An engineering practice established by authority or mutual agreement and described in a document to assure dimensional compatibility, quality of product, uniformity of evaluation procedures, or uniformity of engineering language. Examples are documents prescribing screw thread dimensions, chemical composition and mechanical properties of steel, dress sizes, safety standards for motor vehicles, method of test for sulfur in oil, and codes for highway signs.

5.3 MEASUREMENT STANDARD

A device or physical phenomenon which is used to define or determine some characteristic of a thing in terms of a unit of measurement established by authority. Examples are gage blocks, weights, thermometers, and mean solar day.

5.4 INTERNATIONAL SYSTEM OF UNITS (SI)

The coherent system of units based upon and including the meter (length), kilogram (mass), second (time), kelvin (temperature), ampere (electric current), and candela (luminous intensity) as established by the General Conference on Weights and Measures in 1960 under the Treaty of the Meter. The radian (plane angle) and the steradian (solid angle) are supplementary units of the system. All other units are derived from these eight units.

5.5 CUSTOMARY UNITS OF MEASUREMENT

The units most commonly used in trade within a country. In metric countries, they are the units in use prior to the adoption of the International System of Units. In the United States, they are units related to the yard and pound but are frequently referred to as the "inch-pound system."

5.6 METRICATION

Any act tending to increase the use of the metric system (SI), whether it be increased use of metric units or of engineering standards that are based on such units.

6. FUNCTION OF ENGINEERING STANDARDS

The function of an engineering standard varies from one to another, but it is one or more of the following:

6.1 DIMENSIONAL SPECIFICATIONS

Standards of this type are essential either for the product or system to function or for interchangeability of parts. For example, the distance between rails (gage) and between wheels in a railroad must conform to a standard in order to have the railroad function. On the other hand, standards aimed toward interchangeability of parts may be applicable to production of an entire industry or of a single company. For instance, automobile tires are interchangeable on an industry-wide level; whereas, the wheels on which they are mounted are generally interchangeable only on vehicles of the same make produced by a single company since the number and spacing of the bolt holes in the wheels have not been standardized for the industry. Sizes in dimensional specifications are usually simple multiples or submultiples of the measurement unit. *As a consequence, the system of units is generally an important factor in such standards.*

6.2 QUALITY SPECIFICATIONS

The purpose of these standards is to assure (1) a quality level adequate for the required service and (2) uniformity in quality from one item to another. Quality level is a dominant factor in safety standards; for example, seat belt standards and specifications for steel forgings for pressure vessel shells. Measurement units serve as a language in quality specifications, and hence are not critical. Different systems of units in quality specifications create problems analogous to those encountered in standards expressed in different written languages. Incompatibilities in requirements among quality specifications result from differences in engineering practices and *not* from the measurement units.

6.3 METHODS OF TEST

These standards provide a common basis for evaluating materials and products. They establish standardized procedures for determining critical dimensions or product quality, and are essential for determining compliance of a product with a specification. A typical method is mechanical testing of steel products. Methods of test can generally be based on any measurement units, and the results of test can be transformed from one system of units to another. Thus, the units in methods of test, as in quality specifications, serve as a language. Incompatibilities can result from the restrictive way in which a method is written or from differences in engineering practices.

6.4 DESCRIPTIVE STANDARDS

These standards comprise those standardized engineering practices which do not involve units of measurement. They include codes, symbols, sampling and other statistical practices, terminology, format for engineering drawings, and other descriptive engineering practices. Typical examples are sample size to estimate the average quality of a lot or process, color coding of electronic components, code for highway signs, identification colors for pipes conveying gases and liquids, international code for the abbreviation of titles of periodicals, and nuclear energy glossary. Although measurement units are not involved, descriptive standards may be as incompatible as dimensional specifications. For example, the practice of keeping to the left side of the roadway in some countries and to the right side in others is not amenable to a compromise or compatible solution. Other than live with both, the only resolution is for one group of countries to change their practice.

6.5 MULTIFUNCTIONAL STANDARDS

Some standards for products include dimensional requirements, quality requirements, methods of test and descriptive provisions. More commonly, separate standards are issued for methods of test and descriptive standards since a single such standard is generally applicable to a broad class or group of materials or products. These standards become part of material or product specifications by reference. Similarly, a quality specification is frequently issued for a material used in a wide range of products; for example, a quality specification for a certain grade of cement or steel. Such specifications are then referenced in the specifications for products in which these materials are required. Even a dimensional specification such as screw threads is referenced in specifications for numerous fasteners and other products. Thus, the function of any particular standard depends on its scope. Measurement units are not vital in most standards. In dimensional specifications, measurement units play a language role. In addition, they usually become one of the factors incorporated into the practice of the engineering standard. This dual role accounts for their importance in most dimensional specifications.

7. COMPATIBILITY OF STANDARDS

Two standards are compatible when the same engineering practice is prescribed. It is not necessary that the same measuring units and written words be used. For example, certain pipe standards in many countries are compatible even though each country uses its customary units and written language in the standard. On the other hand, standards for pipe thread in England and the U.S. are not compatible even though they are both expressed in the same measurement unit and written language. *Thus, it is the engineering practice rather than the measurement units which determine compatibility or incompatibility of standards, and a change in units without a change in engineering practice will not resolve present incompatibilities among standards.* The importance of measurement units is their role in developing the engineering practice. In the past, most products made in a series of sizes conformed to whole numbers, multiples of binary fractions or simple decimals in the system of units used. For example, steel bar and rod are usually made in the U.S. in increments of 1/16 inch in the smaller sizes, 1/8 inch in the intermediate sizes, and 1/4 inch in the larger sizes. In metric countries, the increments are 1, 2, or 5 millimeters. As a consequence, the two standards are not compatible. In order to resolve this problem and to select sizes on a rational basis, the tendency today is to use the rational system proposed by Charles Renard in 1879 for establishing sizes. This system known as preferred numbers is based on a geometrical (rather than arithmetical) progression for selecting sizes. For applications requiring an arithmetical progression for sizes, for example in building construction, the modular system is being used in standards. Whether preferred numbers or modules are used for determining sizes, a choice must be made for the base size. A base module of 100 millimeters is generally not compatible with one of 4 inches (101.6 mm). Likewise, a preferred number series based on U.S. customary units is not compatible with one based on SI units unless the difference of 1.6 percent can be tolerated. In a few instances, worldwide agreement exists on sizes, based on either U.S. customary or metric units. *For most products, agreement does not exist and the practices in many or all countries must be changed to achieve compatibility of sizes.*

8. DEVELOPMENT PROCESS FOR ENGINEERING STANDARDS

Engineering standards are developed and promulgated at three levels; namely, by a single organization, by a national organization, and by an international organization. The degree of coordination increases as a standard progresses from the single to the national to the international organization.

8.1 STANDARDS ISSUED BY A SINGLE ORGANIZATION

These standards which are issued by a local government or a single company, either a producer or consumer, are generally poorly coordinated. They include local building codes, company purchase specifications, and producers specifications for the products he sells or uses in his manufacturing process. The objective of these standards is to provide interchangeability of parts and/or to obtain a quality level in products purchased or sold. Codes issued by some 6,000 local governments prescribe minimum quality levels for building construction and repair. Insofar as a standard issued by a single organization is incompatible with other standards for the same product, it restricts trade. When there are numerous company standards instead of an industry or national standard, similar parts for products of different companies (e.g., wheels on automobiles of different makes) are not interchangeable. Hence the demand for a replacement part is inversely related to the number of different standards for the part. As a consequence, the market for a part made to a particular company standard may be too small to attract manufacture by anyone other than that company. Thus, company standards may foster proprietary interests and reduce the availability of replacement parts to the consumer. In some instances replacements for proprietary parts must be ordered from the manufacturer with all the attendant delays of such purchases.

8.2 NATIONAL STANDARDS

Standards used throughout a country and issued by an organized group within the country are national standards. In Russia and a few other countries, they are issued by the government and are mandatory. In the U.S. and most other countries, only regulatory standards are mandatory. Most engineering standards are voluntary. In most countries, a single group or organization issues most or all national standards. In the U.S., about 400 organized groups issue standards that are recognized nationally. They include

TABLE 1. Sources of American National Standards

Approved by American National Standards Institute

Member Organizations:
- American Association of Textile Chemists and Colorists
- American Concrete Institute
- American Dental Association
- American Gear Manufacturers Association
- American Institute of Architects
- American Petroleum Institute
- American Society of Civil Engineers
- American Society of Heating, Refrigerating, and Air-Conditioning Engineers
- American Society of Mechanical Engineers
- American Society for Quality Control
- American Society for Testing and Materials
- American Water Works Association
- American Welding Society
- Anti-Friction Bearing Manufacturers Association
- Architectural Aluminum Manufacturers Association
- Association of American Railroads
- Builders Hardware Manufacturers Association
- Compressed Gas Association
- Conveyor Equipment Manufacturers Association
- Diamond Core Drill Manufacturers Association
- Edison Electric Institute
- Electronic Industries Association
- Federation of Societies for Paint Technology
- Illuminating Engineering Society
- Institute of Electrical and Electronic Engineers
- Institute of Traffic Engineers
- Insulated Power Cable Engineers Association
- Mechanical Power Transmission Association
- National Electrical Manufacturers Association
- National Fire Protection Association
- National Fluid Power Association
- Resistance Welder Manufacturers Association
- Society of Automotive Engineers
- Technical Association of the Pulp and Paper Industry
- Underwriters' Laboratories

Government Organizations:
- American Association of State Highway Officials
- Bureau of Mines, Department of Interior
- Department of Defense
- Department of Health, Education, and Welfare
- General Services Administration
- Interstate Commerce Commission
- National Bureau of Standards, Department of Commerce

Foreign and International Organizations:
- Institute of Petroleum (London)
- International Electrotechnical Commission
- International Organization for Standardization

the government, organizations of government officials such as the American Association of State Highway Officials, the Association of Official Analytical Chemists and National Association of State Purchasing Officials, and private voluntary organizations such as the American National Standards Institute, American Pharmaceutical Association, American Society for Testing and Materials, American Society of Mechanical Engineers, Institute of Electrical and Electronic Engineers, Society of Automotive Engineers, industrial trade associations, etc. The degree of coordination depends on the organization issuing the standard. American National Standards issued by the American National Standards Institute (ANSI) probably represent the greatest degree of coordination among the voluntary standards and are recognized internationally as our national standards. Most of these standards are developed by 35 member organizations of ANSI and seven government organizations listed in table 1, but only a small portion of standards developed by these organizations have thus far become American National Standards. ANSI does not issue standards for food, drugs, and other biological materials. National standards may restrict trade, but they tend to be less restrictive than standards issued by a single organization. Although there is no deliberate attempt to do so, measurement units customarily used within a country and the sizes of products based on the measurement system can serve in national standards as trade restrictions in international commerce.

8.3 INTERNATIONAL STANDARDS

International standardization began informally when immigrants to the United States continued to use the engineering practices that they brought with them. The first formal movement began in 1882 when a small group of workers in experimental engineering held an international conference in Munich to stimulate standardization of testing procedures. This movement rapidly expanded and larger meetings were held in 1884 (Dresden), 1886 (Berlin), 1888 (Munich), 1893 (Vienna), and 1895 (Zurich). At the Zurich Congress, the International Association for Testing Materials (IATM) was formally organized with headquarters in Vienna, Austria. Many members of IATM were in the United States. They organized the American Section of IATM on June 16, 1898, which was incorporated in March 1902 under the name of American Society for Testing Materials (ASTM).[2] During this period interest also developed in international standardization in the field of electricity, and a resolution at the 1904 meeting of the International Electrical Congress held in St. Louis led to the formation of the International Electrotechnical Commission (IEC) in 1906 with headquarters in London. Instead of individual memberships as in IATM, the members of IEC were national committees in participating countries. The U.S. National Committee for IEC was founded in 1907.

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[2] Name was changed in 1961 to American Society for Testing and Materials.

Interest in international standardization within the United States reached a peak just before World War I. At that time, 623 or over 20 percent of the 2,849 members of IATM were in the U.S.; Germany was second with 466 members. To promote the international use of ASTM Standards, twenty specifications for steel products were published in the English, French, German and Spanish languages by ASTM in 1913. Subsequently, the U.S. Department of Commerce translated ASTM Standards having an important bearing on export trade and distributed them to Consular Offices throughout the world.

U.S. interest in international standardization continued during and after World War I, but it decreased markedly after IATM ceased to function in 1915. Neither the new IATM nor the International Standards Association (ISA), both of which were formed in 1926, revived the interest in international standardization that existed prior to World War I. Both the new IATM and ISA ceased to function in World War II.

The need for international standardization was recognized by the Allied Nations. In 1944, they formed the United Nations Standards Coordinating Committee to coordinate standards for products produced in the various countries. The need for continuing the work of the committee after the war led to the establishment of the International Organization for Standardiza-

TABLE 2. Countries Participating in International Standardization: IEC and ISO

Country	*IEC*	*ISO*	*Country*	*IEC*	*ISO*
Argentina	X		Korea (North)	X	X
Australia	X	X	Korea (South)	X	X
Austria	X	X	Lebanon		X
Belgium	X	X	Malaysia		X
Brazil	X	X	Mexico		X
Bulgaria	X	X	Morocco		X
Canada	X	X	Netherlands	X	X
Ceylon		X	New Zealand		X
Chile		X	Norway	X	X
China	X		Pakistan	X	X
Columbia		X	Peru		X
Cuba	X	X	Philippines		X
Czechoslovakia	X	X	Poland	X	X
Denmark	X	X	Portugal	X	X
Finland	X	X	Romania	X	X
France	X	X	Singapore		X
Germany	X	X	South Africa	X	X
Ghana		X	Spain	X	X
Greece	X	X	Sweden	X	X
Hungary	X	X	Switzerland	X	X
India	X	X	Thailand		X
Indonesia	X	X	Turkey	X	X
Iran	X	X	USSR	X	X
Iraq		X	United Arab Republic	X	X
Ireland		X	United Kingdom	X	X
Israel	X	X	United States	X	X
Italy	X	X	Venezuela	X	X
Japan	X	X	Yugoslavia	X	X

tion (ISO) in 1946. IEC, which was able to survive both World Wars I and II, affiliated with ISO in 1947 but retained its autonomy. *These two voluntary organizations have become predominant in international standardization.* Participating countries in these organizations are listed in table 2. There are also regional organizations. The Pan American Standards Commission (COPANT) operates in the Western Hemisphere. The International Commission on Rules for the Approval of Electrical Equipment (CEE), the Economic Commission for Europe (ECE), and the Committee for the Coordination of European Standards in the Electrical Field (CENEL) are concerned with standardization in Europe. The U.S. is represented in IEC, ISO and COPANT by the American National Standards Institute.

Because of the worldwide representation in IEC and ISO, their Recommendations reflect the greatest degree of coordination. The use of IEC and ISO Recommendations is voluntary, but many countries are adopting them as their national standards. IEC and ISO Recommendations reflect the engineering practices of the nations that participate in drafting them. As a consequence, a nation which does not participate at the drafting stage may be at a disadvantage in international trade because adequate consideration was not given to its engineering practices during the deliberations leading to the recommendations.

8.4 TECHNICAL COMMITTEES

Both national and international organizations engaged in standardization operate through technical committees. A committee is responsible for standards in a particular field indicated by its title; for example, Committee on Steel. ASTM, the largest voluntary standardizing organization in the U.S., has 115 technical committees. At the international level, there are 70 technical committees in IEC and 139 in ISO. Technical committees may have subordinate organizational units such as subcommittees, sections, working groups, task groups, etc. The lowest unit generally develops the initial draft of a standard and has the greatest influence in selecting the particular practice that is standardized. Therefore, participation is necessary at both the committee and lower organizational levels to have adequate consideration given to a practice of particular interest. Nationally, it requires active participation by a company or other organization. Internationally, participation is even more important since engineering practices generally vary among countries more than among companies within a country. Yet, the United States has been poorly represented as evidenced by the following participation in ISO:

Organizational unit	Total number	U.S. participation	
		Number	Percent
Technical committee	139	96	69
Subcommittee	305	196	64
Working groups	566	214	36
All units	1010	506	50

Participation in IEC cannot be readily ascertained since all documents, except working group documents, are automatically circulated to each National Committee. However, members of the U.S. National Committee have made an estimate of 95 percent participation in technical committees and subcommittees. At the working group level, participation is estimated to be 50 percent or less.

Effective representation is probably less than indicated by these figures since U.S. delegates do not attend many meetings of bodies on which there is nominal participation. Continuity in representation by competent delegates who serve for extended periods of time is essential to make participation effective. *Lack of participation in these international meetings equals or exceeds measurement units as a factor responsible for the incompatibility of U.S. standards and many international recommendations.*

8.5 PROCESS FOR ESTABLISHING ENGINEERING STANDARDS

Wherever a multiplicity of practices is both possible and likely to occur, group cooperation for the achievement of some desirable social goal may require the acceptance, by the members of the group, of some joint decision to use one or a limited number of the possible alternatives. When the activities involved relate to social behavior the agreements (standards) are called laws. When related to religious behavior they are canons. And when related to manufacturing, testing, measurement practices and conventions, properties and performance of materials, or to the performance or characteristics of things, they are variously called standards of practice, code regulations, or conventions. All of these latter are commonly lumped together under the term "engineering standards."

The pattern of standards development has evolved into two main classes. At the industry level, standards are developed by materials and parts producers and device assemblers and presented to the ultimate consumer in the marketplace. Alternatively, the standards may be promulgated as procurement specifications by a buyer that is sufficiently large and important to have the standards met—for example, the Federal Government. Clearly, the two methods of arriving at standards—one initiated by the supplier and the other by the buyer—will often yield different decisions, with differing sets of advantages and disadvantages. A third class, where the ultimate consumer would set standards, has not emerged, probably because of lack of organization and competence among the body of consumers.

Where small groups which have developed standards seek to get together to form a larger aggregate of cooperation, they must resolve the differences in standards to arrive at a new set for the enlarged group. This process is called coordination or harmonization of standards. If the standard is established, first off, for the enlarged group, the costly waste motions of standard setting followed by later change and readjustment within the groups is eliminated.

Coordination or harmonization of standards at the national or international level proceeds in a similar manner. A draft is presented by a single organization or nation to the appropriate committee or task group. After study, modifications are made and a proposal or tentative standard is drafted for approval by letter ballot of the group. Disapprovals by members of the group are considered at subsequent meetings. After a consensus is reached, the drafting group submits the document to the full technical committee for approval. Again, a letter ballot is taken and disapprovals are referred back to the drafting group for consideration. If possible, modifications are made to resolve the objections. If the modifications are substantial, the document is again balloted. When a consensus is reached in the committee, the document is submitted to the parent organization for further processing.

In the case of ISO, the document progresses from a Draft Proposal to a Draft Recommendation when the technical committee approves it. The Draft Recommendation is submitted to all member countries for letter ballot. Disapprovals and comments are referred back to the technical committee for consideration. When a consensus has finally been reached, the document is issued as a Recommendation. An ISO Recommendation may subsequently become an ISO Standard, but thus far no standard has been issued.

IEC functions differently than ISO since all National Committees automatically receive all committee drafts of IEC Recommendations for comment. When a final draft is prepared, it is circulated for letter ballot of National Committees under a "six-month's rule." Modifications to reconcile objections are circulated for letter ballot under a "two-month's procedure." An IEC Recommendation is issued on the basis of the best consensus.

Obviously, the process for establishing engineering standards takes a long time. A national standard generally requires 2 or more years to process. The process for an international recommendation takes about 6 years, two to three times longer than that for a national standard. Minor amendments or revisions can be processed somewhat faster, but a substantial revision takes as long to process as the original document.

Thus, once an IEC or ISO Recommendation is issued, it is in effect for a long period before a change can be made. As the recommendation becomes incorporated in more and more national standards, a substantial change in the recommendation becomes more difficult to make. As a consequence, any particular industry in the U.S. which does not participate in the drafting of the original recommendation discovers that it is too late to effect a change after a recommendation has been issued. When U.S. practices differ markedly from those in the international recommendations, the industry concerned may be adversely affected in international trade.

9. MAGNITUDE OF STANDARDIZATION EFFORT

9.1 UNITED STATES

Except for the few regulatory standards issued by some government agency, the use of engineering standards in the U.S. is voluntary. Their effectiveness depends on the extent to which the voluntary standards are included in procurement contracts. Even though voluntary, the need for standards has long been recognized, at both the national and international level. To this end, many have voluntarily contributed the necessary technical knowledge and financial support. Yet, there has never been a single organization in the U.S. covering the entire gamut of engineering standards. Standardization activities have grown without coordination and have been fragmented among more than 400 standardizing groups.[3] Only a small portion of national standards issued by about 40 member organizations are coordinated by the American National Standards Institute. Standards for foods, drugs, and other biological materials are not included in the scope of ANSI or its member organizations.

Fragmentation and lack of central responsibility have led to duplication of effort and confusion. For example, standards for steel pipe are issued by three Federal Agencies and five private organizations. Some of these standards are essentially duplicates, others differ to some extent. Numerous standards for essentially the same product can be costly, particularly when adjustments in the manufacturing process must be made to satisfy the requirements of slightly different specifications. Further, the multiplicity of

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[3] See Directory of United States Standardization Activities, National Bureau of Standards Miscellaneous Publication 288.

standards for a particular product leads to opposition of many producers to standards and to objections by consumers to higher prices and restricted sources for replacement parts.

In spite of fragmentation and duplication, voluntary organizations in the United States have developed about 20,000 national standards. In the field of materials alone, ASTM has issued over 4,000 standards. However, these 20,000 standards include only those of interest to the members and whose development the members have been willing to finance. The Department of Defense has issued almost 35,000 specifications or standards, in addition to the 5,000 Federal specifications issued by the General Services Administration, in order to function. This number, which is more than twice the number of standards issued by private organizations, includes many for consumer goods, such as food and clothing, as well as those for electronic equipment and other products involving advanced technology. As a consequence, many Federal and military specifications are effectively national standards, particularly for end products used by the ultimate consumer. Very few such standards issued by private organizations are in existence. The 1970 ANSI Catalog lists only 125 standards for consumer goods and most of these pertain to items used in home construction. The consumer benefits from other standards such as standard bearings, fasteners, and other parts used in the manufacture of consumer products. Nevertheless, a large void remains in standards for consumer goods.

The small number of standards for consumer goods probably stems from the lack of representation of the ultimate consumer on most committees. Standards development is costly and consumers are not directly able to send knowledgeable representatives. For example, the development of national standards for color television employed 10,000,000 engineering man-hours. Small companies and consumer organizations generally cannot afford to participate actively on the numerous committees of interest to them. Thus, the most active members on committees are representatives of large consumers, producers and the government since these organizations can support the necessary laboratory and investigative work needed to establish standards. The interests of the individual consumer are indirectly represented to a limited extent by government involvement in standards development and ultimately by the play of the marketplace. Recent trends toward consumer awareness and participation indicate that the existing play of the marketplace is not enough. Either a very large organization of consumers that can have competent representation on committees or greater government involvement may be necessary to represent fully the consumer's interest.

The upper limit for the number of national standards required in the civilian economy would appear to be 40,000 since many specifications used by the Department of Defense are for items used by the military only. Although the 20,000 standards issued by voluntary organizations have many duplications, this number would appear to be the lower limit since these organizations have not yet established standards for many items, particularly for consumer goods.

9.2 OTHER COUNTRIES

In many countries a single organization issues standards. In other countries, one organization issues standards for all materials and products, except food, drugs and biological materials. In either case, they are supported to some extent by their governments and are officially recognized. Thus, the general practice is to have one or a very small number of organizations responsible for national standards. The approximate number of standards issued by some of these national organizations are as follows:

Association Francaise de Normalization	*7,000
British Standards Institution	*5,500
Deutschen Normenausschuss	11,000
Ente Nazionale Italiano di Unificazone	*6,000
Gosudarstvenny j Komitet Standartov, USSR	13,000
Indian Standards Institution	5,000
Japanese Standards Association	*7,000

*Does not include standards for food, drugs, and biological materials.

India, a developing nation, expects to have over 10,000 standards at the completion of the fourth plan. The number of standards is increasing rapidly in other countries also, stimulated by the rapidly expanding technologies in these countries in recent years.

There is also a movement to harmonize standards among certain countries, particularly in Europe. The policy in many countries is to base the national standards on IEC and ISO Recommendations whenever possible to do so. For example, India, which formerly based its standards on British, French, German, or U.S. standards, is now basing them on IEC and ISO Recommendations. Other developing countries are also looking to IEC and ISO for their standards. The countries of Europe harmonizing their standards are also using international recommendations insofar as possible. Thus, if engineering practices in the United States are to be used internationally, they must be incorporated into the IEC and ISO Recommendations.

9.3 THE CRITICAL DECADE AHEAD

There were slightly over 400 IEC Recommendations and about 1,200 ISO Recommendations issued at the end of 1969. This number must be increased by a factor of 10 or more to meet minimum requirements of a technological world economy. Currently, there is great pressure on IEC and ISO to speed the issuance of recommendations. These organizations are responding as evidenced by the data in figures 1 and 2 which show the standards issued yearly by IEC and ISO, respectively since 1950. Tables 3 and 4 summarize the same data in 5-year periods. Nearly two-thirds of the international recommendations have been issued in the past 5 years and the pace of issuance is accelerating. The worldwide impetus for standards development should result in drafting most of the international recommendations

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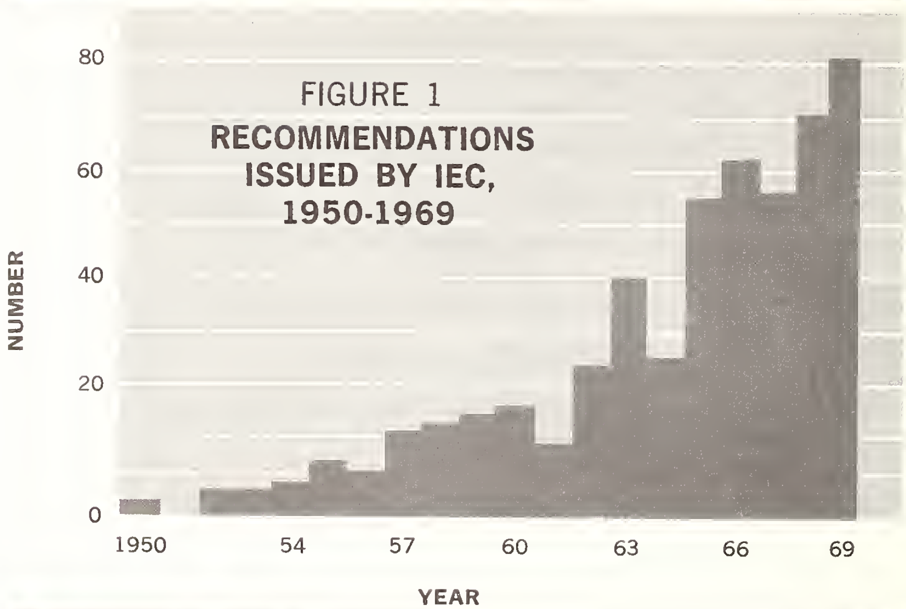
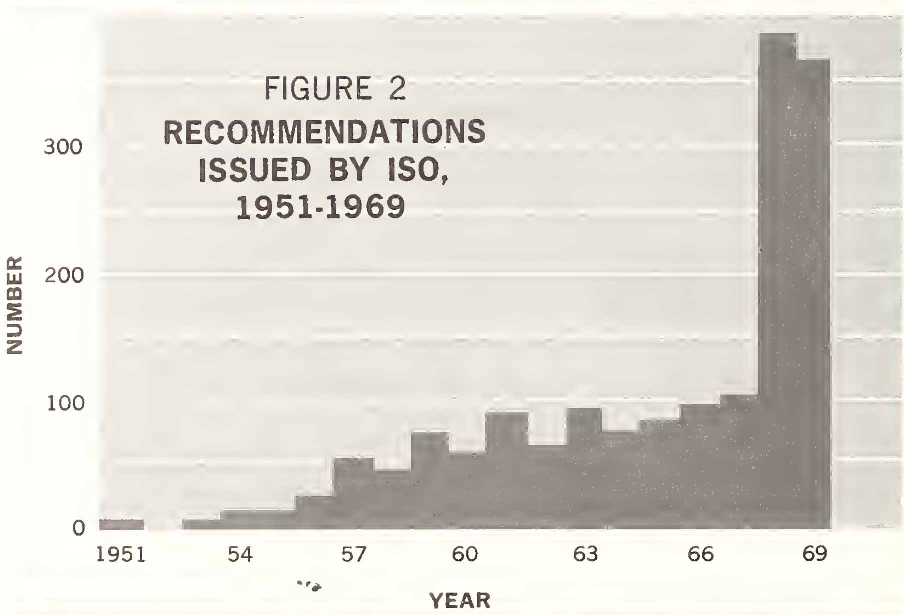




during the next 10 years. In this critical decade of standards development the United States cannot afford to be absent from the negotiations if it expects to have its technology and practices reflected in emerging international standards.

TABLE 3. IEC Recommendations

		Percent
1906–1938	60 issued, 14 have been revised since 1950, 3 are still active, remainder superseded or discontinued.	1
1938–1949	None issued.	
1950–1954	13 issued, 4 revised	3
1955–1959	53 issued, 16 revised	13
1960–1964	94 issued, 32 revised	24
1965–1969	272 issued, 42 revised	59
Total 1950–1969	432 issued, 94 revised	100

TABLE 4. ISO Recommendations

		Percent
1950–1954	11 issued	1
1955–1959	125 issued	10
1960–1964	283 issued, 1 revised	23
1965–1969	786 issued, 36 revised	66
Total 1950–1969	1206 issued, 37 revised	100

Cost of sending delegates overseas to meetings is privately financed, generally by individual companies or organizations paying the cost of travel and salary of their employees who are delegates. Thus far, U.S. participation and success in having U.S. standards adopted internationally are due mainly to the interest and financial support of a few organizations. The necessary continuity of representation by competent individuals is also dependent on the interest of their employers. This cost to individual companies is perhaps the principal deterrent to participation in many international committees. Travel expenses of a delegate to an overseas meeting averages about $800. Thus, to send two delegates to each of the estimated 1,100 meetings of committees, subcommittees, and working groups of IEC and ISO each year would cost nearly $2,000,000. This cost does not include salaries of delegates for time spent at meetings or devoted to committee activities between meetings. The costs are much higher when the Secretariat of a committee is held. As a result, the U.S. has 65 Secretariats of IEC and ISO Committees and Subcommittees as compared to France and England which have about 130 each and Germany which has over 70.

Standards activities in the United States, by virtue of their voluntary nature, have been free from any form of government control, a freedom cherished by ANSI and the industries. As a consequence, participation in international standardization varies from one industry to another. Even those industries most interested in international standardization generally support only direct technical involvement and they are reluctant to support overhead type of coordinating activity, particularly those required by having a Secretariat of a Committee with its many advantages.

It begins to appear that the freely voluntary process which worked domestically in spite of its shortcomings will not meet the challenge of the future on two fronts. Domestically consumers are being heard and will demand a voice in establishing standards. Internationally, effectiveness in IEC and

ISO requires that the U.S. point of view be presented at all meetings, and not just those of interest to particular producers. Whatever readjustments must be made, it is quite clear that the critical decade has already begun and that international standardization will move forward toward completion of the bulk of the work in this decade. If the U.S. turns its back or disassociates, international standardization will still continue and serve the needs of others. The U.S. can let it do so and try to adjust later. Alternatively, the U.S. can become a full participant and help formulate standards consistent with its practices.

The increasing rate of standards development is already creating problems in processing the large number of documents. *There is an urgent need for review at both the national and international levels of the administrative process involved in the issuance of standards in order to handle the increasing numbers.*

10. MEASURING UNITS IN ENGINEERING STANDARDS

Engineering standards can be based on any system of measuring units and can be converted from one system to another. However, the use of a common system would eliminate both errors that may be introduced by conversion of units and the man-hours that are required for such conversion.

As previously noted, the role of measurement units depends on the category of the standard; that is, dimensional specification, quality specification, method of test, or descriptive standard. A survey of the ISO Recommendations in the 1970 catalog indicates that about 25 percent are dimensional specifications, about 15 percent are quality standards, about 45 percent are methods of test, and about 15 percent are descriptive standards. An exact breakdown is not possible since a single recommendation could be placed in more than one category. A similar breakdown for the standards issued in the United States is not possible, since there is no composite list and there is considerable duplication. However, the distribution would probably be about the same as that for the 1,200 ISO Recommendations since they are a typical representation of national standards. If company standards were surveyed, the proportion of dimensional specifications would probably be higher than 25 percent since the dimensions of most products are not standardized nationally.

Since descriptive standards do not have measurement units and since units in methods of test and quality specifications serve only as a language, measurement units do not have an important role in about 75 percent of engineering standards. Even among the 25 percent that are dimensional specifications, measurement units are not at issue where sizes are already agreed internationally. For the other dimensional specifications which are now incompatible, there is an opportunity during standardization to adopt more rational sizes for international use.

Some of the existing IEC and ISO Recommendations include two systems of units and two series of sizes based on the inch and meter, respectively. However, *the present tendency is to use SI units* as evidenced by the following excerpt from Resolution 37 adopted by ISO Council in September 1969: "The Council . . . *instructs* the Secretary-General to ensure that from 1 January 1970 the units contained in ISO/R1000 are used in all Draft ISO Recommendations submitted to Member Bodies, together with corresponding values in other units if deemed desirable, and to make every effort to encourage Technical Committees to accept SI units as the first preference . . . ." (ISO Recommendation R1000 is entitled "Rules for the use of units of the International System of Units and a selection of the decimal multiples and submultiples of the SI units" and is reproduced in appendix II by permission of the Americal National Standards Institute.) Thus, future national standards which do not use SI are not likely to receive due consideration in the development of international standards, and the nations concerned will be at a disadvantage in future dealings with nations using SI. This trend was recognized by ASTM when it issued the ASTM Metric Practice Guide in 1964. The 1970 revision of this Guide is reproduced in appendix III by permission of the American Society for Testing and Materials. In order to promote ASTM Standards internationally, SI units are now required in addition to the customary units. ASME, SAE, and other standardization organizations have taken similar action, either requiring or recommending inclusion of SI units in their standards.

The importance of measurement units in international negotiations is well summarized in the following statement of a member of the Society of Plastics Industry given in the report presented at the first National Metric Study Conference in Deerfield, Massachusetts: "I have been involved for sometime with the industry's representation to ISO, particularly with TC 5/SC6 *(Ed. Plastic Pipe and Fittings)*. The United States is in a weakened position when we constantly have to fight for inclusion of conversion tables in recommendations and other documents being written by ISO from time to time. Things which are very important to the United States in the Standardization effort must be defended vigorously by delegates from the United States. If we spend much of our time in persuasion, trying to incorporate conversion tables, and defend our indefensible position on the use of the pounds and inches, we make ourselves ineffectual on the things that really are important to the United States in the world market."

In addition to uniformity in language, the use of SI units in engineering standards simplifies the measurement system and calculations. Numerous units for the same property in customary systems, either U.S. or metric, make conversions within a system necessary. The factors for converting must be either memorized or obtained from published tables. For example, in metric countries, the following units for energy are used in different fields of science and technology: calorie (6 variations), electron volt, erg, frigorie, (metric) horsepower-hour, joule, kilogram (force)-meter, kilowatt-hour, liter-atmosphere, thermie, and (metric) ton of TNT. In the U.S., the following units for energy are used: BTU (5 variations), calorie (6 variations), cubic foot-atmosphere, electron volt, foot-pound (force), foot-poundal, horsepower-hour (4 variations), inch-pound (force), kilowatt-hour, therm, and ton of TNT. Few, if any, engineers or scientists can make these conversions without the use of handbooks or other publications that give the conversion factors. In linear measure, there are over 50 units used in the U.S., including 20 customary metric units. Linear measure is further complicated by the numerous gages for metal sheet, strip, and wire. Over 70 gage systems were developed in various countries and used in the early part of this century. Although many are no longer used, there are still about 30 gage systems, 10 of which are being used in the United States.

In the International System of Units (SI), there is one and only one unit for a particular property. The same name is not used for the units of two or more properties. Units derived from the six base and two supplementary units are always related by a factor of unity. Thus, the confusion and complications in both U.S. and metric customary systems are eliminated in SI. To facilitate the expression of different magnitudes of a property, 14 prefixes may be used for multiples or submultiples of the units, ranging from a factor of 10^{-18} (atto) to 10^{12} (tera). For example, for the SI energy unit-joule, an attojoule is used in place of an electron volt (about 1/6 attojoule), a megajoule is used in place of kilowatt-hour (3.6 megajoules), and a terajoule is used in place of a ton of TNT (about 4.2 terajoules). This simplification and rationalization of the measurement system is the principal reason for the inclusion of SI units in new and revised international and national standards, and for their mandatory or proposed mandatory use in some 25 countries.

The inclusion of SI units in engineering standards is a recent innovation. Except for standards in which the metric customary and SI units are identical (primarily some length, mass and electrical units), the first standards incorporating SI units for all properties were published in 1967. Interestingly, they included several British Standards and one ASTM Standard. Although the survey of standards issued during the last few years in metric countries is sketchy, it appears that the incorporation of SI units in their national standards began even later. Thus, the measurement units in engineering standards are undergoing change in both metric and nonmetric countries, and it appears that standards of most, if not all, countries will have SI units in the future.

11. DIMENSIONAL SPECIFICATIONS

11.1 GEOMETRY

Spatial geometry is the important feature of engineering standards in which critical dimensions are involved. This geometry is not governed by the measuring units, but may be related to them. For example, electrical receptacles and plugs must have the same spatial geometry in order to fit and be interchangeable. The dimensions can be measured or expressed in either U.S. customary or metric units. Further, the dimensions may or may not be simple whole numbers (or multiples of binary fractions) in either system of units. However, *there is a tendency in existing standards to use whole numbers, multiples of binary fractions, or simple decimals in the system of units used so that products based on different systems are not interchangeable.* On the other hand, *products based on the same units of measurement may not be interchangeable;* e.g., products made in different metric countries are frequently not interchangeable since the spatial geometry differs. Likewise, British and U.S. pipe threads are not interchangeable even though both are based on the inch unit.

11.2 STANDARDIZATION OF DIMENSIONS

The dimensions of most products are governed by company standards. National and international standards exist for the dimensions of relatively few products. However, these standard products are mainly basic commodities in common supply for use in many industries; for example, sheet and structural metal, wire and rod, screw fasteners, pipe, and bearings. Hence, the dimensional standards for these products influence company standards for final products. For example, drill sizes influence hole sizes, fastener dimensions influence flange dimensions, etc.

The dimensional standards for such common items comprise about 25 percent of national and international standards, but they are the most difficult to standardize internationally. The design and sizing of products are generally related to the customary units of measurements and the engineering practices in the various countries. International standardization for spatial interchangeability can be achieved only by agreeing to a single system of units and practices for the design, but actual dimensions may be expressed in customary units.

11.3 STANDARD SIZES FOR PRODUCTS

Currently, standards for most products made in a series of sizes base the sizes on whole numbers, multiples of binary fractions, or simple decimals in the system of units used. The sizes form an arithmetic progression, or several arithmetic progressions with larger steps for larger sizes. In the U.S., the steps are generally multiples of the binary fractions; namely, 1/64, 1/32, 1/16, 1/8, 1/4, and 1/2 inch. In metric countries, the steps tend to be multiples of 0.1, 0.5, 1, 2, 5, and 10 mm. Thus, U.S. and metric sizes for a particular product differ. The metric sizes in different countries may also differ since the same progression is not always used. For a few products, the same sizes are used internationally; for example, most sizes of ball bearings used in the U.S. are metric and threaded fasteners for aircraft used in metric countries are generally U.S. sizes.

ISO is encouraging the international standardization of sizes based on the rational system of preferred numbers wherever possible. These numbers progress geometrically by the fifth, tenth, twentieth or fortieth root of 10 depending on the size of the steps desired. Table 5 is taken from ISO Recommendation R3 and gives the preferred numbers for the four series R5, R10, R20 and R40. These numbers are rounded slightly from the theoretical values in column 7, but deviate from them by less than 1.3 percent.

The series can be extended to higher or lower values by multiplying or dividing by 10, 100, 1000, etc.

ISO Recommendation R497 gives the following advantages for adhering strictly to preferred numbers:

"2.1 Best progression

Preferred numbers ensure the best progression from the point of view of regularity and the possibility of adapting them to new requirements for the creation of closer series by the insertion of intermediate values.

"2.2 Universal applicability

Preferred numbers offer the most logical means of uninterrupted coverage of the complete range of requirements in a given field (power of motors, output of pumps, etc.).

TABLE 5. ISO Recommendation R3, July 1953.

(Preferred Numbers—Series of Preferred Numbers)

[1. Basic Series of Preferred Numbers]

Basic series				Serial number	Theoretical values		Percentage differences between basic series and calculated values
R5	R10	R20	R40		Mantissae of logarithms	Calculated values	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.00	1.00	1.00	1.00	0	000	1.0000	0
			1.06	1	025	1.0593	+0.07
		1.12	1.12	2	050	1.1220	−0.18
			1.18	3	075	1.1885	−0.71
	1.25	1.25	1.25	4	100	1.2589	−0.71
			1.32	5	125	1.3335	−1.01
		1.40	1.40	6	150	1.4125	−0.88
			1.50	7	175	1.4962	+0.25
1.60	1.60	1.60	1.60	8	200	1.5849	+0.95
			1.70	9	225	1.6788	+1.26
		1.80	1.80	10	250	1.7783	+1.22
			1.90	11	275	1.8836	+0.87
	2.00	2.00	2.00	12	300	1.9953	+0.24
			2.12	13	325	2.1135	+0.31
		2.24	2.24	14	350	2.2387	+0.06
			2.36	15	375	2.3714	−0.48
2.50	2.50	2.50	2.50	16	400	2.5119	−0.47
			2.65	17	425	2.6607	−0.40
		2.80	2.80	18	450	2.8184	−0.65
			3.00	19	475	2.9854	+0.49
	3.15	3.15	3.15	20	500	3.1623	−0.39
			3.35	21	525	3.3497	+0.01
		3.55	3.55	22	550	3.5481	+0.05
			3.75	23	575	3.7584	−0.22
4.00	4.00	4.00	4.00	24	600	3.9811	+0.47
			4.25	25	625	4.2170	+0.78
		4.50	4.50	26	650	4.4668	+0.74
			4.75	27	675	4.7315	+0.39
	5.00	5.00	5.00	28	700	5.0119	−0.24
			5.30	29	725	5.3088	−0.17
		5.60	5.60	30	750	5.6234	−0.42
			6.00	31	775	5.9566	+0.73
6.30	6.30	6.30	6.30	32	800	6.3096	−0.15
			6.70	33	825	6.6834	+0.25
		7.10	7.10	34	850	7.0795	+0.29
			7.50	35	875	7.4989	+0.01
	8.00	8.00	8.00	36	900	7.9433	+0.71
			8.50	37	925	8.4140	+1.02
		9.00	9.00	38	950	8.9125	+0.98
			9.50	39	975	9.4406	+0.63
10.00	10.00	10.00	10.00	40	000	10.0000	0

"2.3 Simplification of technical and commercial calculations

Since the products and quotients of preferred numbers are by definition also preferred numbers, calculations, which should be made by using the logarithmic values or serial numbers and not the preferred numbers themselves, are considerably simplified, especially when the series of values (dimensions, list prices, etc.) are multiplied or divided in the same proportions.

"2.4 Conversion into other systems of measurement

Conversion into other systems of measurement is greatly facilitated when the series of values in which the measurements are expressed comprise preferred numbers and, at the same time, the conversion factors approximate to preferred numbers."

Preferred numbers can be used with any measurement unit. However, when standard sizes are based on preferred numbers in ISO Recommendations, the meter or one of its submultiples is always used.

11.4 APPLICATION OF PREFERRED NUMBERS

11.4.1 SHEET METAL AND WIRE

ISO Recommendation R388 gives the preferred thicknesses of sheet metal and diameters of wire. Table 6 gives a comparison of the R20 series in ISO/R388 (last 2 cols.) with customary U.S. gages for steel sheet (col. 2), steel wire (col. 3), and nonferrous sheet and wire (American wire gage) (col. 4). The AWG and ISO values (cols. 4 and 5) correspond quite closely, particularly for the higher gage numbers, since the American wire gage is also based on a geometric progression with a ratio between adjacent gages of 1.123 as compared to 1.122 for the R20 series of preferred numbers. The steel gages do not follow a regular geometric progression and do not agree with each other. In addition to the three gages given in table 2, seven other gages are used for sheet metal and wire in the U.S. About 30 gage systems are used in various countries. The confusion caused by these numerous gages used either within or outside the U.S. would be avoided by the universal use of the preferred sizes in ISO/R388. Further, since the odd number gage sizes are seldom used for many products, the stocking of only the R10 sizes could achieve considerable economy and would suffice for nearly all needs. It should be noted that ANSI B32.1 *Preferred Thicknesses for Uncoated Thin Flat Metals* and ANSI B32.2 *Preferred Diameters of Round Wire* use preferred numbers. The sizes in ANSI B32.2 up to 5 mm conform to those in ISO/R388 and a large number of the sizes in ANSI B32.1 are also in accord. The extent to which these standards are replacing the gage sizes in table 6 has not been determined.

TABLE 6. Sheet Metal Thickness and Wire Diameter

Gage No.	Steel sheet	Steel wire	AWG wire	ISO Rec. No. R388*	
	inch	inch	inch	inch	mm
7/0		.4900		.6299	16.000
6/0		.4615	.5800	.5518	14.000
5/0		.4305	.5165	.4921	12.500
4/0		.3938	.4600	.4409	11.200
3/0		.3625	.4096	.3937	10.000
2/0		.3310	.3648	.3543	9.000
0		.3065	.3249	.3150	8.000
1		.2830	.2893	.2795	7.100
2		.2625	.2576	.2480	6.300
3	.2391	.2437	.2294	.2205	5.600
4	.2242	.2253	.2043	.1969	5.000
5	.2092	.2070	.1819	.1772	4.500
6	.1943	.1920	.1620	.1575	4.000
7	.1793	.1770	.1443	.1398	3.550
8	.1644	.1620	.1285	.1240	3.150
9	.1495	.1483	.1144	.1102	2.800
10	.1345	.1350	.1019	.0984	2.500
11	.1196	.1205	.0907	.0882	2.240
12	.1046	.1055	.0808	.0787	2.000
13	.0897	.0915	.0720	.0709	1.800
14	.0747	.0800	.0641	.0630	1.600
15	.0673	.0720	.0571	.0552	1.400
16	.0598	.0625	.0508	.0492	1.250
17	.0538	.0540	.0453	.0441	1.120
18	.0478	.0475	.0403	.0394	1.000
19	.0418	.0410	.0359	.0354	.900
20	.0359	.0348	.0320	.0315	.800
21	.0329	.0317	.0285	.0280	.710
22	.0299	.0286	.0253	.0248	.630
23	.0269	.0258	.0226	.0221	.560
24	.0239	.0230	.0201	.0197	.500
25	.0209	.0204	.0179	.0177	.450
26	.0179	.0181	.0159	.0158	.400
27	.0164	.0173	.0142	.0140	.355
28	.0149	.0162	.0126	.0124	.315
29	.0135	.0150	.0113	.0110	.280
30	.0120	.0140	.0100	.0098	.250
31	.0105	.0132	.0089	.0088	.224
32	.0097	.0128	.0080	.0079	.200
33	.0090	.0118	.0071	.0071	.180
34	.0082	.0104	.0063	.0063	.160
35	.0075	.0095	.0056	.0055	.140
36	.0067	.0090	.0050	.0049	.125
37	.0064	.0085	.0045	.0044	.112
38	.0060	.0080	.0040	.0039	.100
39		.0075	.0035	.0035	.090
40		.0070	.0031	.0032	.080

*mm values are R20 preferred numbers, the inch values are equivalents.

11.4.2 RUBBER HOSE

Another illustration of the use of preferred numbers is for bore sizes of rubber hose. International agreement between metric and nonmetric countries was achieved by the use of the R10 series of preferred numbers. A comparison of the ISO and conventional bore sizes used in both metric and nonmetric countries is given in table 7. The list omits several conventional bore sizes found unnecessary when sizes were based on a rational basis. The ISO sizes are taken from ISO Recommendation R1307 and are based on the R10 series. They correspond reasonably well with conventional inch and metric sizes and with few exceptions are within the tolerances permitted in the conventional sizes. Thus, the application of preferred numbers achieves economy both through reduction in number of sizes and through international standardization.

TABLE 7. Bore Sizes for Rubber Hose

ISO*		Conventional	
mm	*inch*	*inch***	*mm****
3.2	0.126	1/8	3.5
4	.157	5/32	
5	.197	3/16	5
6.3	.248	1/4	6(6)
8	.315	5/16	8
10	.394	3/8	10(9)
12.5	.492	1/2	12(13)
16	.630	5/8	15(16)
20	.787	3/4	20(19)
25	.984	1	25(25)
31.5	1.24	1 1/4	30(32)
40	1.57	1 1/2	40(38)
50	1.97	2	50(50)
63	2.48	2 1/2	60(63)
80	3.15	3	75(75)
100	3.94	4	100(100)
125	4.92	5	125
160	6.30	6	150
200	7.87	8	200
250	9.84	10	250
315	12.40	12	300

*The millimeter values correspond to R10 series of preferred numbers.
**Countries using English units.
***Countries using metric units; values in parentheses were used in some metric countries.

11.4.3 ROUNDING OF PREFERRED NUMBERS

Sometimes it is not possible to use the preferred numbers in table 5; e.g., a gear must have a whole number of teeth. ISO Recommendation R497 gives rules for further rounding the preferred numbers in table 5 when necessary. Greater rounding is also suggested when the number of significant figures in the preferred number would be misleading; e.g., 2.24 would be rounded to 2.2 if the uncertainty were 10 percent. However, ISO/R497 urges that the preferred numbers in table 5 be used wherever possible to facilitate national and international standardization, to simplify the problem of sizing, and to facilitate engineering calculations. For example, if preferred numbers are used for linear dimensions, then areas and volumes are preferred numbers with about 2 and 3 times the deviations given in column 8 of table 5.

11.5 STANDARDIZATION OF NONPREFERRED SIZES

Although the choice of measuring unit is independent of the choice of sizes (preferred numbers or otherwise), the two are joined in engineering standards. Maximum economy and simplification is achieved when the same measuring units and sizes are used internationally. Although ISO encourages the use of preferred numbers for established standard sizes, there are many ISO Recommendations in which standard sizes are not based on preferred numbers. The following examples are illustrative:

11.5.1 ROLLING BEARINGS

Bore sizes in ISO Recommendation R15 conform to the R40 series of preferred numbers above 500 mm. Between 3 and 500 mm, the sizes are a whole number of millimeters, many of which are not preferred numbers. The steps between sizes are 1, 2, 3, or 5 mm for bores between 3 and 50 mm. From 50 to 110 mm, steps of 5 mm are used. From 110 to 200 mm, the steps are 10 mm and from 200 to 500 mm, the steps are 20 mm. These ISO sizes reflect past practice. The present tendency in this country is to use metric bore sizes. However, some metric bearings produced in the U.S. do not conform with ISO Recommendations for dimensions other than bore size.

11.5.2 STEEL PIPE

Table 8 gives the nominal size, outside diameter, and inside diameter of steel pipe as specified in ANS 36.10-1959 and ASTM A53-68 for standard pipe and in ISO Recommendation R65 (medium series). Although neither the dimensions for outside nor inside diameter are based on preferred numbers, the inside diameters approximate the R10 series of preferred numbers given in the last column of table 8. The R10 series includes both 8 and 10

TABLE 8. Dimensions of Standard Steel Pipe

Nominal size		Outside diameter			Inside diameter			
USA [1]	ISO [2]	USA [1]		ISO [2]	USA [1]		ISO [2]	R10 [3]
inch	*mm*	*inch*	*mm*	*mm*	*inch*	*mm*	*mm*	*mm*
1/8	6	0.405	10.2	10.2	0.269	6.8	6.2	6.5
1/4	8	.540	13.7	13.6	.364	9.2	8.9	8.0
								10.0
3/8	10	.675	17.1	17.1	.493	12.5	12.4	12.5
1/2	15	.840	21.3	21.4	.622	15.8	16.1	16.0
3/4	20	1.050	26.7	26.9	.824	20.9	21.6	20.0
1	25	1.315	33.4	33.8	1.049	26.6	27.3	25.0
1 1/4	32	1.660	42.2	42.4	1.380	35.1	35.9	31.5
1 1/2	40	1.900	48.3	48.4	1.610	40.9	41.9	40.0
2	50	2.375	60.3	60.2	2.067	52.5	52.9	50.0
2 1/2	65	2.875	73.0	76.0	2.469	62.7	68.7	63.0
3	80	3.500	88.9	88.8	3.068	77.9	80.7	80.0
3 1/2	90	4.000	101.6	101.2	3.548	90.1	93.1	
4	100	4.500	114.3	114.0	4.026	102.3	105.0	100.0
5	125	5.563	141.3	139.6	5.047	128.2	129.9	125.0
6	150	6.625	168.3	165.2	6.065	154.1	155.5	160.0
8	200	8.625	219.1	(4)	7.981	202.7		200.0
10	250	10.750	273.0	(4)	9.970	253.2		250.0
12	300	12.750	323.9	(4)	12.000	304.8		315.0

[1] ASTM A53-68, standard pipe.
[2] ISO Recommendation R65, Medium series.
[3] R10 Series of preferred number (See table 5).
[4] USA dimensions are used.

mm but no 9 mm size. Otherwise, the R10 series identifies the pipe sizes at least as well as the nominal sizes, either inch or mm. Except for two sizes, the outside diameters are essentially the same for corresponding U.S. and ISO sizes. The outside diameter of the 65 mm pipe is slightly larger than that of the 2 1/2-inch pipe, and the reverse applies for the 150 mm and 6-inch pipes. The wall thickness and hence strength of neither U.S. pipe nor ISO pipe increase with size in a uniform manner. There is an abrupt increase in thickness of U.S. pipe between 2 and 2 1/2 inch so that wall thickness of U.S. pipe above 2-inch nominal size is between 25 and 30 percent greater than ISO pipe. Pipe standards are discussed in more detail later.

11.5.3 TEST SIEVES

Aperture sizes of test sieves in ISO Recommendation R565 progress by the square root 2, instead of one of the preferred series in table 5. U.S. standard sieves in the numbered series progress by the fourth root of 2, so that every other sieve is an ISO size. There is also an inch series of U.S. sieves ranging from 1/4 to 4 inch in steps of 1/16, 1/8, 1/4, or 1/2 inch, depending on the size. Some of the inch sieves have apertures corresponding to the ISO sieves. The ISO sieves should suffice for most, if not all, sieve testing.

11.6 BUILDING DIMENSIONS

In construction, the present tendency is to select dimensions that are multiples of some basic module. For example, windows and doors are made in sizes that are multiples of 2 inches. ISO Recommendation R1006 specifies 100 mm for the basic module, but in an Annex permits 4 inches (101.6 mm) for countries using the "foot-inch system of measurement." This difference of 1.6 percent in the dimensions can restrict trade between countries using different basic modules, particularly for components such as appliances, cabinets, doors, panels, and windows.

11.7 TOLERANCES

Although dimensional specifications can be expressed in any system of units, the system on which the dimensions are based does have an influence. Both the specified value for a dimension and the tolerances are generally selected to be convenient numbers in the selected system. For example, the selection of a dimension and tolerance might be 0.375 ± 0.015 inch in the U.S. customary system or 10.00 ± 0.40 mm in the metric system. When the values in one system are converted to the other, they become 9.525 ± 0.381 mm and 0.3937 ± 0.01575 inch, respectively. Since these numbers reflect a precision greater than required, they are rounded to reflect the precision of the original numbers. This rounding causes problems. If the original limits are not violated, the converted limits are always within the original limits; for example, 9.52 ± 0.37 mm and 0.394 ± 0.015 inch. Thus, a U.S. manufacturer using a dimensional specification based on metric units and converted to the inch unit is at a disadvantage. Conversely, a manufacturer in a metric country is at a disadvantage when using an inch-based specification converted to metric units. The conversion of tolerances in dimensional specifications expressed in both metric and inch units is a problem that is now confronting organizations which are including SI units in their standards.

12. QUALITY SPECIFICATIONS

These standards are becoming more numerous and important. About 15 percent of ISO Recommendations relate to product quality; most of them have been issued in the last few years. They may include requirements for chemical composition, physical properties, and performance or simulated service. Safety standards are included among them. Measurement units in quality-specifications serve only as a language. For example, the minimum requirement for tensile strength can be expressed in pound-force per square inch, kilogram-force per square millimeter, or newton per square meter.

Whether requirements are expressed in the same or different measurement units, standards of different countries may not be compatible. For example, ISO Recommendation R898 gives the requirements for mechanical properties of bolts. For comparable inch and metric bolts, the hardness limits for metric bolts tend to be lower than those for inch bolts reflecting differences in practice between U.S. and metric countries. Thus, for one grade of bolts, the limits for Brinell hardness are 110 to 170 for metric bolts and 121 to 241 for inch bolts. For another grade, the limits are 280 to 365 for metric bolts and 302 to 352 for inch bolts. In one case, the metric bolts have lower and narrower limits than the inch bolts. In the other case, the metric bolts have wider limits and extend above and below those for inch bolts. Since there is considerable overlap in the hardness requirements for the various grades, a manufacturer could make metric and inch bolts within the same hardness limits by sacrificing some of the tolerances permitted by the specifications.

Quality specifications may also differ because different characteristics are specified in national standards. For example, the seat belt standard in the U.S. has requirements for resistance to microbiological deterioration and to light deterioration; whereas, the British Standard does not. On the other

422-764 OL - 71 - 4

hand, the British Standard has a simulated service requirement which the U.S. standard does not have.

To recapitulate, incompatibility of quality specifications may arise from differences in the limits for a particular requirement or from differences in the choice of requirements included in the specification. *Measurement units per se are not the cause of incompatibility in these standards.*

13. METHODS OF TEST

Standard methods of test comprise the largest portion of engineering standards; about 45 percent of the ISO Recommendations issued thus far are in this category. *Measurement units in these standards, as in quality specifications, serve as a language.* However, needless incompatibility can arise when a standard requires a test to be conducted on equipment graduated in a particular system of units, or the procedure is written for convenient use with one system and inconvenient with another system. For example, many U.S. standards prescribe a specimen having a cross sectional area of a simple fraction of a square inch, and a tensile tester graduated in a multiple or submultiple of pound-force and having a rate of traverse expressed in inches per minute. Such a test cannot be conducted in a laboratory operating with metric equipment. Methods so written are not acceptable to metric countries. The same basic procedure can be written for use in laboratories operating with either measurement units. Results obtained in U.S. customary units can easily be translated into SI units and vice versa. U.S. standards so written are considered on their merits in the international forum with those of other nations.

ASTM recognized the need for metric units in their standards to have them accepted internationally and issued its first metric practice guide in 1964. This guide which used customary metric units was revised in 1966 using SI units, and again revised in 1970 (see app. III). However, the application of the guide has not been consistent. Some committees have included only the exact SI equivalents of U.S. customary units; whereas, other committees have modified their standards to permit their use in laboratories operating with either U.S. customary or SI units. International acceptance of ASTM methods has been much greater in the latter case.

Other organizations promulgating standards have published very few containing metric units, except biological or chemical methods which use customary metric units almost exclusively. However, ASME, SAE, and other organizations have started to include SI units. The inclusion of SI units applies to dimensional and quality specifications as well as methods of test. The tempo has been increasing so that within 5 years SI units are likely to be included in most engineering standards.

14. DESCRIPTIVE STANDARDS

These standards which do not have measurement units comprise a substantial portion of engineering standards; about 15 percent of the ISO Recommendations are in this category. Although measurement units are not involved, the extent of incompatibility among national standards is comparable to that for other standards. In the case of terminology, the incompatibility arises from different meanings attached to the same word. Such differences exist even within a country among different industries. Many practices in descriptive standards are as difficult to resolve internationally as differences in dimensional specifications. For example, driving on the right side versus the left side of the highway, conventions regarding projections in engineering drawings, differences in color coding, and even conventions for designating time. These incompatibilities in descriptive standards support the previous finding that the engineering practices, rather than the measurement units, are responsible for the differences in national standards. The units may be a contributing factor in the engineering practice. In some dimensional specifications, a change in the measurement unit may be beneficial in changing the engineering practices and resolving differences, but *a change in units without a change in the practices would not resolve present incompatibilities among standards of any type.*

15. IEC AND ELECTRICAL ENGINEERING STANDARDS

15.1 BACKGROUND

Electrical engineers were among the first to realize that international standardization would become a necessity in the modern world. A number of electrical congresses were held at the end of the 19th and the beginning of the 20th centuries at which it was agreed that a permanent organization was needed to facilitate the coordination and unification of national electrotechnical standards in a methodical and continuous manner. As a result of a resolution passed by the Chamber of Government delegates to the 1904 International Electrical Congress held in St. Louis, Missouri, the International Electrotechnical Commission (IEC) was organized in 1906. Lord Kelvin was the first president. The Central Office was in London until 1947 when it was transferred to Geneva. IEC was the only organization concerned with voluntary international standardization that survived the two World Wars. Although affiliated with ISO as its electrical division since 1947, IEC has retained its technical and administrative autonomy. The membership in IEC has increased from 14 countries at its first meeting in 1908 to 41 countries today. The United States National Committee of the IEC was founded in 1907, and has been affiliated with the American National Standards Institutes or its predecessors since 1931. IEC has become the leading international organization for engineering standards in the electrical and electronics industries.

15.2 MEASUREMENT UNITS

At the beginning of this century, nine systems of units had been introduced. Therefore, the early electrical congresses and later IEC were greatly concerned with the standardization of measurement units as well as engineering practices. Three systems were extensively used for electrical units; namely, the CGS electrostatic units, the electromagnetic units, and the practical units. Among these systems was the MKS system proposed by Professor Giovanni Giorgi of the University of Rome in 1901 which subsequently became the basis for the International System of Units (SI) adopted by the General Conference on Weights and Measures in 1960. Professor David Robertson of Bristol University in a letter to the *Electrician* in April 1904 independently advocated the adoption of a similar MKS system by the St. Louis International Electrical Congress and suggested the "newton" for the unit of force and the "kram" for the unit of mass in order to eliminate the prefix in the base unit "kilogram." The proposed MKS system was little used until IEC decided to adopt it in 1935. After further delay caused by World War II, the International Committee on Weights and Measures recommended its adoption in 1946 and the ampere was adopted as a base unit at the Ninth General Conference on Weights and Measures in 1948. The system was further developed and finally SI was formally adopted in 1960.

The leading role of IEC in developing and promoting the rationalized MKS system accounts for the number of special names given to derived electrical units being more numerous than the number of special names for all other derived units. For example, of the following names that have been given to the base and derived SI units, eight of the 15 special names are for derived electrical units:

Base	*General*	*Electricity*	*Light*
meter	hertz	coulomb	lumen
kilogram	joule	farad	lux
second	newton	henry	
ampere	watt	ohm	
kelvin	pascal**	tesla	
candela		volt	
radian*		weber	
steradian*		siemens**	

*Supplementary units.
**Proposed names.

These eight electrical units together with the ampere, hertz and watt are now used in the U.S. and other countries. U.S. customary units are frequently used in place of the other base and general units in electrical and electronics standards in the U.S. IEC Recommendations use the SI units and in some instances also include such customary units as the inch.

15.3 IEC ORGANIZATION

Each of the 41 member countries of IEC is represented by a national committee. Although each member has nominally equal status and voice in developing IEC Recommendations, actual control resides in the technical committees and subcommittees. The chairman and particularly the secretaries of committees have a great influence, and the possession of a secretariat is a great asset to a nation in having its engineering practices incorporated into an IEC Recommendation. Table 9 and figure 3 show the number of chairmanships and secretariats of committees and subcommittees held by member countries. They show the United Kingdom has the most chairmanships and secretariats, with France in second place. The U.S. holds the same number of chairmanships as France but is in fourth place in number of secretariats, the Netherlands being in third place. Thus, the U.S. is among the more active nations. However, this activity appears to be relatively recent since chairmanships and secretariats held by the U.S. are much greater for the younger committees and subcommittees than for those established many years ago. Currently, the U.S. participates in about 95 percent of the IEC technical committees and subcommittees, but participation in working groups is estimated to be less than 50 percent.

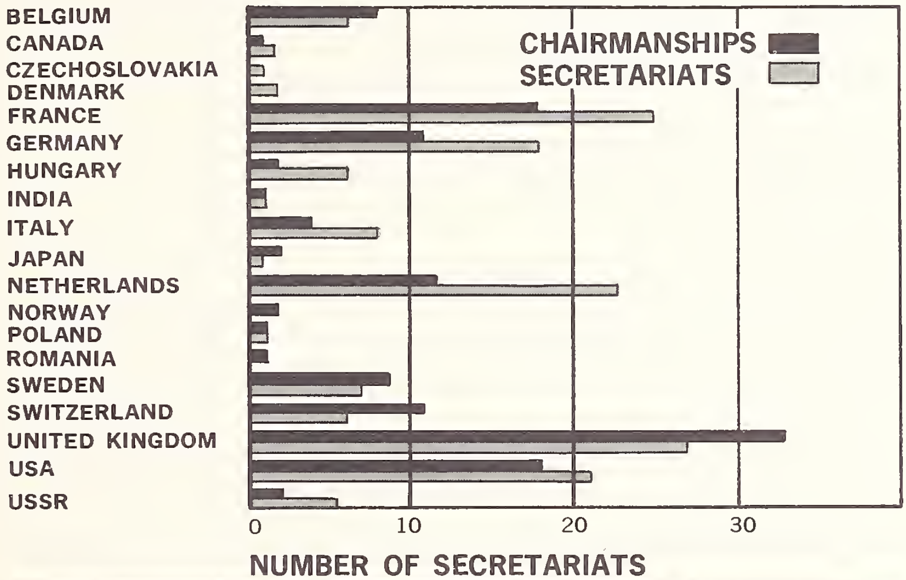
TABLE 9. IEC Technical Committees and Subcommittees

(Distribution of Chairmen and Secretariats Among Countries)

Country	Chairman	Secretariat
Belgium	8	6
Canada	1	2
Czechoslovakia	0	1
Denmark	0	2
France	18	25
Germany	11	19
Hungary	2	6
India	1	1
Italy	14	8
Japan	2	1
Netherlands	12	23
Norway	2	0
Poland	1	1
Romania	1	0
Sweden	9	7
Switzerland	11	6
United Kingdom	33	27
USA	18	21
USSR	2	5

FIGURE 3

DISTRIBUTION OF CHAIRMANSHIPS AND SECRETARIATS IEC TECHNICAL COMMITTEES AND SUBCOMMITTEES



15.4 IEC RECOMMENDATIONS

Many IEC Recommendations have several parts issued as separate documents, essentially each part being a separate recommendation. Counting each such part, there were 436 IEC Recommendations in effect at the beginning of 1970. A list of these documents taken from the 1970 Catalog of the American National Standards Institute is given in table 10.

These documents were reviewed and divided into those containing length units and those having either no measurement unit or only electrical units which are the same in all countries including the U.S. About one-third contained length units. They were examined in greater detail and will be discussed later. Among the rest, only IEC Recommendation 38 on standard voltages and IEC Recommendation 196 on standard frequencies were examined. These two documents had two series of standard voltages and frequencies reflecting differences in practices in different countries. For example, in North America the standard household electrical supply is single phase 120 volts (two wire) or 120/240 volts (three wire), 60 hertz alternating current. In Europe, the standard supply is single phase 220 volts, 50 hertz alternating current. These supplies are not compatible and equipment designed for one supply must be modified or adapted for use with the other supply. Although IEC was organized over 60 years ago, it was obviously not early enough to prevent this incompatibility. Thus, there must be early standardization of new technological developments to prevent development of diverse practices that can be harmonized only at great cost. It should again be emphasized that measurement units were not involved in these diverse practices.

The IEC Recommendations having length units were classified into the following categories depending on the units in the original standard from which the recommendation was developed:

A. All metric
B. Dominantly metric
C. Mixed
D. Dominantly inch
E. All inch

Since IEC Recommendations prescribe length dimensions in both metric and inch units, the following rationale was used to decide on the original unit:

1. In a few instances, the original unit is identified in the recommendation.
2. For recommendations issued since the IEC rules for rounding and significant digits were adopted, these rules were used to identify the original unit.
3. For older recommendations, an original inch unit can occasionally be identified when the value was derived from a conventional inch fraction. In other instances, a comparison of the terminal zeros in the inch and metric values revealed the original unit.

Table 11 summarizes this examination of documents with length units. The current editions of such IEC Recommendations are dated from 1955 to 1969. They are grouped into documents having dates from 1955 to 1961 and those from 1962 to 1969. Each category is subdivided into recommendations on which a vote by the U.S. is recorded and those having no indication of U.S. participation in voting. The following conclusions may be drawn from the information in table 11.

1. The number of documents involving length units that were issued during the 7 years from 1955 to 1961 and still effective is less than 20 percent of the number issued during the 8 years from 1962 to 1969.
2. No document issued prior to 1962 is based on an original inch standard or predominantly inch standard.
3. The lack of inch-based documents issued prior to 1962 does not appear to be due to the level of U.S. participation since the U.S. voted on 20 of the 23 recommendations (87%) issued during 1955 to 1961 and on 98 of the 134 recommendations (73%) issued during 1962 to 1969.
4. An appreciable portion (10%) of the recommendations issued during the last 8 years are based on standards using all inch or predominantly inch length unit. However, there is no trend toward greater

use of inch-based standards since more careful examination indicates eight of the 56 recommendations issued during 1962 to 1965 were inch-based and only six of the 78 recommendations issued during 1966 to 1969 were inch-based.

5. U.S. voted on 12 of the 14 recommendations (86%) based on inch or predominantly inch length unit and on 76 of the 106 recommendations (72%) based on metric or predominantly metric length unit issued during 1962 to 1969. Two inch-based recommendations were adopted apparently without U.S. participation.
6. With respect to electrical engineering standards, the U.S. is bilingual and apparently uses the metric length unit as frequently or more frequently than the inch unit.

Table 12 lists the IEC recommendations by number which include a length unit and corresponding national standards in the United States, United Kingdom, Germany, Japan and India that were so indicated in the catalogs of the standardizing organization and in France that were obtained by correspondence with the Association Francaise de Normalization. The length unit in the recommendation is indicated by letters A to E which correspond to the five groups in table 11. ANSI catalog for 1970 indicates that only two ANSI electrical standards are in agreement with IEC Recommendations (60 and 83) which have length units. The other ANSI standards in table 12 are in partial agreement. The extent of agreement for the other national standards is difficult to determine in most instances, but some national standards catalogs do indicate the similarities and differences.

In summary, it appears that measurement units are not a significant factor in the incompatibility that exists between national electrical standards in the U.S. and those in other countries. It also is evident that IEC has been able to reduce but has not been able to eliminate the diverse practices in electrical engineering. *Early standardization of new technological developments is required to do so, and such standardization should be initiated at the international, rather than the national, level.* Failure to do so results in incompatibility of practices that increases costs unnecessarily. For example, the diverse systems for color television in Europe and North America increases the cost to interchange programs by satellite or otherwise.

TABLE 10

IEC RECOMMENDATIONS

The corresponding American National Standards are shown by cross references enclosed in parentheses ( ). Since cross references must be brief, the following system has been used: where there is complete agreement with an international recommendation, the words "Agrees with" precede the number designation of the international recommendation; where there is partial agreement, only the number designation is given. The actual relationships can be determined only through careful comparison of the documents involved.

IEC No.

27 (1966) Letter Symbols to be Used in Electrical Technology

28 (1925) International Standards of Resistance for Copper

34-1 (1969) Rotating Electrical Machines, Part 1: Rating and Performance

34-1A (1965) Irregularities of Waveform, Supplement to Publication 34-1

34-2 (1960) Recommendations on Determination of Efficiency of Rotating Electrical Machinery (Excluding Machines for Traction Vehicles)

34-3 (1968) Rotating Electrical Machines Part 3: Ratings and Characteristics of Three-Phase, 50 Hz Turbine Type Machines

34-4 (1967) Recommendations for Rotating Electrical Machinery (Excluding Machines for Traction Vehicles) Part 4: Methods for Determining Synchronous Machine Quantities from Tests

34-5 (1968) Rotating Electrical Machines Part 5: Degrees of Protection of Enclosures for Rotating Machinery

34-6 (1969) Rotating Electrical Machines: Part 6: Methods of Colling Rotating Machinery

38 (1967) Standard Voltages *(C84.1-1954 and C92.2-1967)*

41 (1963) International Code for the Field Acceptance Tests of Hydraulic Turbines

43 (1960) Recommendations for AC Watt-Hour Meters

45 (1958) Recommendations for Steam Turbines, Part I; Specification

46 (1962) Recommendations for Steam Turbines, Part II, Rules for Acceptance Tests,

Amendment 1 (1965)

48 (1961) Rules for Electric Traction Motors.

50-05 (1956) International Electrotechnical Vocabulary, Group 05: Fundamental Definitions

50-07 (1956) International Electrotechnical Vocabulary, Group 07: Electronics

50-08 (1960) International Electrotechnical Vocabulary, Group 08: Electro-Acoustics *(S1.1-1960)*

50-10 (1956) International Electrotechnical Vocabulary, Group 10: Machines and Transformers

50-11 (1956) International Electrotechnical Vocabulary, Group 11: Static Convertors.

50-12 (1955) International Electrotechnical Vocabulary, Group 12: Transductors.

50-15 (1957) International Electrotechnical Vocabulary, Group 15: Switchboards and Apparatus for Connection and Regulation *(C37.100-1966)*

50-16 (1956) International Electrotechnical Vocabulary, Group 16: Protective Relays *(C37.100-1966)*.

IEC No

50-20 (1958) International Electrotechnical Vocabulary, Group 20: Scientific and Industrial Measuring Instruments

50-25 (1965) International Electrotechnical Vocabulary, Group 25: Generation, Transmission, and Distribution of Electrical Energy

50-26 (1968) International Electrotechnical Vocabulary, Nuclear Power Plants for Electric Energy Generation

50-30 (1957) International Electrotechnical Vocabulary, Group 30: Electric Traction

50-31 (1959) International Electrotechnical Vocabulary, Group 31: Signalling and Security Apparatus for Railways

50-35 (1958) International Electrotechnical Vocabulary, Group 35: Electromechanical Applications.

50-37 (1966) International Electrotechnical Vocabulary, Group 37. Automatic Controlling and Regulating Systems

50-40 (1960) International Electrotechnical Vocabulary, Group 40: Electro-Heating Applications

50-45 (1958) International Electrotechnical Vocabulary, Group 45: Lighting

50-50 (1960) International Electrotechnical Vocabulary, Group 50: Electrochemistry and Electrometallurgy

50-62 (1961) International Electrotechnical Vocabulary, Group 62: Waveguides

50-65 (1964) International Electrotechnical Vocabulary, Group 65: Radiology and Radiological Physics

50-66 (1968) International Electrotechnical Vocabulary: Detection and Measurement of Ionizing Radiation by Electric Means

50-70 (1959) International Electrotechnical Vocabulary, Group 70: Electro-Biology *(C42.80-1957)*

51 (1960) Recommendations for Indicating Electrical Measuring Instruments and Their Accessories, .

Amendment (1967),

52 (1960) Recommendations for Voltage Measurement by Means of Sphere-Gaps (one sphere earthed) *(C68.1-1968)*

54 (1936) Recommendations for Standard Direction of Motion of Operating Devices and for Indicating Lamps for Circuit-Breakers

55-1 (1965) Tests on Impregnated Paper Insulated Metal-Sheathed Cables, Part 1: Cables for Alternating Voltages from 10 kV up to and including **66** kV (excluding Gas-Pressure, Oil-Filled and Non-Draining Cables)

Amendment 1 (1967).

IEC No.

55-2 (1965) Tests on Impregnated Paper Insulated Metal-Sheathed Cables, Part 2: Non-Draining Cables for Alternating Voltages from 10 kV uo to and includino 33 kV (excludino Gas-Pressure Cables),
Amendment 1 (1967),
56-1 (1954) Specification for Alternating-Current Circuit-Breakers, Chapter I: Rules for Short-Circuit Conditions (second edition, 1954), *(Appropriate C37 Standards)*

56-1-A (1959) Supplement to Chapter 1, Rules for Short-Circuit Conditions; a) Recommendations for the Unit Testing by Direct Methods of Circuit-Breakers for Making-Capacity and Breaking-Capacity; b) Methods for Determining Inherent Restriking-Voltage Waveforms
56-1-B (1962) Amendments to Chapter
56-2 (1955) Specification for Alternating-Current Circuit-Breakers, Chapter II: Rules for Normal Load Conditions, Part 1, Rules for Temperature Rise *(Appropriate C37 Standards)*
56-3 (1959) Specification for Alternating-Current Circuit-Breakers, Chapter II: Rules for Normal Load Conditions, Part 2: Rules for Operating Conditions, Part 3: Coordination of Rated Voltages, Rated Breaking-Capacities and Rated Normal Current *(Appropriate C37 Standards)*
56-4 (1959) Specification for Alternating-Current Circuit-Breakers, Chapter III: Rules for Strength of Insulation; Chapter IV: Rules for the Selection of Circuit-Breakers for Service; Chapter V: Rules for the Erection and Maintenance of Circuit-Breakers in Service, *(Appropriate C37 Standards)*
Amendment 1 (1965),
56-5 (1963) Specification for Alternating-Current Circuit-Breakers, Guide to the Field Testing of Circuit-Breakers with Respect to the Switching of Overhead Lines on No-Load *(Appropriate C37 Standards)*
56-6 (1963) Specification for Alternating-Current Circuit-Breakers, Guide to the Testing of Circuit-Breakers with Respect to the Switching of Cables on No-Load *(Appropriate C37 Standards)*
56-7 (1963) Specification for Alternating-Current Circuit-Breakers, Guide to the Testing of Circuit-Breakers, with Respect to the Switching of Shunt Capacitor Banks
59 (1938) Standard Current Ratings
60 (1962) High Voltage Test Techniques *(Agrees with C68 1-1968 and C77.1-1943 (R1953))*
61-1 (1969) Lamp Caps and Holders Together with Gauges for the Control of Interchangeability and Safety, Part 1: Lamp Caps *(Appropriate C81 standards)*
61-2 (1969) Lamp Caps and Holders Together with Gauges for the Control of Interchangeability and Safety, Part 2: Lampholders *(Appropriate C81 standards)*
61-3 (1969) Lamp Caps and Holders Together with Gauges for the Control of Interchangeability and Safety, Part 3: Gauges *(Appropriate C81 standards)*
62 (1968) Marking Codes for Values and Tolerances of Resistors and Capacitors,
Amendment 1 (1968),
63 (1963) Preferred Number Series for Resistors and Capacitors, *(Agrees with C83.2-1949 (R1961))*
Amendment 1 (1967)
64 (1961) Tungsten Filament Lamps for General Service.

64A (1962) Lamps with a Life of 2,500 Hours, Supplement to Publication 64,
65 (1965) Safety Requirements for Mains Operated Electronic and Related Equipment for Domestic and Similar General Use (CEE 1-1965)
Amendment 1 (1967),
Appendix A (1969) Safety Requirements for Splash-Proof Mains Operated Electronic Equipment,

66 (1953) Specification for Fuses for Voltages Not Exceeding 1,000 Volts for AC and DC
67 (1966) Dimensions of Electronic Tubes and Valves, including

IEC No

67A (1967) Supplement to Publication 67, sold separately
68-1 (1968) Basic Environmental Testing Procedures for Electronic Components and Electronic Equipment, Part 1: General.
68-2 Basic Environmental Testing Procedures for Electronic Components and Electronic Equipment, Part 2 Tests (includes all tests listed below)

68-2-1 (1966) Test A: Cold
68-2-2 (1966) Test B. Dry Heat
68-2-3 (1969) Test Ca: Damp Heat Steady State
68-2-4 (1960) Test D: Accelerated Damp Heat
68-2-6 (1966) Test F: Vibration,

68-2-6A (1967) Supplement to Publication 68-2-6,

68-2-6B (1967) Supplement to Publication 68-2-6,

68-2-6C (1969) Supplement to Publication 68-2-6

68-2-7 (1968) Test Ga: Acceleration, Steady State
68-2-8 (1960) Test H: Storage
68-2-10 (1968) Test J: Mould Growth,

68-2-10A (1969) Suoolement to Publication 68-2-10 (1968),

68-2-11 (1964) Test Ka: Salt Mist
68-2-13 (1966) Test M: Low-Air Pressure
68-2-14 (1960) Test N. Change of Temperature
68-2-17 (1968) Test O: Sealing
68-2-20 (1968) Test T: Soldering
68-2-21 (1960) Test U: Robustness of Terminations, includino

Amendment 1 (1967), to Pub. 68-2-21,
68-2-27 (1967) Test Ea: Shock,
Supplement 68-2-27A (1968)
Note: All the above tests should be used in conjunction with Publication 68-1.
68-2-28 (1968) Guidance for Damp Heat Tests
68-2-29 (1968) Test Eb: Bump.
69 (1954) Recommended Methods of Measurement of Receivers for Amplitude Modulation Broadcast Transmissions *(C16.19-1951 (R1961))*
70 (1967) Power Capacitors,
70-A (1968) Supplement to Publication 70
71 (1967) Insulation Coordination, *(C92.1-1967 and C84 1-1954)*
71-A (1962) Application Guide to Publication 71.
72-1 (1967) Dimensions and Output Ratings of Electrical Machines, Part 1: Foot-Mounted Electrical Machines with Shaft H ghts Between 56 and 315 mm (2-5/8 and 12-1/2 in.) *(C50.8-1955)*
72-2 (1967) Dimensions and Output Ratings of Electrical Machines, Part 2: Dimensions of Mounting Flanges
73 (1955) Recommendations Regarding the Color of Push-Buttons *(C19.1-1959)*
74 (1963) Method for Assessing the Oxidation of Insulating Oils
76 (1967) Power Transformers *(Appropriate C57.12 Standards)*
77 (1968) Rules for Electric Traction Equipment
78 (1967) Characteristic Impedances and Dimensions of Radio-Frequency Coaxial Cables
79 (1957) Recommendations for the Construction of Flame-proof Enclosures of Electrical Apparatus
79-2 (1962) Electrical Apparatus for Explosive Gas Atmospheres, Part 2: Pressurized Enclosures
79-3 (1963) Electrical Apparatus for Explosive Gas Atmosphere, Part 3: Testing of Intrinsically Safe Apparatus
79-4 (1966) Electrical Apparatus for Explosive Gas Atmospheres, Part 4 Method of Test for Ignition Temperature
79-5 (1967) Electrical Apparatus for Explosive Gas Atmospheres, Part 5: Sand-Filled Apparatus,

79-5A (1969) Supplement to Publication 79-5 (1967),

IEC No.
79-6 (1968) Electrical Apparatus for Explosive Gas Atmospheres, Part 6: Oil-Immersed Apparatus
79-7 (1969) Electrical Apparatus for Explosive Gas Atmospheres, Part 7: Construction and Test of Electrical Apparatus Type of Protection "8"
79-8 (1969) Electrical Apparatus for Explosive Gas Atmospheres, Part 8: Classification of Maximum Surface Temperatures
80 (1964) Fixed Capacitors for Direct Current Using Impregnated Paper or Paper/Plastic Film Dielectric *(Agrees with C83.11-1968)*
81 (1961) Specification for Tubular Fluorescent Lamps for General Lighting Service
82 (1962) Ballasts for Fluorescent Lamps, *(C82.1-1968, C82.2-1963, and C82.3-1962)*
Amendment 1 (1965)
83 (1957) Standards for Plugs and Socket-Outlets for Domestic and Similar General Use *(Agrees with C73.10-, .15-, .21-, .23-, .26-, and .27-1966. Partially agrees with C73.11-1966 and C73.25-1966)*
84 (1957) Recommendations for Mercury-Arc Converters, *(C34.1-1958)*
84A (1966) Mercury-Arc Inverters, Supplement to Publication 84,
84B (1967) Mercury-Arc Converters, Supplement to Publication 84,
85 (1957) Recommendations for the Classification of Materials, tor the Insulation of Electrical Machinery and Apparatus in Relation to their Thermal Stability in Service
86-1 (1962) Primary Cells and Batteries, Part 1: General, *(C18.1-1965)*
Amendment 1 (1965)
86-2 (1963) Primary Cells and Batteries, Part 2: Specification Sheets, *(C18.1-1965)*
Amendment 1 (1965)
86-3 (1965) Primary Cells and Batteries, Part 3: Terminals, *(C18.1-1965)*
Amendment 1 (1967)
88 (1957) Standard Rated Currents (2 to 63 Amperes) of Fuse Links for Low Voltage Fuses
90 (1957) Recommendations for the Dimensions of Polarized Plugs for Hearing Aids
91 (1958) Recommended Methods of Measurement on Receivers tor Frequency-Modulation Broadcast Transmission *(C16.12-1949 (R1961))*
92-1 (1964) Electrical Installations in Ships, Part 1: General Requirements
92-2 (1965) Electrical Installations in Ships, Part 2: Graphical Symbols
92-3 (1965) Electrical Installations in Ships, Part 3: Cables (Construction, Testing, and Installations)

Amendment 1 (1969)
92-4 (1965) Electrical Installations in Ships, Part 4: Switchgear, Electrical Protection, Distribution, and Controlgear
92-5 (1965) Electrical Installations in Ships, Part 5: Transformers for Power and Lighting, Semiconductor Rectifiers, Generators (with Associated Prime-Movers) and Motors, Electric Propulsion Plant, Tankers
92-6 (1965) Electrical Installations in Ships, Part 6: Accessories, Lighting, Accumulator (Storage) Batteries, Heating and Cooking Appliances, Internal Communications, Lightning Conductors
93 (1958) Recommended Methods of Test for Volume and Surface Resistivities of Electrical Insulating Materials *(C59.3-1968)*
94 (1968) Magnetic Tape Recording and Reproducing Systems: Dimensions and Characteristics
95-1 (1961) Lead-Acid Starter Batteries, Part I: General Requirements and Methods of Test
95-2 (1965) Lead-Acid Starter Batteries, Part II: Dimensions of Batteries
95-3 (1963) Lead-Acid Starter Batteries, Part III: Dimensions and Markings of Terminals

IEC No.
96-1 (1962) Radio-Frequency Cables, Part I: General Requirements and Measuring Methods,

Amendment 1 (1965)
Amendment 2 (1966)
96-1A (1964) Supplement to Publication 96-1.
96-2 (1961) Radio-Frequency Cables, Part II: Relevant Cable Specifications,
96-2A (1965) Supplement to Publication 96-2
96-2B (1966) Supplement to Publication 96-2,
97 (1967) Fundamental Parameters for Printed Wiring Techniques
98 (1964) Processed Disk Records and Reproducing Equipment,
Amendment 1 (1967)
99-1 (1958) Recommendations for Lightning Arresters, Part 1: Non-Linear Resistor Type Arresters, *(C62.1-1967)*
99-1A (1965) Supplement to Publication 99-1,
99-2 (1962) Lightning Arresters, Part II: Expulsion-Type Lightning Arresters *(C62.1-1967)*
100 (1962) Recommended Methods for the Measurement of Direct Inter-Electrode Capacitances of Electronic Valves and Tubes, *(C60.6-1959)*
Amendment 1 (1969),
101 (1958) Rules for Auxiliary Machines on Motor Vehicles (Electric Motors and Generators)

102 (1958) Rules for the Electric Transmission of Vehicles with Diesel Engines (Main DC Motors and Generators)
103 (1969) Aluminum Electrolytic Capacitors for Long Life (Type 1) and for General Purpose Application (Type 2).
104 (1958) Recommendations for an International Specification for Aluminum Alloy Conductor Wire of the Aluminum-Magnesium-Silicon Type.
105 (1958) Recommendations for Commercial-Purity Aluminum Busbar Material *(C7.27-1964)*.

106 (1959) Recommended Methods of Measurement of Radiation trom Receivers for Amplitude-Modulation and Television Broadcast Transmissions,
106A (1962) Supplement to Publication 106
107 (1960) Recommended Methods of Measurements on Receivers for Television Broadcast Transmissions
108 (1967) Ceramic Dielectric Capacitors Type 1
109 (1959) Recommendations for Fixed Non-Wirewound Resistors Type 2,
Amendment 1 (1962),
110 (1959) Recommendations for Power Capacitors for Frequencies Between 100 and 20,000 Hz (c/s)

111 (1959) Recommendation for the Resistivity of Commercial Hard-Drawn Aluminum Electrical Conductor Wire *(C7.20-1960)*
112 (1959) Recommended Method for Determining the Comparative Tracking Index of Solid Insulating Materials Under Moist Conditions
113 (1959) Classification and Definitions of Diagrams and Charts Used in Electrotechnology
114 (1959) Recommendation for Heat-Treated Aluminum Alloy Busbar Material of the Aluminum-Magnesium-Silicon Type.
115 (1959) Recommendations for Fixed Non-Wirewound Resistors Type 1 for Use in Electronic Equipment,

Amendment 1 (1963)
Amendment 2 (1965)
Amendment 3 (1968)

116 (1959) Recommendations for Receiver-Type Metallized Mica Capacitors for Use in Electronic Equipment
117-1 (1960) Recommended Graphical Symbols, Part 1: Kind of Current, Distribution Systems, Methods of Connection, and Circuit Elements,
Amendment 1 (1966)
Amendment 2 (1967)

IEC No.

117-2 (1960) Recommended Graphical Symbols, Part 2: Machines, Transformers, Primary Cells, and Accumulators,

Amendment 1 (1966),

117-3 (1963) Recommended Graphical Symbols, Part 3: Contacts, Switchgear, Mechanical Controls, Starters, and Elements of Electromechanical Relays, (1966), *(Y32.2-1967)*

Amendment 1 (1966)

117-4 (1963) Recommended Graphical Symbols, Part 4: Measuring Instruments and Electric Clocks

117-5 (1963) Recommended Graphical Symbols, Part 5: Generating Stations and Substations, Lines for Transmission and Distribution.

117-6 (1964) Recommended Graphical Symbols, Part 6: Variability, Examples of Resistors, Elements of Electronic Tubes, Valves, and Rectifiers, *(Y32.2-1967)*

Amendment 1 (1966),

Amendment 2 (1967)

117-7 (1966) Recommended Graphical Symbols, Part 7: Semiconductor Devices, Capacitors *(Agrees with Y32.2-1967)*.

117-8 (1967) Recommended Graphical Symbols, Part 8: Symbols for Architectural Diagrams

117-9 (1968) Recommended Graphical Symbols, Part 9: Telephony, Telegraphy, and Transducers

117-10 (1968) Recommended Graphical Symbols, Part 10: Aerials (Antennas) and Radio Stations *(Y32.2-1967)*

117-11 (1968) Recommended Graphical Symbols, Part 11: Microwave Technology.

117-12 (1968) Recommended Graphical Symbols, Part 12: Frequency Spectrum Diagrams

118 (1959) Recommended Methods for Measurements of the Electro-Acoustical Characteristics of Hearing Aids *(S3.3-1960)*

119 (1960) Recommendations for Polycristalline Semi-conductor Rectifier Stacks and Equipments

120 (1960) Recommendations for Ball and Socket Couplings of String Insulator Units

121 (1960) Recommendation for Commercial Annealed Aluminum Electrical Conductor Wire *(C7.23-1965)*

122-1 (1962) Quartz Crystal Units for Oscillators, Section 1: Standard Values and Conditions; Section 2 Test Conditions:

Amendment 1 (1967)

Amendment 2 (1969)

122-2 (1962) Quartz Crystal Units for Oscillators, Section 3: Guide in the Use of Quartz Oscillator Crystals,

Amendment 1 (1969)

122-3 (1962) Quartz Crystal Units for Oscillators, Section 4 Standard Outlines,

122-3A (1968) Supplement to Publication 122-3,

123 (1961) Recommendations for Sound Level Meters *(S1.4-1961)*

124 (1960) Recommendations for the Rated Impedances and Dimensions of Loudspeakers.

125 (1961) General Classification of Ferromagnetic Oxide Materials and Definitions of Terms,

Amendment 1 (1965)

Amendment 2 (1968)

126 (1961) IEC Reference Coupler for the Measurement of Hearing Aids Using Earphones Coupled to the Ear by Means of Ear Inserts *(S3.3-1960)*

127 (1962) Cartridge Fuse Links for Miniature Fuses

128 (1961) International Code for the Designation of Photographic Projector Lamps.

129 (1961) Alternating-Current Isolators (Disconnectors) and Earthing Switches,

Amendment 1 (1963),

129A (1968) Supplement to Publication 129,

IEC No.

130-1 (1982) Connectors for Frequencies Below 3 MHz (Mc/s), Part 1: General Requirements and Measuring Methods,

Amendment 1 (1964)

130-1A (1968) Supplement to Publication 130-1

130-2 (1965) Connectors for Frequencies Below 3 MHz (Mc/s), Part 2: Connectors for Radio Receivers and Associated Sound Equipment,

Amendment 1 (1969)

130-3 (1965) Connectors for Frequencies Below 3 MHz (Mc/s), Part 3: Battery Connectors

130-4 (1966) Connectors for Frequencies Below 3 MHz (Mc/s), Part 4: Circular Multipole Connectors with Threaded Coupling

130-5 (1966) Connectors for Frequencies Below 3 MHz (Mc/s), Part 5: Rectangular Multipole Connectors with Blade Contacts

130-6 (1965) Connectors for Frequencies Below 3 MHz (Mc/s), Part 6: Rectangular Miniature Multipole Connectors with Blade Contacts.

130-8 (1969) Connectors for Frequencies Below 3 MHz (Mc/s), Part 8: Concentric Connectors for Audio Circuits in Radio Receivers

131-1 (1962) Toggle Switches, Part 1: General Requirements and Measuring Methods

131-2 (1963) Toggle Switches, Part 2: Requirements for Toggle Switches, Type 1

131-3 (1969) Lever Switches, Part 3: Requirements for Switches of Type 2, Quick Make, Quick Break (Toggle Switches)

132-1 (1962) Rotary Wafer Switches (Low Current Rating), Part 1: General Requirements and Measuring Methods

132-2 (1963) Rotary Wafer Switches (Low Current Rating), Part 2: Rotary Wafer Switches with Central Mounting,

132-2A (1965) Supplement to Publication 132-2,

132-3 (1963) Rotary Wafer Switches (Low Current Rating), Part 3: Rotary Wafer Switches with Two-Hole Mounting,

132-2A (1965) Supplement to Publication 132-2,

132-4 (1966) Rotary Wafer Switches (Low Current Rating), Part 4: Rotary Wafer Switches with Central Mounting; Maximum 12 Positions; Maximum Diameter 40mm

132-5 (1966) Rotary Wafer Switches (Low Current Rating), Part 5: Rotary Wafer Switches with Two-Hole Mounting; Maximum 26 Positions; Maximum Diameter 60mm.

133 (1967) Dimensions for Pot-Cores Made of Ferromagnetic Oxides and Associated Parts.

134 (1961) Rating Systems for Electronic Tubes and Valves and Analogous Semiconductor Devices (1961)

135 (1961) Numbering of Electrodes and Designation of Units in Electronic Tubes and Valves (1961)

136-1 (1962) Dimensions of Brushes and Brush-Holders for Electrical Machinery, Part 1: Principal Dimensions and Tolerances *(C64.1-1963)*

136-2 (1967) Dimensions of Brushes and Brush-Holders for Electrical Machinery, Part 2: Complementary Dimensions of Brushes, Terminations of Brushes *(C64.1-1963)*.

137 (1962) Bushings for Alternating Voltages Above 1,000 V *(C76.1-1964)*.

138 (1962) Methods of Measurement of Essential Electrical Properties of Receiving Aerials in the Frequency Range from 30 MHz (Mc/s) to 1,000 MHz (Mc/s),

138-A (1963) Supplement to Publication 138,

139 (1962) Preparation of Outline Drawings of Oscilloscope and Picture Tubes.

140 (1962) Glassware for Lighting Fittings

141-1 (1963) Tests on Oil-Filled and Gas-Pressure Cables and Their Accessories, Part I: Oil-Filled, Paper-Insulated, Metal-Sheathed Cables and Accessories for Alternating Voltages up to 275 kV,

Amendment 1 (1967)

IEC No

141-2 (1963) Tests on Oil-Filled and Gas-Pressure Cables and Their Accessories, Part II Internal Gas-Pressure Cables and Accessories for Alternating Voltages up to 275 kV, including

Amendment 1 (1967)

141-3 (1963) Tests on Oil-Filled and Gas-Pressure Cables and Their Accessories, Part III. External Gas-Pressure (Gas Compression) Cables and Accessories for Alternating Voltages up to 275 kV,

Amendment 1 (1967),

142 (1962) Magnetic Sound Recording on 16mm and 35mm Film for the International Exchange of Television Programmes

143 (1963) Series Capacitors for Power Systems

144 (1963) Degrees of Protection of Enclosures for Low-Voltage Switchgear and Controlgear

145 (1963) Var-Hour (Reactive Energy) Meters

146 (1963) Monocrystalline Semiconductor Rectifier Cells, Stacks, Assemblies, and Equipments

147-0 (1966) Essential Ratings and Characteristics of Semiconductor Devices and General Principles of Measuring Methods Part O: General and Terminology,

147-OA (1969) Supplement to Publication 147-0

147-1 (1963) Essential Ratings and Characteristics of Semiconductor Devices and General Principle of Measuring Methods, Part 1: Essential Ratings and Characteristics,

147-1A (1963) Supplement to 147-1,

147-1B (1969) Supplement to 147-1 and 147-1A,

147-2 (1963) Essential Ratings and Characteristics of Semiconductor Devices and General Principles of Measuring Methods, Part 2. General Principles of Measuring Methods, including

147-2A (1969) Supplement to 147-2,

148 (1969) Letter Symbols for Semiconductor Devices and Integrated Microcircuits

149-1 (1963) Sockets for Electronic Tubes and Valves, Part I: General Requirements and Methods of Test

149-2 (1965) Sockets for Electronic Tubes and Valves, Part II: Specification Sheets for Sockets and Dimensions of Wiring Jigs and Pin Straighteners,

149-2A (1968) Supplement to Publication 149-2

149-2B (1969) Supplement to Publication 149-2

150 (1963) Testing and Calibration of Ultrasonic Therapeutic Equipment

151-0 (1966) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part 0: Precautions Relating to Methods of Measurement of Electronic Tubes and Valves

151-1 (1963) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part I: Measurement of Electrode Current

151-2 (1963) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part II: Measurement of Heater or Filament Current

151-3 (1963) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part III: Measurement of Equivalent Input and Output Admittances

151-4 (1963) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part IV: Methods of Measuring Noise Factor

151-5 (1964) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part V: Methods of Measuring Hiss and Hum

151-6 (1965) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part VI: Methods of Application of Mechanical Shock (Impulse) Excitation to Electronic Tubes and Valves

151-7 (1964) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part VII: Measurement of Equivalent Noise Resistance *(C60.9-1964)*

IEC No

151-8 (1966) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part VIII: Measurement of Cathode Heating Time and Heater Warm-Up Time

151-9 (1966) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part IX: Methods of Measuring the Cathode-Interface Impedance

151-10 (1966) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part X: Methods of Measurement of Audio-Frequency Output Power and Distortion *(C60.15-1963)*

151-11 (1966) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XI: Methods of Measurement of Radio-Frequency Output Power *(Agrees with C60.15-1963)*..

151-12 (1966) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XII: Methods of Measuring Electrode Resistance, Transconductance, Amplification Factor, Conversion Resistance, and Conversion Transconductance *(C60.15-1963)*.

151-13 (1966) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XIII: Methods of Measurement of Emission Current from Hot Cathodes for High-Vacuum Electronic Tubes and Valves *(C60.15-1963)*

151-14 (1968) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XIV. Methods of Measurement of Radar and Oscilloscope Cathode-Ray Tubes

151-15 (1967) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XV: Methods of Measurement of Spurious and Unwanted Electrode Currents

151-16 (1968) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XVI: Methods of Measurement for Television Picture Tubes

151-17 (1969) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XVII: Methods of Measurement of Gasfilled Tubes and Valves

151-18 (1968) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XVIII: Methods of Measurement of Noises Due to Mechanical or Acoustic Excitations

151-19 (1969) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XIX: Methods of Measurement on Corona Stabilizers

151-20 (1969) Measurements of the Electrical Properties of Electronic Tubes and Valves, Part XX: Measurement of Thyratron Pulse Modulators

152 (1963) Identification by Hour Numbers of the Phase Conductors of 3-Phase Electric Systems

153-1 (1964) Hollow Metallic Waveguides, Part I: General Requirements and Measuring Methods

153-2 (1964) Hollow Metallic Waveguides, Part II: Relevant Specifications for Ordinary Rectangular Waveguides, including Amendment 1 *(C83.10-1963)*

Amendment 1 (1968), sold separately

153-3 (1964) Hollow Metallic Waveguides, Part III: Relevant Specifications for Flat Rectangular Waveguides

153-4 (1964) Hollow Metallic Waveguides, Part IV: Relevant Specifications for Circular Waveguides,
(C83.19-1958)

Amendment 1 (1968)

153-5 (1968) Hollow Metallic Waveguides, Part V: Relevant Specifications for Rectangular Waveguides with Circular Outside Cross-Section

153-6 (1967) Hollow Metallic Waveguides, Part VI: Relevant Specifications for Medium Flat Rectangular Waveguides

154-1 (1964) Flanges for Waveguides, Part I: General Requirements and Measuring Methods

154-2 (1968) Flanges for Waveguides, Part II: Relevant Specification for Flanges for Ordinary Rectangular Waveguides

154-3 (1968) Flanges for Waveguides, Part III: Relevant Specifications for Flanges for Flat Rectangular Waveguides

154-4 (1969) Flanges for Waveguides, Part IV: Relevant Specifications for Flanges for Circular Waveguides.

155 (1963) Glow Starters for Tubular Fluorescent Lamps *(C78.180-1966)*,

Amendment 1 (1965)

IEC No.

156 (1963) Method for the Determination of the Electric Strength of Insulating Oils.

157-1 (1964) Low-Voltage Distribution Switchgear, Part I: Circuit-Breakers, *(C37.13-1963, C37.15-1954 (R1967), C37.16-1963, and C37.17-1962)*

157-1A (1966) Supplement to Publication 157-1, ol

158-1 (1964) Low-Voltage Controlgear for Industrial Use, Part I: Contactors.

159 (1964) Dimensions of the Mating Parts of Radio-Frequency Connectors

160 (1963) Standard Atmospheric Conditions for Test Purposes

161 (1965) Capacitors for Radio Interference Suppression

162 (1965) Lightng Fittings for Tubular Fluorescent Lamps

163-1 (1988) Sensitive Switches, Part I: General Requirements and Measuring Methods

164 (1964) Recommendations in the Field of Quantities and Units Used in Electricity.

165 (1963) Rules for the Testing of Electric Rolling Stock on Completion of Construction and Before Entry into Service

166 (1965) Fixed Metallized Paper Dielectric Capacitors for Direct Current

167 (1964) Method of Test for the Determination of the Insulation Resistance of Solid Insulating Materials *(C59.3-1968)*

168 (1964) Tests on Indoor and Outdoor Post Insulators for Systems with Nominal Voltages Greater than 1000 V *(C29.7-1961 and C29.9-1961)*

169-1 (1965) Radio-Frequency Connectors, Part I: General Requirements and Measuring Methods.

169-2 (1965) Radio-Frequency Connectors, Part 2: Coaxial Unmatched Television Aerial Feeder Connector

169-3 (1965) Radio-Frequency Connectors, Part 3: Two Pin Connector for Twin Balanced Aerial Feeders.

169-4 (1967) Radio-Frequency Connectors, Part 4: R. F. Coaxial Connectors for Cables 96 IEC 50-12

170 (1964) Class 1.0 Alternating-Current Watthour Meters.

171 (1964) Fundamental Parameters of Connectors for Printed Wiring Boards,

Amendment 1 (1969),

172 (1966) Test Procedure for the Evaluation of the Thermal Endurance of Enamelled Wire by the Lowering of the Electric Strength Between Twisted Wires

173 (1964) Colours of the Cores of Flexible Cables and Cords

174 (1966) AC Electric Pedestal Type Fans and Regulators.

175 (1965) AC Electric Table Type Fans and Regulators.

176 (1966) AC Electric Ceiling Type Fans and Regulators

177 (1965) Pure Tone Audiometers for General Diagnostic Purposes *(Z24.5-1951)*

178 (1965) Pure Tone Screening Audiometers *(Z24.12-1952)*

179 (1965) Precision Sound Level Meters.

180 (1965) Nominal Cross-Sectional Areas and Composition of Circular Copper Conductors for Rubber or Polyvinyl Chloride Insulated Cables and Flexible Cords with a Rated Voltage Not Exceeding 750V.

181 (1964) Index of Electrical Measuring Apparatus Used in Connection with Ionizing Radiation,

Supplements 181-A and 181-B

Amendment 1 (1967), sold s-

181-A (1965) Supplement to Pub. 181

181-B (1966) Supplement to Pub. 181

182-1 (1964) Basic Dimensions of Winding Wires, Part I: Diameters of Conductors for Round Winding Wires.

182-2 (1964) Basic Dimensions of Winding Wires, Part II: Maximum Overall Diameters of Enamelled Round Winding Wires

183 (1965) Guide to the Selection of High-Voltage Cables

184 (1985) Methods for Specifying the Characteristics of Electro-Mechanical Transducers for Shock and Vibration Measurements.

185 (1968) Current Transformers

186 (1969) Voltage Transformers.

187 (1965) Ceramic Dielectric Capacitors Type 2.

188 (1965) Schedule for High-Pressure Mercury Vapour Lamps *(C78.1301-1968, C78.1305-1968, C78.1308-1968, C78.1309-1968, C78.1310-1968, and C78.1311-1968)*

IEC No.

189-1 (1965) Low-Frequency Cables and Wires with P.V.C. Insulation and P.V.C. Sheath, Part 1: General Test and Measuring Methods.

189-2 (1965) Low-Frequency Cables and Wires with P.V.C. Insulation and P.V.C. Sheath, Part 2: Cables in Pairs, Triples, Quadruples, and Quintuples for Telephone and Telegraph Exchanges,

Amendment 1 (1965)

Amendment 2 (1969)

189-3 (1967) Low-Frequency Cables and Wires with P.V.C. Insulation and P.V.C. Sheath, Part 3: Equipment Wires, Type 1, with Solid or Stranded Conductor, P.V.C. Insulated, Single

189-4 (1968) Low-Frequency Cables and Wires with P.V.C. Insulation and P.V.C. Sheath, Part 4: Distribution Wires with Solid Conductors, P.V.C. Insulated, in Pairs, Triples, Quadruples, and Quintuples.

189-5 (1969) Low-Frequency Cables and Wires with P.V.C. Insulation and P.V.C. Sheath, Part 5: Equipment Wires and Cables with Solid or Stranded Conductors, P.V.C. Insulated, Screened, Single or One Pair

190 (1968) Non-Wirewound Potentiometers Type 2

191-1 (1966) Mechanical Standardization of Semiconductor Devices, Part 1: Preparation of Drawings of Semiconductor Devices, *(C37.40-1962 through C37.47-1962)*

191-1A (1969) Supplement to Publication 191-1, sold separately

191-2 (1966) Mechanical Standardization of Semiconductor Devices, Part 2: Dimensions,

191-2A (1967) Supplement to Publication 191-2 (1966),

191-2B (1969) Supplement to Publications 191-2 and 191-2A,

192 (1965) Schedule for Sodium Lamps (Integral Type).

193 (1965) International Code for Model Acceptance Tests of Hydraulic Turbines

194 (1965) Terms and Definitions for Printed Circuits.

195 (1965) Method of Measurement of Current Noise Generated in Fixed Resistors.

196 (1965) IEC Standard Frequencies.

197 (1965) High-Voltage Connecting Wire with Flame Retarding Insulation for Use in Television Receivers

198 (1966) International Code for the Field Acceptance Tests of Storage Pumps

199 (1965) Dimensions of Lead-Acid Motor Scooter Batteries

200 (1966) Methods of Measurement of Loudspeakers

201 (1965) Power Sources for Portable Prospecting Equipment for Radioactive Materials

202 (1965) Polyester Film Dielectric Capacitors for Direct Current

203 (1966) Dimensions of the Crimp Area of Machined Crimp Type Contacts

204-1 (1965) Electrical Equipment of Machine-Tools, Part 1: Electrical Equipment of Machines for General Use,

Amendment 1 (1967),

204-2 (1967) Electrical Equipment of Machine-Tools, Part 2: Electrical Equipment of Machines Used in Large Series Production Lines.

204-3 (1968) Electrical Equipment of Machine-Tools, Part 3: Electronic Equipment of Machine-Tools

205 (1966) Calculation of the Effective Parameters of Magnetic Piece Parts,

205A (1968) Supplement to Publication 205,

206 (1966) Designation of the Quantities Characterizing the Magnetic and Electric Properties of Vacuum and a Substance

207 (1966) Aluminum Stranded Conductors *(C7.21-1965)*

208 (1966) Aluminum Alloy Stranded Conductors (Aluminum - Magnesium - Silicon Type)

209 (1966) Aluminum Conductors, Steel-Reinforced *(C7.22-1965)*

210 (1968) Aluminum Alloy Conductors, Steel-Reinforced

IEC No.

211 (1966) Maximum Demand Indicators, Class 1.0

212 (1966) Standard Conditions for Use Prior to and During the Testing of Solid Electrical Insulating Materials.

213 (1966) Tests on Solid-Core Insulators for Overhead Electric Traction Lines with a Voltage Greater Than 1000 V

214 (1966) On-Load Tap-Changers

215-1 (1966) Safety Requirements for Radio Transmitting Equipment, Part 1: Requirements

215-2 (1967) Safety Requirements for Radio Transmitting Equipment, Part 2: Test Methods

216 (1966) Guide for the Preparation of Test Procedures for Evaluating the Thermal Endurance of Electrical Insulating Materials

217 (1967) Electronic Voltmeters

218 (1966) Guide for the Drafting of Performance Specifications for Cores of Tuned Transformers and Inductors of Ferromagnetic Oxides for Telecommunication

219 (1966) Guide for the Drafting of Performance Specifications for Cores of Broad-Band Transformers of Ferromagnetic Oxides for Telecommunication.

220 (1966) Dimensions of Tubes, Pins and Rods of Ferromagnetic Oxides

221 (1966) Dimensions of Screw Cores Made of Ferromagnetic Oxides,

Amendment 1 (1968)

222 (1966) Methods for Specifying the Characteristics of Auxiliary Equipment for Shock and Vibration Measurement

223 (1966) Dimensions of Aerial Rods and Slabs of Ferromagnetic Oxides

224 (1966) Marking of Control Settings on Hearing Aids

225 (1966) Octave, Half-Octave, and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibrations *(S1.11-1966)*

226 (1967) Dimensions of Cross Cores (X-Cores) Made of Ferromagnetic Oxides and Associated Parts

227 (1967) Polyvinyl Chloride Insulated Flexible Cables and Cords with Circular Conductors and a Rated Voltage Not Exceeding 750 V

Amendment 1 (1969)

228 (1966) Nominal Cross-Sectional Areas and Composition of Conductors of Insulated Cables

229 (1966) Tests on Anti-Corrosion Protective Coverings of Metallic Cable Sheaths

230 (1966) Impulse Tests on Cables and Their Accessories

231 (1967) General Principles of Nuclear Reactor Instrumentation

232 (1966) General Characteristics of Nuclear Reactor Instrumentation

233 (1967) Tests on Large Hollow Porcelains for Use in Electrical Installations

234 (1967) Dimensions of Ceramic Dielectric Capacitors of the Plate Type

235-1 (1967) Measurement of the Electrical Properties of Microwave Tubes and Valves, Part 1: General Terms and Definitions.

236 (1967) Methods for the Designation of Electrostatic Deflecting Electrodes of Cathode-Ray Tubes

237 (1967) Ignitrons To Be Used in Welding Machine Control

238 (1967) Edison Screw Lampholders . . . .

239 (1967) Nominal Dimensions of Cylindrical Machined Graphic Electrodes with Threaded Sockets and Connecting Pins for Use in Electric Arc Furnaces

240 (1967) Characteristics of Electric Infra-Red Emitters for Heating Purposes

241 (1966) Fuses for Domestic and Similar Purposes

242 (1967) Standard Frequencies for Centralized Network Control Installations.

243 (1967) Recommended Methods of Test for Electric Strength of Solid Insulating Materials at Power Frequencies

244-1 (1968) Methods of Measurement for Radio Transmitters, Part 1: General Conditions of Measurement, Frequency, Output Power, and Power Consumption,

244-1A (1966) Supplement to Publication 244-1,

IEC No.

244-2 (1969) Methods of Measurement for Radio Transmitters, Part 2: Bandwidth, Out of Band Power, and Power of Non-Essential Oscillations,

244-2A (1969) Supplement 1 to Publication 244-2

244-2B (1969) Supplement 2 to Publication 244-2

245 (1967) Rubber Insulated Flexible Cables and Cords with Circular Conductors and a Rated Voltage Not Exceeding 750 V,

Amendment 1 (1969)

246 (1967) Connecting Wires Having a Rated Voltage of 20 kV and 25 kV DC and a Maximum Working Temperature of 105° C for Use in Television Receivers.

247 (1967) Recommended Test Cells for Measuring the Resistivity of Insulating Liquids and Methods of Cleaning the Cells

248 (1967) External Diameter of Planchets Used in Nuclear Electronic Instruments.

249-1 (1966) Metal-Clad Base Materials for Printed Circuits, Part 1: Test Methods

250 (1969) Recommended Methods for the Determination of the Permittivity and Dielectric Dissipation Factor of Electrical Insulating Materials at Power, Audio and Radio Frequencies, including Metre Wavelengths

251-1 (1966) Methods of Test for Winding Wires, Part 1: Enamelled Round Wires

252 (1967) AC Motor Capacitors

253 (1967) Power Supply for Air and Land Vehicle-Mounted Prospection Equipment for Radioactive Materials.

254 (1967) Lead-Acid Traction Batteries.

255-1 (1967) Electrical Relays, Part 1: Instantaneous All-Or-Nothing Relays *(C37.1-1962 (R1967))*

256 (1967) External Diameters of Cylindrical Radiation Probes Containing Geiger-Muller or Proportional Counter Tubes or Scintillation Detectors

257 (1966) Fuse-Holders for Miniature Cartridge Fuse-Links

258 (1968) Direct Recording Electrical Measuring Instruments and Their Accessories

259 (1966) Miscellaneous Lamps and Ballasts *(C78 Series)*

260 (1966) Test Enclosures of Non-Injection Type for Constant Relative Humidity

261 (1966) Sealing Test for Pressurized Waveguide Tubing and Assemblies

262 (1969) Ballasts for High Pressure Mercury Vapour Lamps *(C82.4-1968, C82.5-1966, C82.6-1965, and C82.7-1963)*

263 (1968) Scales and Sizes for Plotting Frequency Characteristics

264-1 (1966) Packaging of Winding Wires, Part 1: Containers for Round Winding Wires

264-2 (1966) Packaging of Winding Wires, Part 2: Delivery Spools for Winding Wires

265 (1966) High Voltage Switches *(C37.30-1962, C37.31-1962, C37.32-1965, C37.33-1962, C37.34-1962, and C37.35-1962),*

265A (1969) Supplement to 265,

265B (1969) Supplement to 265,

266 (1969) Fixed Wirewound Resistors Type 2

267 (1966) Guide to the Testing of Circuit-Breakers with Respect to Out-of-Phase Switching

268-1 (1966) Sound System Equipment, Part 1: General

269-1 (1966) Low-Voltage Fuses with High Breaking Capacity for Industrial and Similar Purposes, Part 1: General Requirements

270 (1968) Partial Discharge Measurements

271 (1969) Preliminary List of Basic Terms and Definitions for the Reliability of Electronic Equipment and the Components (or Parts) Used Therein

272 (1966) Preliminary Reliability Considerations

273 (1966) Dimensions of Indoor and Outdoor Post Insulators and Post Insulator Units for Systems with Nominal Voltages Greater Than 1000 V *(C29.8-1961 and C29.9-1961)*

274 (1966) Tests on Insulators of Ceramic Material or Glass for Overhead Lines with a Nominal Voltage Greater Than 1000 V *(C29.1-1961)*

IEC No.

275 (1988) Polystyrene Film Dielectric Capacitors

278 (1969) Definitions and Nomenclature for Carbon Brushes, Brush-Holders, Commutators, and Slip-Ring *(Agrees with C64.1-1963)*

277 (1998) Definitions for Switchgear and Controlgear *(C37.100-1966 and C42.25-1956)*

278 (1999) Documentation To Be Supplied with Electronic Measuring Apparatus

279 (1999) Measurement of the Winding Resistance of an A.C. Machine during Operation at Alternating Voltage.

290 (1968) Class 0.5 Alternating-Current Watthour Meters

291 (1989) Magnetic Cores for Application in Coincident Current Matrix Stores Having a Nominal Selection Ratio of 2:1

292-1 (1988) High-Voltage Fuses, Part 1: Current-Limiting Fuses

293 (1968) Methods for the Measurement of Frequency and Equivalent Resistance of Unwanted Resonances of Filter Crystal Units

294 (1969) Rules of Behaviour with Respect to Possible Hazards When Dealing with Electronic Equipment and Equipment Employing Similar Techniques.

299 (1969) Packaging of Components on Continuous Tapes

297 (1999) Calculation of the Continuous Current Rating of Cables (100% Load Factor)

299-1 (1999) Tube and Valve Shields, Part 1: General Requirements and Methods of Test

288-2 (1999) Tube and Valve Shields, Part 2: Specification Sheets for Shields for Tubes and Valves and Dimensions of Testing Devices and Gauges for Shields *(C57.12.00-1968, C57.12.90-1968, and C57.16-1958)*

299 (1969) Reactors *(C57.12.00-1968. C57.12.90-1968. C57.16-1958)*

290 (1969) Evaluation of the Thermal Endurance of Electrical Insulating Varnishes by the Helical Coil Bond Test

291 (1969) Fuse Definitions *(C37.40 through C37.47-1962)*

292-1 (1999) Low-Voltage Motor Starters, Part 1: Direct-on-Line (Full Voltage) AC Starters

293 (1988) Supply Voltages for Transistorized Nuclear Instruments

294 (1989) Measurement of the Dimensions of a Cylindrical Component Having Two Axial Terminations

295 (1969) DC Periodmeters: Characteristics and Test Methods.

296 (1969) Specification for New Insulating Oils for Transformers and Switchgear.

297 (1969) Dimensions of Panels and Racks (for Nuclear Electronic Instruments) *(C83.9-1968)*

299 (1969) Measurement of the Performance Characteristics of Electric Blankets

300 (1969) Managerial Aspects of Reliability.

301 (1969) Preferred Diameters of Wire Terminations of Capacitors and Resistors.

304 (1969) Standard Colours for P.V.C. Insulation for Low-Frequency Cables and Wires *(C83.1-1969)*.

IEC No.

305 (1969) Characteristics of String Insulator Units of the Cap and Pin Type *(C29.2-1962 (R1969))*

307 (1989) Electric Fans and Regulators for Use in Ships

TABLE 11. Original Length Unit in IEC Recommendations

Original length unit	U.S. participated in voting	1955–1961		1962–1969	
		Number	Percent *	Number	Percent *
A. All metric	Yes	8	34.8	40	29.9
	No	2	8.7	23	17.2
		10	43.5	63	47.1
B. Metric dominant	Yes	8	34.8	36	26.9
	No	1	4.3	7	5.2
		9	39.1	43	32.1
C. Mixed	Yes	4	17.4	10	7.5
	No	0	0	4	3.0
		4	17.4	14	10.5
D. Inch dominant	Yes	0	0	7	5.2
	No	0	0	1	0.7
		0	0	8	5.9
E. All inch	Yes	0	0	5	3.7
	No	0	0	1	0.7
		0	0	6	4.4
Total		23		134	

*Percent of total.

TABLE 12. International Electrical Standards Having Length Units

IEC Rec.	Original length unit *	U.S. (ANSI)	U.K. (BS)	Germany (DIN)	Japan (JIS)	India (IS)	France (AFNOR)
41	B		353	1948			
45	B		132		B8101		
46	B		752	1953	B8102		
52	A	C68.1	358		C1001	1876	
55-1	A						
55-2	A					692	
56-4	B	C37	116				
60	C	C68.1, C77.1				2071	
61	B	(1)	(3)	(4)	C7709	418, 1258	
61-1	B						
61-2	B						
61-3	B						
64	A		161	49810	C7501, 7517	418	
65	A		415			616	
67	D		448	(5)	C7104	2684	
68-2-6	A			40046/8	C5025		C90-163
68-2-7	A						C90-165
68-2-11	A				C5028		
68-2-13	A				C5029	2106	C93-001
68-2-17	A			40046/15	C5031	589	C93-001
68-2-20	A			40046/18		589	C93-001
68-2-21	A			40046/19	C5035	589	C93-001
68-2-27	B				C0912		C90-180
68-2-29	B						C90-162
72-1	C	C50.8	3979	(6)		1231	
72-2	B		3979	(6)		2223	
74	B		148		C2101	335	
76	B	C57.12			C4301, 4305	2026	C52-100
78	C		3040				
79	C		229		C0901, 0903	2148	
79-4	B		4056				
79-6	A						
79-7	A						
81	C		1853	49862	C7601	2418	C72-210
82	B	C82.1, C82.2 C82.3	2818	(7)	C8101	1534	
83	C	(2)	546, 1363	49440-1	C8302	1293	
86-2	A	C18.1		(8)		(12)	
86-3	A	C18.1	397	(8)			
92-1	B			89001			
92-3	C			89001	C3410		
93	C	C59.3	2782		C6481	3396	
94	B			(9)	C5509, 5550 5551	4377	
95-2	A		3911	72311/1-12			
95-3	A			72311/1-12			

TABLE 12. International Electrical Standards Having Length Units — Con.

IEC Rec.	Original length unit *	U.S. (ANSI)	U.K. (BS)	Germany (DIN)	Japan (JIS)	India (IS)	France (AFNOR)
96-2	A		2316				
97	B			40801	C5010		
98	C		1928	45536-7, 45546-7	C8502		
99-2	C	C62.1				3070, 4850	
100	D	C60.6			C7111	4096	
103	B		2134	41230, 41240 41332	C5140, 6411 6440, 6451	4317	
104	B			48200/6			
106	A		905	45300		4546	
108	B		2133A	41920	C6422	1980	
109	B		2112		C6401, 6406	2903	
111	B	C7.20	215, 2627	48200/5			
114	B		2898	1748/1, 43670			
115	B		2112	44050, 44052	C6406, 6401	2902	
116	B		2132	41120	C6441	2001	
118	A	S3.3		45600	C5512	3641	
121	A	C7.23	2627			4800	
122-3	E			(10)			
124	A				C5515	2382	
126	A	S3.3	3171	42601	C5512	3641	
130-1	A					3826	
130-2	A						
130-3	B			45315, 45316		2926	
130-4	B						
130-5	B			41622			
130-6	B			41618			
131-1	A					3452	
131-2	B						
131-3	D						
132-1	A			41619, 41631		2628	
132-3	B			41619, 41631			
132-4	B						
132-5	B			41631			
133	B		4061	41293, 41294	C2516		
136-1	E	C64.1		(11)		3003	C51-902
136-2	B	C64.1				3003	C51-902
140	B		364	40450, 49999	C7708		
141-1	A				C3607		
141-2	A				C3608		
141-3	A						
142	D		2981	15552, 15655, 15687			
149-2	D			41557/1, 2, 6 41559/1, 2, 6		3354	
149-2A	B						
149-2B							

TABLE 12. International Electrical Standards Having Length Units—Con.

IEC Rec.	Original length unit *	U.S. (ANSI)	U.K. (BS)	Germany (DIN)	Japan (JIS)	India (IS)	France (AFNOR)
151-3	B						
151-18	A						
153-1	B					4493	
153-2	E	C83.10		47302			
153-3	B			47302			
153-4	D	C83.19		47302/2			
153-5	C						
153-6	D						
154-1	B						
154-2	D						
154-3	B						
154-4	B						
158-1	A					2959	
159	C			44424	C6504, 6506		
161	B		2135	41170		3723	
162	B		3820		C7601, 7602	1913, 1777	
169-2	E						
169-3	B			45317			
169-4	B						
171	A						
172	A				C3003		
174	A				C9601	1169	
175	A		380		C9601	555	
180	A		3361			2982	
182-1	A			46435	C3102-3	4800	
182-2	A			46435	C3202-3, 3210-1	4800	
183	A						
187	A		2133	41920	C6422	2786	
189-1	A				C3005		
189-2	A						
189-3	A						
189-4	A						
189-5	A						
191-1	C			41871, 41879		5001	
191-2	C					5000	
199	A				D5302	1145	
203	E						
207	B	C7.21	215	48200/5, 48201/5, 48202/1	C3109	398	
208	A		3242	48200/6 48201/6 48202/3			C34-125
209	A	C7.22	215	48202, 48204		398	C34-120

TABLE 12. International Electrical Standards Having Length Units—Con.

IEC Rec.	Original length unit *	U.S. (ANSI)	U.K. (BS)	Germany (DIN)	Japan (JIS)	India (IS)	France (AFNOR)
210	A			48202, 48406			C34–125
220	A						
221	C				C2515		
226	A			41277, 41299/1			
227	A				C3312	694	
228	C						
234	A				C5101, 5130		
238	A		98		C8302		
239	A						
245	A		7, 4180		C3302	694	
246	A						
248	A		3775	44423			
250	A					4486	C26–230
251–1	A			46453	C3003	4800	
256	A			44422			
257	A						
259	B						
264–1	A			46396	C3205		
264–2	A						
273	C						C66–037
286	B						C93–720
288–1	A						
288–2	E						
294	A				C5102, 5202		C93–013
297	A				C6010		
299	C						
301	A				C5001		
305	A						
307	A						

*A, all metric; B, metric dominant; C, mixed; D, inch dominant; E, all inch.

United States (ANSI)
(1) C81.51, .101, .102, .103, .104, .105, .106, .107, .108, .109 and .111.
(2) C73.10, .15, .21, .23, .26 and .27. Partially agrees with C73.11 and C73.25.

United Kingdom (BS)
(3) 52, 98, 1164, 1875.

Germany (DIN)
(4) 49663, 49665, 49675, 49680, 49685, 49710, 49715, 49729, 49740.
(5) 41534, 41536–41539, 41549, 41544–41547, 41551, 41601, 41603, 41605, 51607, 44431.
(6) 42671–42673, 42676–42679, 42681, 42946, 42948, 42973.
(7) 49665, 49710, 49715, 49729, 49740.
(8) 40856, 40855, 40869, 40870, 40875.
(9) 45511, 45513, 45515, 45517.
(10) 45111, 45113, 45117, 45118.
(11) 43000, 43008, 43021, 43028, 43040, 43042.

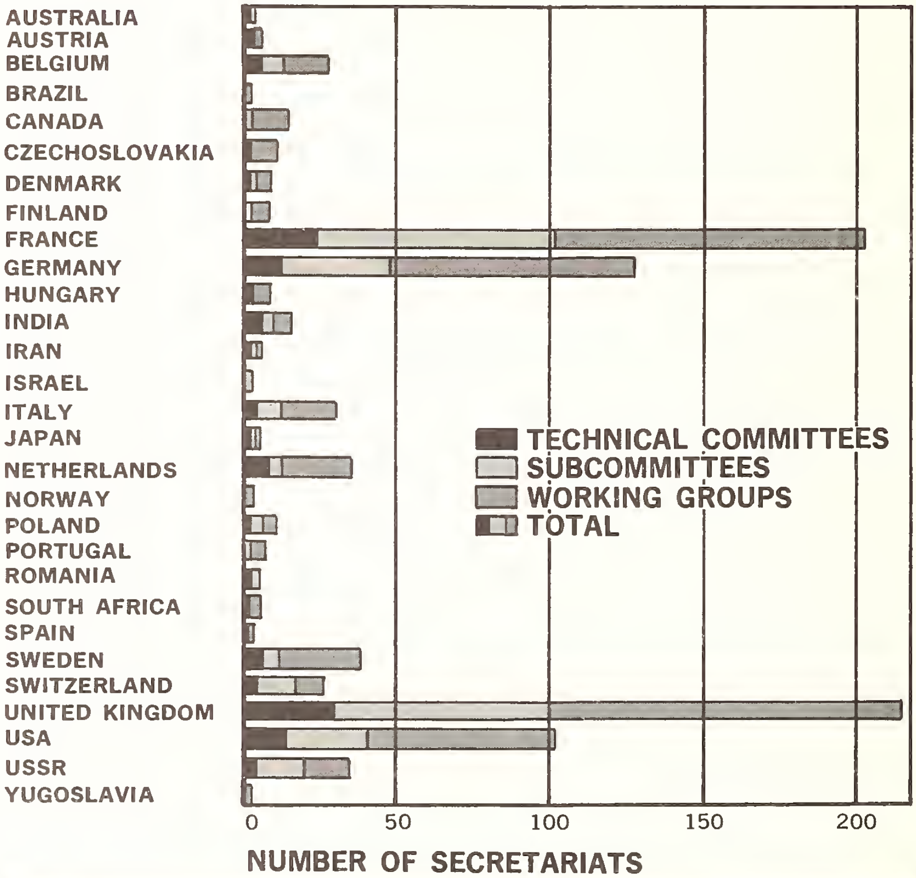
India (IS)
(12) 203, 267, 556, 586, 2576.

16. ISO RECOMMENDATIONS

The International Organization for Standardization (ISO) is concerned with standardization in all fields except electricity which is the responsibility of IEC. Since its organization in 1948, 139 technical committees have been established. Additional ones are being established each year. Thus far, there is no committee for pharmaceuticals and drugs; but in the field of health and safety there are committees dealing with anesthetic and breathing equipment, athletic equipment, dentistry, food, medical syringes, protective clothing and equipment for personal safety, stretchers, and transfusion equipment. Most of the committees deal with industrial materials and equipment including such products as aircraft, agricultural machines, automobiles, computers, earth moving machines, office machines, and shipbuilding. The work of a technical committee results in an ISO Recommendation or an ISO Standard. An ISO Recommendation requires approval of a majority of the member countries participating in the technical committee and 60 percent of the member countries of ISO that voted either positively or negatively. An ISO Standard requires that no member body of ISO objects to transforming an ISO Recommendation into an ISO Standard.

The Secretariats of ISO technical committees, subcommittees and working groups are distributed among 29 member countries shown in figure 4. The predominance of the United Kingdom and France in number of Secretariats held is very striking. Together, they have 420 or over 40 percent of the 1,010 total. Germany has 128 and the United States has 99. Thus, these four countries have nearly two-thirds of the Secretariats. The remainder are distributed among 25 countries, mainly Sweden (41), Netherlands (38), USSR (36), Italy (33), Belgium (30), and Switzerland (28). The industrial Western European countries hold nearly 75 percent of the Secretariats, Eastern European countries hold about 8 percent, the U.S. holds about 10 percent, and all other regions combined hold about 4 percent.

FIGURE 4
DISTRIBUTION OF ISO SECRETARIATS



Secretariats for seven subcommittees and 43 working groups are not yet allocated. In view of the advantages associated with a Secretariat, it is not surprising that most ISO Recommendations are based on national standards of European countries.

The ISO Recommendations that were issued from 1951 through 1969 are listed in table 13. If those issued in two or more parts are considered as a separate recommendation for each part, about 1,200 ISO Recommendations are in this list. The time period between initiation of work by the Technical Committee and its issuance as an ISO Recommendation is 5 years or more. After issuance, they are reviewed at least every 5 years. Thus far, 37 of the ISO Recommendations listed are revisions.

These 1,200 ISO Recommendations are a small percentage of the number of national standards in industrial countries. Nevertheless, even this number is too large to compare with national standards in this survey in view of the limited funds and manpower available. Therefore, this survey is restricted to a comparison of ISO Recommendations with national standards for the following industrial materials and products which were selected to be representative of the status of international standardization and the role of measurement units in such standardization:

Materials	*Products*
Ferrous metal (steel)	Antifriction bearings
Non-ferrous metal	Building construction
Plastics	Pipe and tubing
Rubber	Screw threads and fasteners

For each of these groups, there are sufficient ISO Recommendations to be indicative of the problems involved and the achievements in harmonizing national standards.

TABLE 13. Numerical List—ISO Recommendations

Ref.	Title
R1 -1951	Standard reference temperature for industrial length measurements
R2 -1966	Designation of the direction of twist in textile yarns and related products, 2nd Edition, replacing R2-1951 and R2/A1 1961
R3 -1953	Preferred numbers. Series of preferred numbers
R4 -1953	International code for the abbreviation of titles of periodicals
R5 -1954	Diffuse transmission density
R6 -1954	Method for determining photographic speed and exposure index
R7 -1954	Pipe threads for gas list tubes and screwed fittings where pressure-tight joints are made on the threads (⅛ inch to 6 inches)
R8 -1954	Layout of periodicals
R9 -1968	International system for the transliteration of slavic cyrillic characters, 2nd Edition
Errata	Errata of first printing Sept. 1968
R10 -1954	Aircraft connection for ground air-conditioning
R11 -1954	Aircraft pressure cabin ground test connection
R12 -1955	Identification of aircraft pipe-lines
R13 -1955	Cast iron pipes, special castings and cast iron parts for pressure main lines
R13/A1 -1968	Amendment 1 to ISO Recommendation R 13–1955
R14 -1955	Straight-sided splines (for cylindrical shafts). Nominal dimensions in millimetres
R15/I -1968	Rolling bearings. Radial bearings. Boundary dimensions. General plan. Part 1. Diameter series 8, 9, 0, 1, 2, 3 and 4, 2nd Edition
R16 -1955	Standard tuning frequency (Standard musical pitch)
R17 -1955	Guide to the use of preferred numbers and of series of preferred numbers
R17/A1 -1966	Amendment 1 to ISO Recommendation R 17–1955
R18 -1955	Short contents list of periodicals or other documents
R19 -1956	Deckbolts
R20 -1956	Rivets for hatches
R21 -1956	Sprocket wheels
R22 -1956	Widths of flat transmission belts and corresponding pulleys
R23 -1956	Emulsion and sound record positions in camera for 35 mm sound motion picture film
R24 -1956	Emulsion and sound record positions in projector for 35 mm sound motion picture film
R25 -1956	Emulsion position in camera for 16 mm silent motion picture film
R26 -1956	Emulsion position in projector for direct front projection of 16 mm silent motion picture film
R27 -1956	Emulsion and sound record positions in camera for 16 mm sound motion picture film
R28 -1956	Emulsion position in camera for 8 mm silent motion picture film
R29 -1956	Emulsion position in projector for direct front projection of 8 mm silent motion picture film
R30 -1956	Bibliographical strip
R31/I -1965	Basic quantities and units of the International System of units (SI units) 2nd Edition, replacing R 31/I–1956
Erratum	Erratum of first printing December 1965
R31/II -1958	Quantities and units of periodic and related phenomena
R31/III -1960	Quantities and units of mechanics
R31/IV -1960	Quantities and units of heat
R31/V -1965	Quantities and units of electricity and magnetism
R31/VII -1965	Quantities and units of acoustics
R31/XI -1961	Mathematical signs and symbols for use in physical sciences and technology
R32 -1957	Identification of medical gas cylinders
R32/A1 -1966	Amendment 1 to ISO Recommendation R 32–1957
R33 -1957	Du Pont constant load method of measuring abrasion resistance of vulcanized natural and synthetic rubbers
Erratum E	Erratum of first printing. Nov. 1961
Erratum F	
Erratum F2	
R34 -1957	Determination of tear strength of vulcanized natural and synthetic rubbers (crescent test piece)
R35 -1957	Determination of the mechanical stability of latex
R36 -1969	Determination of the adhesion strength of vulcanized rubbers to textile fabrics, 2nd Edition
R37 -1968	Determination of tensile stress-strain properties of vulcanized rubbers, 2nd Edition
R38 -1957	Bollards (vertical type) with and without lugs
R39 -1957	Anchor chains. Lugless joining shackles, Kenter type
R40 -1957	Anchor chains. Studless links
R41 -1957	Covers for deck openings for 220 mm pumps
R42 -1957	Mushroom ventilators
R43 -1957	Aircraft jacking pads
R44 -1957	Directions of operation of toggle switches on aircraft
R45 -1957	Aircraft pressure refuelling connections
R46 -1957	Aircraft fuel nozzle grounding plugs and sockets
R47 -1957	Aircraft toilet flushing and draining connections
R48 -1968	Determination of hardness of vulcanized rubbers, 2nd Edition
R49 -1957	Malleable cast iron pipe fittings screwed in accordance with ISO Recommendation R 7
R50 -1957	Steel sockets screwed in accordance with ISO Recommendation R 7. Minimum lengths
R51 -1957	Pipe-lines for the transport of combustible liquids. Nominal diameters
R52 -1957	Grooved pulleys for V-belts. Groove sections A, B, C, D, E
R53 -1957	Basic rack of cylindrical gears for general engineering
R54 -1966	Modules and diametral pitches of cylindrical gears for general engineering and for heavy engineering, 2nd Edition, replacing R 54–1957

TABLE 13. Numerical List — ISO Recommendations — Continued

Ref.	*Title*
R55 –1957	Specification for seedlac
R56 –1957	Specification for shellac
R56/A1 –1966	Amendment 1 to ISO Recommendation R 56–1957
R57 –1957	Specification for bleached lac
R58 –1958	Substances of paper
R59 –1958	Determination of the percentage of acetone soluble matter in phenolic mouldings
R60 –1958	Determination of apparent density of moulding material that can be poured from a specified funnel
R61 –1958	Determination of apparent density of moulding material that cannot be poured from a specified funnel
R62 –1958	Determination of water absorption
R62/A1 –1965	Amendment 1 to ISO Recommendation R 62–1958
R63 –1958	Lengths of flat transmission belts
R64 –1958 –Add. 1969	Steel tubes — Outside diameters (larger than 419 mm (16.5 in))
R65 –1958	Steel tubes suitable for screwing in accordance with ISO Recommendation R 7
R66 –1958	Paper vocabulary. First series of terms (English, French, Russian)
R66/A1 –1964	Amendment 1 to ISO Recommendation R 66–1958
R66/A2 –1968	Amendment 2 to R66–1958
R67 –1958	Muscovite mica blocks, thins and films. Methods for grading by size
R68 –1969	ISO General purpose screw threads — Basic profile — 2nd Edition
R69 –1958	Dimensions for 16 mm motion-picture film with perforations along one and two edges
R70 –1958	Photographic sound record on 35 mm prints
R71 –1958	Photographic sound record on 16 mm prints
R72 –1958	Sound records and scanning area of 35 mm double width push-pull sound prints. Normal and offset centerline types
R73 –1958	Image produced by camera aperture and projected image area for 35 mm films
R74 –1958	Image produced by camera aperture and projected image area for 8 mm films
R75 –1958	Determination of temperature of deflection under load
R76 –1958	Ball and roller bearings. Methods of evaluating static load ratings
R77 –1958	Bibliographical references. Essential elements
R78 –1968	Guide on the form for standards for chemical products and for methods of chemical analysis, 2nd Edition
R79 –1968	Brinell hardness test for steel, 2nd Edition
R80 –1968	Rockwell hardness test (B and C scales) for steel, 2nd Edition
R81 –1967	Vickers hardness test for steel (Load 5 to 100 kgf), 2nd Edition
R82 –1959	Tensile testing of steel
R83 –1959	Charpy impact test (U-notch) for steel
R84 –1959	Izod impact test for steel
R85 –1959	Bend test for steel
R86 –1959	Tensile testing of steel sheet and strip less than 3 mm and not less than 0.5 mm thick
R87 –1959	Simple bend testing of steel sheet and strip less than 3 mm thick
R88 –1959	Reverse bend testing of steel sheet and strip less than 3 mm thick
R89 –1959	Tensile testing of steel wire
R90 –1959	Hermetically sealed metal food containers. General data: determination of capacity, designation, marking, definitions, procedure for dimensional specification
R91 –1959	Petroleum measurement tables
R92 –1959	Definition of side (left or right) of spinning machinery
R93/I –1963	Cylindrical sliver cans 2nd Edition, replacing R 93–1959
R93/II –1969	Cylindrical sliver cans. Heights over 1000 mm
R93/III –1969	Cylindrical sliver cans on castors
R94 –1959	Spindle gauges for ring-spinning and ring-doubling frames
R95 –1959	Rings for ring-spinning and ring-doubling frames for ≪C≫ travellers (reversible)
R96 –1959	Rings for ring-spinning and ring-doubling frames for ≪C≫ travellers (non-reversible)
R97 –1959	Rings for ring-spinning and ring-doubling frames for ear-shaped travellers
R98 –1959	Diameters of drafting rollers for cotton, wool, spun silk and staple fibre
R99 –1959	Diameters of pulleys for flat transmission belts
R100 –1959	Crowns of pulleys for flat transmission belts
R101 –1959	Width of sheets of paper
R102 –1959	Gravity filling orifices for aircraft
R103 –1959	Sizes and mounting dimensions of aircraft instrument cases (rear-mounting type)
R104 –1966	Thrust bearings with flat seats. Boundary dimensions, 2nd Edition, replacing section 2 of R104–1959
R105/I –1959	Test for colour fastness of textiles. First series. *(Former reference: R105–1959)*
R105/A1 –1963	Amendment to the first edition.
R105/I/A2 –1968	Second amendment to the first edition
R105/II –1963	Tests for colour fastness of textiles. Second series
R105/III –1963	Tests for colour fastness of textiles. Third series
R105/IV –1968	Tests for colour fastness of textiles. Fourth Series
R105/V –1969	Tests for colour fastness of textiles. Fifth series
R106 –1959	Light metal rivets for shipbuilding. Nominal diameters, rivet hole diameters and clearances
R107 –1959	Light metal rivets for shipbuilding. Rivet heads
R108 –1959	Weaving looms. Definition of side (left or right)
R109 –1968	Weaving looms. Working width, 2nd Edition

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R110 –1959	Paper cones for yarn winding (cross wound). Taper 9° 15′
R111 –1959	Paper cones for yarn winding (cross wound) Taper 4° 20′
R112 –1959	Paper cones for yarn winding (cross wound). Taper 3° 30′
R113 –1969	Rolling bearings. Accessories, 2nd Edition
R114 –1959	Composition of 99.8 unalloyed magnesium ingots
R115 –1968	Classification and composition of unalloyed aluminum ingots for remelting, 2nd Edition
R116 –1959	Common names for pesticides. First list (English, French, Russian)
R117 –1959	Determination of boiling water absorption
R118 –1959	Determination of methanol-soluble matter in polystyrene
Erratum F	
R119 –1959	Determination of free phenols in phenolformaldehyde mouldings
R120 –1959	Determination of free ammonia and ammonium compounds in phenol-formaldehyde mouldings
R121 –1959	Composition of magnesium-aluminum-zinc alloy castings
R122 –1959	Composition of magnesium-aluminum-zinc alloy ingots for casting purposes
R123 –1968	Sampling of latex, 2nd Edition
R124 –1966	Determination of total solids of latex, 2nd Edition, replacing R 124–1959
R125 –1966	Determination of alkalinity of latex, 2nd Edition, replacing R 125–1959
R126 –1959	Determination of dry rubber content of latex
R127 –1959	Determination of KOH number of latex
R128 –1959	Engineering drawing. Principles of presentation
R129 –1959	Engineering drawing. Dimensioning
R130 –1959	Colour identification of mechanical control circuits for aircraft
R131 –1959	Expression of the physical and subjective magnitudes of sound or noise
R132 –1959	Determination of resistance to flex cracking of vulcanized natural or synthetic rubber (De Mattia type machine)
R133 –1959	Determination of resistance to crack growth of vulcanized natural or synthetic rubber (De Mattia type machine)
R134 –1962	Non-screwed steel tubes for general purposes 2nd Edition, replacing R 134–1959
R135 –1959	Paper vocabulary. Second series of terms
R135/A1 –1964	Amendment 1 to ISO Recommendation R135–1959
R136 –1959	Simple torsion testing of steel wire
R137 –1960	Determination of wool fibre diameter. Projection microscope method
R138 –1960	Universal yarn count system
R139 –1967	Standard atmospheres for conditioning and testing textiles, 2nd Edition
R140 –1960	Field and laboratory measurements of airborne and impact sound transmission
R141 –1960	Pirn winders and cross winders. Definition of side (left or right)
R142 –1960	Weaving preparatory machines. Definition of side (left or right)
R143 –1969	Weft pirns for box-loaders for automatic looms. Pirn tip dimensions. 2nd Edition
R144 –1960	Reverse bend testing of steel wire
R145 –1960	Wrapping test for steel wire
R146 –1968	Verification of Vickers hardness testing machines, 2nd Edition
Erratum	Erratum of first printing March 1968
R147 –1960	Load calibration of testing machines for tensile testing of steel
R148 –1960	Beam impact test (V-notch) for steel
R149 –1960	Modified Erichsen cupping test for steel sheet and strip
R150 –1960	Raw, refined and boiled linseed oil
R151 –1960	Marking of hatchway beams
R152 –1960	Marking of wooden hatchway covers
R153 –1960	Ordinary glasses for scuttles and lights. Dimensions
R154 –1960	Marking of rolled, drawn and extruded products in light metals or in light alloys for shipbuilding details
R155 –1960	Limiting values for the adjustment of centres for transmission pulleys
R156 –1967	Verification of Brinell hardness testing machines, 2nd Edition
R157 –1960	Determination of forms of sulphur in coal
Errata E	Erratum of first printing. Nov. 1961
R158 –1960	Determination of ash of hard coal
Erratum	Erratum of first printing. Nov. 1961
R159 –1960	Determination of total sulphur in coal by the Strambi method
Errata E	Errata of first printing. Nov. 1961
R160 –1960	Asbestos cement pressure pipes
R161 –1960	Pipes of plastics materials for the transport of fluids (Outside diameters and nominal pressures). Part I: Metric series
R162 –1960	Location of recording heads for three magnetic sound records on 35 mm film and one magnetic sound record on 17.5 mm film
R163 –1960	Magnetic striping of 16 mm film perforated along both edges
R164 –1960	Composition of aluminium alloy castings
Errata	Errata of first printing. Nov. 1961
R165 –1960	Flanging test on steel tubes
R166 –1960	Drift expanding test on steel tubes
R167 –1960	Bend test on steel tubes
R168 –1960	Stretchers, stretcher carriers and hospital trolleys. Dimensions
R169 –1960	Sizes of photocopies (on paper) readable without optical devices
R170 –1960	Anchor chains, stud links (common links, enlarged links, end links and joining shackles)
R171 –1961	Determination of bulk factor of moulding materials
R172 –1961	Detection of free ammonia in phenolformaldehyde mouldings (qualitative method)
R173 –1961	Determination of the percentage of styrene in polystyrene with Wijs solution
R174 –1961	Determination of viscosity number of polyvinylchloride resin in solution

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R175 -1961	Determination of the resistance of plastics to chemical substances
R176 -1961	Determination of the loss of plasticizers from plastics by the activated carbon method
R177 -1961	Determination of migration of plasticizers from plastics
R178 -1961	Determination of flexural properties of rigid plastics
R179 -1961	Determination of the Charpy impact resistance of rigid plastics (Charpy impact flexural test)
Erratum E	Erratum of first printing. June 1961
R180 -1961	Determination of the Izod impact resistance of rigid plastics (Izod impact flexural tests)
R181 -1961	Determination of incandescence resistance of rigid self-extinguishing thermosetting plastics
R182 -1961	Determination of the thermal stability of polyvinyl chloride and related copolymers and their compounds by the Congo red method
R183 -1961	Determination of the bleeding of colourants from plastics
R184 -1961	Brinell hardness test for grey cast iron
R185 -1961	Classification of grey cast iron
R185/A1 -1969	Amendment 1 to ISO Recommendation R 185-1961
R186 -1968	Method of sampling paper and board for testing, 2nd Edition
R187 -1961	Method for the conditioning of paper and board test samples
R188 -1961	Accelerated ageing or simulated service tests on vulcanized natural or synthetic rubbers
R189 -1961	Principles of operation of standards marks
R190 -1961	Tensile testing of light metals and their alloys
R191 -1961	Brinell hardness test for light metals and their alloys
R192 -1961	Vickers hardness test for light metals and their alloys
R193 -1961	Microcopies on transparent bases. Sizes of recommended bases
R194 -1961	List of equivalent terms used in the plastics industry (English, French, Russian)
R 194/ Add. 1 -1969	Second supplement to list of equivalent terms used in the plastics industry (will be merged with Draft ISO Recommendation No. 751)
R194/P1 -1963	Appendix P1: Corresponding Polish terms
R194/Cs -1964	Appendix Cs: Corresponding Czech terms
R194/D -1964	Appendix D: Corresponding German terms
R194/NL -1968	Appendix NL: Corresponding Dutch terms
R195 -1961	Drift expanding test on copper and copper alloy tubes
R196 -1961	Method of mercurous nitrate test for copper and copper alloys
R197 -1961	Classification of coppers
R198 -1961	Double-dick flat pallets for through transit of goods
R199/I -1961	Thrust ball bearings with flat seats. Normal tolerances
R199/II -1968	Rolling bearings. Thrust ball bearings with flat seats. Tolerances. Part 2—Tolerances classes 6, 5 and 4
R200 -1961	Internal clearance in unloaded bearings. Definitions
R201 -1961	Radial internal clearance in unloaded radial groove type ball bearings with cylindrical bore. Values
R202 -1961	Flattening test on steel tubes
R203 -1961	Interrupted creep testing of steel at elevated temperatures (load and temperature interrupted)
R204 -1961	Non-interrupted creep testing of steel at elevated temperatures
R205 -1961	Determination of proof stress and proving test for steel at elevated temperatures
R206 -1961	Creep stress rupture testing of steel at elevated temperatures
R207 -1961	Composition of 99.95 unalloyed magnesium ingots
R208 -1961	Composition of aluminium alloy castings (complement to R 164)
R209 -1968	Composition of wrought products of aluminium and aluminium alloys. Chemical composition (per cent), 2nd Edition
R210 -1961	Essential oils. Packing
R211 -1961	Essential oils. Labelling and marking containers
R212 -1961	Essential oils. Sampling
R213 -1961	Lathe tool posts (overall internal height)
R214 -1961	Abstracts and synopses
R215 -1961	Presentation of contributions to periodicals
R216 -1961	Trimmed sizes of writing paper and certain classes of printed matter
R217 -1961	Method of expression of dimensions and direction of manufacture of unprocessed writing and printing paper
R218 -1961	Microcopies. Scale of 35 mm microfilms for international exchange
R219 -1961	Common names for pesticides. Second list
R219/A1 -1968	Amendment 1 to R219-1961
R220 -1961	Method of sampling raw cotton for testing
R221 -1961	Steel tubes. Thicknesses
R222 -1961	Voltages for aircraft electrical systems
R223 -1961	Safety features for ground power units for D.C. aircraft servicing and engine starting
R224 -1961	Standard form of declaration of performance of aircraft electrical equipment
R225 -1961	Bolts, screws and studs. Dimensioning
R226 -1961	Normal equal-loudness contours for pure tones and normal threshold of hearing under free field listening conditions
R227 -1961	Single box pickers for automatic looms
R228 -1961	Pipe threads where pressure-tight joints are not made on the threads (⅛ inch to 6 inches)
R229 -1961	Machine tool speeds and feeds
R230 -1961	Machine tool test code
Errata F	
R231 -1961	Paper vocabulary. Third series of terms
R232 -1961	Straight-sided splines and gauges. Dimensions in inches

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	Title
R233 -1961	International system for the transliteration of Arabic characters
R234 -1961	Files and rasps. Lengths and cross sections
R235 -1961	Parallel shank twist drills jobber and stub series and Morse taper shank twist drills
Erratum E	Erratum of first printing. Sept. 1962
R236 -1961	Hand reamers and long fluted machine reamers, Morse taper shank
Erratum E	Erratum of first printing. Sept. 1962
Erratum E 2	Erratum 2 of first printing. Sept. 1962
R237 -1961	Diameters of shanks and sizes of driving squares for rotating tools with parallel shanks
Erratum E	Erratum of first printing. Sept. 1962
R238 -1961	Reduction sleeves and extension sockets for tools with Morse taper shanks
Erratum E	Erratum of first printing. Sept. 1962
R239 -1961	Drill chuck tapers
R240 -1969	Interchangeability dimensions for milling cutters and cutter arbors or cutter mandrels—Metric series and inch series—2nd Edition
R241 -1961	Shanks for turning and planing tools. Sections and tolerances
R242 -1961	Carbide tips for turning tools. Metric series
Erratum	Erratum of first printing. March 1964
R242–A1 -1966	Amendment 1 to ISO Recommendation R 242–1961
R243 -1961	Turning tools with carbide tips. Metric series
R244 -1962	Aircraft sealing wire
R245 -1962	Aircraft lockwire
R246 -1962	Cylindrical roller bearings. Separate thrust collars. Boundary dimensions
R247 -1962	Determination of ash in raw natural rubber
R248 -1962	Determination of volatile matter in raw natural rubber
R249 -1962	Determination of dirt in raw natural rubber
R250 -1962	Sampling of raw natural rubber
R251 -1962	Widths and lengths of conveyor belts
R252 -1962	Ply adhesion of conveyor belts
R253 -1962	Grooved pulleys for V-belts. Groove sections Y and Z
R254 -1962	Quality, machining and balancing of transmission pulleys
R255 -1962	Geometrical inspection of grooves of pulleys for V-belts
R256 -1962	Section checking of V-belts
R257 -1962	Principles for the selection of common names for pesticides
R257/A1 -1968	Amendment 1 to ISO Recommendation R 257
R258 -1962	Common names for pesticides. Third list
R259 -1962	Transliteration of Hebrew
R260 -1962	Terms relating to microcopies and their bases
R261 -1969	ISO General purpose metric screw threads—General plan—2nd Edition
R262 -1969	ISO General purpose metric screw threads—Selected sizes for screws, bolts and nuts—2nd Edition
R263 -1962	ISO inch screw threads. General plan and selection for screws, bolts and nuts (diameter range 0.06 to 6 in)
R264 -1962	Pipes and fittings of plastics materials. Socket fittings for pipes under pressure. Basic dimensions. Metric Series
R265 -1962	Pipes and fittings of plastics materials. Socket fittings with spigot ends for domestic and industrial waste pipes. Basic dimensions. Metric Series
R266 -1962	Preferred frequencies for acoustical measurements
R267 -1962	Figures for aircraft instrument dials and number plates
R268 -1962	Aircraft instrument dials and pointers
R269 -1962	Sizes of correspondence envelopes and pockets
R270 -1962	Determination of fibre length by measuring the length of individual fibres
R271 -1962	Implementation of the Tex System for designating the size of textile fibres, yarns and similar structures
R272 -1968	Hexagon bolts and nuts. Widths across flats, heights of heads, thicknesses of nuts. Metric series, 2nd Edition
R273/I -1962	Clearance holes for metric bolts
R273 -1962/AI–1969	Amendment I to ISO/R 273–1962
R273/II -1968	Clearance holes for metric bolts, 42 up to and including 150 mm thread diameter
R274 -1962	Copper tubes of circular section. Dimensions: Metric Series
R275 -1962	Zinc oxide
R276 -1962	Linseed stand oils and lithographic varnishes
R277 -1962	Raw tung oil
R278 -1962	Standard layout for methods of analysis of essential oils
R279 -1962	Determination of the density and relative density of essential oils
R280 -1962	Determination of the refractive index of essential oils
R281 -1962	Ball and roller bearings. Methods of evaluating dynamic load ratings
R282 -1962	Sampling of conveyor belts
R283 -1962	Full thickness tensile strength and elongation of conveyor belts. Specifications and method of test
R284 -1962	Electrical conductivity of conveyor belts. Specification and method of test
R285 -1962	Steel tubes. Butt welding bends (90° and 180°)
R286 -1962	ISO System of limits and fits. Part I: General, tolerances and deviations
Errata	Errata of first printing. February 1964
Erratum E	Erratum No. 2 of first printing. February 1964
R287 -1963	Method for the determination of moisture content of paper (Oven-drying method)
R288/I -1963	Slotted and castle nuts with metric thread
R288/II -1969	Slotted and castle nuts with metric thread, 42 up to and including 100 mm thread diameter
R289 -1963	Determination of viscosity of natural and synthetic rubbers by the shearing disk viscometer
R289/A1 -1968	First amendment to the first edition of ISO Recommendation R289–1963

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R290 –1963	Common names for pesticides. Fourth list
R291 –1963	Standard atmospheres for condition and testing
R292 –1967	Plastics. Determination of the melt flow index of polyethylene and polyethylene compounds, 2nd Edition
R293 –1963	Compression moulding test specimens of thermoplastic materials
R294 –1963	Injection moulding test specimens of thermoplastic materials
R295 –1963	Compression moulding test specimens of thermosetting materials
R296 –1963	Self-holding tapers for tool shanks
R297 –1963	7/24 tapers for tool shanks
Errata	Errata of first printing. October 1966
R298 –1963	Lathe centres. Sizes for interchangeability
R298-Add. 1 –1969	Lathe centres. Centre angle
R299 –1963	T slots for machine tools
R300/I –1963	ISO Identification code for rolling bearings. Group I: Radial ball and roller bearings. Group II: Thrust ball and roller bearings. Group III: Tapered roller bearings, metric series
R300/II –1965	ISO Identification code for rolling bearings. Group IV: Tapered roller bearings, inch series
R300/III –1968	ISO identification code for rolling bearings: Group V: Airframe bearings
R301 –1963	Zinc alloy ingots
R302 –1963	Determination of the Kappa number of pulp (Degree of delignification)
R303 –1963	Lighting and signalling for motor vehicles and trailers
R304 –1963	Surface active agents. Determination of surface tension and interfacial tension
R305 –1963	Determination of the thermal stability of polyvinyl chloride and related copolymers and their compounds by the discoloration method
R306 –1968	Plastics—Determination of the Vicat softening temperature of thermoplastics, 2nd Edition
R307 –1963	Determination of the viscosity number of polyamides resins in dilute solution
R308 –1963	Determination of the acetone soluble matter (resin content of material in the unmoulded state) of phenolic moulding materials
R309 –1963	Methods of sampling manganese ores. Part I.—Ore loaded in freight wagons
	R 310 to 323: Analysis of manganese ores
R310 –1963	Determination of hygroscopic moisture
R311 –1963	Determination of silicon dioxide
R312 –1963	Determination of active oxygen (conventionally expressed as manganese dioxide)
R313 –1963	Determination of total iron content
R314 –1963	Determination of carbon dioxide
R315 –1963	Determination of nickel
R316 –1963	Determination of cobalt
R317 –1963	Determination of arsenic
R318 –1963	Determination of aluminium oxide
R319 –1963	Determination of total manganese content
R320 –1963	Determination of sulphur
R321 –1963	Determination of phosphorus
R322 –1963	Determination of copper
R323 –1963	Determination of lead
R324 –1963	Cones for cross winding for dyeing purposes. Half angle of the cone 4° 20′
R325 –1963	Wood cones for cross winding. Half angle of the cone 4° 20′
R326 –1963	Wood cones for cross winding. Nominal half angle of the cone 5° 57′
R327 –1963	Wood cones for cross winding. Half angle of the cone 3° 30′
R328 –1963	Size of picture postcards and of lettercards
R329 –1963	Large pallets for through transit of goods
R330 –1963	Pipes of plastics materials for the transport of fluids (outside diameters and nominal pressures) Part II: inch series
R331 –1963	Determination of moisture in the analysis sample of coal by the direct gravimetric method
R332 –1963	Determination of nitrogen in coal by the Kjeldahl method
R333 –1963	Determination of nitrogen in coal by the semi-micro Kjeldahl method
R334 –1963	Determination of total sulphur in coal by the Eschka method
R335 –1963	Determination of caking power of coal by the Roga method
R336 –1963	Plain end steel tubes, welded or seamless. General table of dimensions and masses per unit length
R337 –1963	Semi-trailer fifth wheel kingpin
R338 –1963	Lifeboats for less than one hundred people
R339 –1963	Definitions of terms appearing in ISO Recommendations for oils and pigments
R340 –1963	Flame resistance of conveyor belts. Specifications and method of test
R341 –1963	Cotton spinning machinery. Working width
R342 –1963	Worsted and woollen cards. Working width
R343 –1963	Warp tubes for ring spinning and ring doubling spindles. Inch dimensions, tolerances and gauges
R344/I –1963	Flyer bobbins
Erratum	Erratum of first printing September 1963
R344/II –1969	Flyer bobbins for spindle diameters of 25 mm or more and lifts of 300 mm and over
R345 –1963	Tests on galvanized steel wire for ropes
R346 –1963	Galvanized steel wire ropes
R347 –1963	Anchor chains. End shackles
R348 –1963	Determination of moisture in the analysis sample of coal by the direct volumetric method
R349 –1963	Audibert-Arnu dilatometer test for coal
R350 –1963	Determination of chlorine in coal by the bomb-combustion method
R351 –1963	Determination of total sulphur in coal by the high temperature combustion method
R352 –1963	Determination of chlorine in coal by the high temperature combustion method
R353 –1963	Method of expression of dimensions of processed writing paper and certain classes of printed matter
R354 –1963	Measurement of absorption coefficients in a reverberation room

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R355/I -1963	Tapered roller bearings. Boundary dimensions. Metric series: Diameter series 2 and 3. Inch series: Lines 1, 2, 3, 4, 5
R355/II -1965	Tapered roller bearings. Boundary dimensions. Metric series: Extension of diameter series 2 and 3
R355/III -1967	Tapered roller bearings. Boundary dimensions. Part III. Metric series. Diameter series 9 and 0
R355/IV -1968	Rolling bearings. Tapered roller bearings. Boundary dimensions. Part 4—Sub-units. Inch series
R355/V -1969	Rolling bearings—Tapered roller bearings—Boundary dimensions—Part V: Sub-units—Metric series
R356 -1963	Essential oils. Preparation of sample. Methods of test
R357 -1963	Expression of the power and intensity levels of sound or noise
R358 -1963	Maximum aspect ratio of projector aperture for projection of 35 mm non-anamorphotic motion-picture films
R359 -1963	Projected image area for 16 mm film
R360 -1963	Location of recording heads for four magnetic sound records on 35 mm film
R361 -1963	Basic ionizing radiation symbol
R362 -1964	Measurement of noise emitted by vehicles
R363 -1964	Flat steel healds for general use
R364 -1967	Twin wire healds for frame weaving, 2nd Edition
R365 -1967	Twin wire healds for Jacquard weaving, 2nd Edition
R366 -1967	Pitch bound reeds, 2nd Edition
R367 -1967	Metal reeds with plate baulk, 2nd Edition
R368 -1964	Warp tubes for ring spinning and ring doubling spindles. Metric dimensions, tolerances and gauges
R369 -1964	Symbols for indications appearing on machine tools
Errata	Erratum of first printing. December 1965
R370 -1964	Conversion of toleranced dimensions from inches into millimetres and vice versa
R371 -1964	Terms relating to microcopy apparatus
R372 -1964	Paper vocabulary. Fourth series of terms
R373 -1964	General principles for fatigue testing of metals
R374 -1964	Ring expanding test on steel tubes
R375 -1964	Tensile testing of steel tube
R376 -1964	Calibration of elastic proving devices
R377 -1964	Selection and preparation of samples and test pieces for wrought steel
R378 -1964	Parallel bars
R379 -1964	Horizontal bar
R380 -1964	Rings
R381 -1964	Vaulting horse and pommelled horse
R382 -1964	Balancing beam
R383 -1964	Interchangeable conical ground glass joints
R384 -1964	Principles of construction and adjustment of volumetric glassware
R385 -1964	Burettes
R386 -1964	Principles of construction and adjustment of liquid-in-glass laboratory thermometers
R387 -1064	Principles of construction and adjustment of hydrometers
R388 -1964	ISO metric series for basic thicknesses of sheet and diameters of wire
R389 -1964	Standard reference zero for the calibration of pure-tone audiometers
R390 -1964	Sampling and inspection of asbestos-cement products
R391 -1964	Building and sanitary pipes in asbestos-cement
R392 -1964	Asbestos-cement pipe fittings for building and sanitary purposes
R393 -1964	Asbestos-cement corrugated sheets for roofing and cladding
R394 -1964	Asymmetrical section corrugated sheets in asbestos-cement for roofing and cladding
R395 -1964	Asbestos-cement slates for roofing and cladding
R396 -1964	Asbestos-cement flat sheets
R397 -1964	Wrapping test for copper and copper alloy wire
R398 -1964	Bend test for copper and copper alloys
R399 -1964	Vickers hardness test for copper and copper alloys (Test loads from 2.5 to 50 kgf)
R400 -1964	Tensile test for copper and copper alloys
R401 -1964	Tensile test for copper and copper alloy tubes of circular section
R402 -1964	Tensile test of copper and copper alloy wire
R403 -1964	Brinell hardness test for copper and copper alloys
R404 -1964	General technical delivery requirements for steel
R405 -1964	Aircraft tow bar connections to tractors
R406 -1964	Inscription of linear and angular tolerances
R407 -1964	Yoke type valve connections for small medical gas cylinders used for anaesthetic and resuscitation purposes
R408 -1964	Safety colours
R409 -1964	Tables of Vickers hardness values (HV) for metallic materials
R410 -1964	Tables of Brinell hardness values (HB) for use in tests made on flat surfaces
R411 -1964	Common names for pesticides. Fifth list
R411/A1 -1968	Amendment 1 to ISO Recommendation R411-1964—Common names for pesticides. Fifth list
R412 -1965	Gum spirit of turpentine and wood turpentines
Errata	Errata of first printing. October 1966
R413 -1965	Heads of aircraft lubricating nipples
R414 -1965	Aircraft tyre valves
R415 -1965	Envelopes, postcards and similar articles. Cancellation area
R416 -1965	Picture postcards. Area reserved for the address
R417 -1965	Methods for determining thiosulphate and tetrathionate in processed black-and-white photographic film, plates and papers
R418 -1965	Specification for photographic grade sodium sulphite
R419 -1965	Specification for photographic grade sodium thiosulphate, crystalline
R420 -1965	Specification for photographic grade potassium bromide
R421 -1965	Method for indicating the stability of the images of processed black-and-white films, plates and papers
R422 -1965	Specification for photographic grade p-methylaminophenol sulphate
Erratum	Erratum of first printing, March 1965

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R423 –1965	Specification for photographic grade hydroquinone
R424 –1965	Specification for photographic grade sodium carbonate, anhydrous
Erratum	Erratum of first printing, March 1965
R425 –1969	Quantity packaging of sensitized photographic materials 2nd Edition
R426 –1965	Classification of brasses, leaded brasses, special brasses and high tensile brasses
R427 –1965	Classification of tin bronzes and special tin bronzes
R428 –1965	Classification of aluminium bronzes and special aluminium bronzes
R429 –1965	Classification of copper-nickel alloys
R430 –1965	Classification of copper-nickel-zinc alloys
R431 –1965	Specification for electrolytic copper wire bars, cakes, slabs, billets, ingots and ingot bars
R432 –1965	Characteristics of construction of ply type conveyor belts
R433 –1965	Marking of conveyor belts
R434 –1965	Lengths of Y-section V-belts (lp=5.3 mm or 0.21 in)
R435 –1965	ISO conventional typographical character for legibility tests (ISO character)
R436 –1965	Informative labelling
R437 –1965	Chemical analysis of steels. Determination of total carbon (Gravimetric method after combustion in a stream of oxygen)
R438 –1965	Method for the determination of the bulking thickness and bulk of paper
R439 –1969	Chemical analysis of steel and cast iron. Determination of total silicon (Gravimetric method), 2nd Edition
R440 –1969	Shape, size and direction of operation of lever controls on aircraft 2nd Edition
R441 –1965	Drop wires for mechanical and electrical warp stop motions
R442 –1965	Verification of pendulum impact testing machines for testing steels
R443 –1965	Marking of aircraft gas cylinders
Erratum	Erratum of first printing. September 1965
R444 –1965	Phlogopite mica blocks, thins and splittings. Methods for grading by size
R445 –1965	Vocabulary of terms relating to pallets
R446 –1965	Microcopies. Legibility tests. Description of the ISO mire (ISO test object) and its use in photographic document reproduction
R447 –1965	Direction of operation of machine tool controls
R448 –1965	Marking of industrial gas cylinders for the identification of the content
R449 –1965	Magnetic compasses and binnacles, Class A, for use in sea navigation. Part I: General requirements
R450 –1965	Aircraft connection for water of drinkable quality
R451 –1965	Aircraft pressure re-oiling connection
R452 –1965	Essential characteristics of 35 mm microfilm reading apparatus
R453	(incorporated in R 862–1968)
R454 –1965	Relation between sound pressure levels of narrow bands of noise in a diffuse field and in a frontally incident free field for equal loudness
R455 –1965	Analysis of soap. Determination of total crude fatty acids
R456 –1965	Analysis of soap. Determination of free caustic alkali
R457 –1965	Analysis of soap. Determination of chlorides
R458 –1965	Determination of stiffness in torsion as a function of temperature
R459 –1965	Grooved pulleys for narrow V-belts. Groove sections SPZ, SPA, SPB
R460 –1965	Lengths of narrow V-belts. Sections SPZ, SPA, SPB
R461 –1965	Connections for aircraft ground electrical supplies
R462 –1965	Recommended practice for the determination of change of mechanical properties after contact with chemical substances
R463 –1965	Dial gauges reading in 0.01 mm, 0.001 in and 0.0001 in
R464 –1965	Bearings with locating snap ring. Dimensions
Errata	Errata of first printing. November 1966
R465 –1965	Double-row self-aligning roller bearings. Radial internal clearance
R466 –1965	Image produced by camera aperture for 16 mm films
R467 –1966	Preferred modules and diametral pitches of cylindrical gears for general engineering
R468 –1966	Surface roughness
R469 –1966	Dimensions and conductor resistance of general purpose electrical cables with copper conductors, for aircraft
R470 –1966	Dimensions and conductor resistance of heat-resisting (190 °C) electrical cables with copper conductors, for aircraft
R471 –1966	Standard atmospheres for the conditioning and testing of rubber test pieces
R472 –1969	Plastics. Definitions of plastics terms, 3d edition
R473 –1966	Lithopone
R474 –1966	Performance requirements for general purpose electrical cables with copper conductors for aircraft
R475 –1966	Dimensions of rectangular refractory bricks
R476 –1966	Pirn winders. Terminology. Basic terms and definitions
R477 –1966	Cone winders or cheese winders. Terminology. Basic terms and definitions
R478 –1966	Paper. Untrimmed stock sizes for the ISO-A series. ISO primary range
R479 –1966	Paper. Untrimmed sizes. Designation. Tolerances
R480 –1966	Perforated metal cheese centres for bast fibre yarns
R481 –1966	Warper's beams. Basic dimensions
R482 –1966	Numbering of aircraft engines, engine cylinders and combustion chambers, and direction of engines and propellers
R483 –1966	Plastics. Methods for maintaining constant relative humidity in small enclosures by means of aqueous solutions
R484 –1966	Shipbuilding details. Ship screw propellers. Manufacturing tolerances for casting and finishing
R485 –1966	Aircraft water-methanol pressure connections

TABLE 13. Numerical List — ISO Recommendations — Continued

Ref.	*Title*
R486 –1966	Cutting and perforating dimensions for double-8 mm motion-picture raw stock film
R487 –1966	Steel roller chains type S 32 to S 88 with their associated chain wheels
R488 –1966	Butyrometers for the determination of the percentage of fat in milk by the Gerber method
R489 –1966	Plastics. Determination of the refractive index of transparent plastics
R490 –1966	Single magnetic sound stripe on 16 mm motion-picture film perforated along one edge
R491 –1966	Cutting and perforating dimensions for 35 mm motion-picture raw stock film
R492 –1966	Rolling bearings. Radial bearings. Tolerances
R493 –1966	Dimensions for single-hole mounting, lever-operated switches for aircraft
R494 –1966	Parallel shank twist drills long series
R495 –1966	General requirements for the preparation of test codes for measuring the noise emitted by machines
R496 –1966	Shaft heights for driving and driven machines
R497 –1966	Guide to the choice of series of preferred numbers and of series containing more rounded values of preferred numbers
R498 –1966	Preparation of dry films from concentrated natural rubber latex
R499 –1966	Paper. Internal diameters of cores of reels
R500 –1966	Power take-off and draw-bar for agricultural tractors
R501 –1966	Determination of the crucible swelling number of coal
R502 –1966	Determination of the Gray-King coke type of coal
R503 –1966	Composition of wrought magnesium-aluminium-zinc alloys
R504 –1966	Turning tools with carbide tips. Designation and marking
R505 –1966	Tear propagation resistance of the carcass of conveyor belts. (Method of test)
R506 –1966	Determination of volatile fatty acid number of latex
R507 –1966	Procedure for describing aircraft noise around an airport
R508 –2966	Identification colours for pipes conveying fluids in liquid or gaseous condition in land installations and on board ships
R509 –1966	Principal dimensions of pallet trucks
Erratum	Erratum of first printing, October 1966
R510 –1966	Red lead
R511 –1966	White lead
R512 –1966	Sound signalling devices on motor vehicles. Acoustic standards and technical specifications
R513 –1966	Application of carbides for machining by chip removal. Designation of main groups of chip removal and groups of application
R514 –1966	Turning tools with carbide tips. Internal tools. (Metric series)
R515 –1966	Dimensions for stereo still photography using 35 mm objectives on 35 mm film, 5-perforation format
R516 –1966	Exposure-time markings for shutters used in still cameras
R517 –1966	Lens aperture markings for still cameras
R518 –1966	Camera accessory shoes
R519 –1966	Dimensions of small flash connections for hand-held cameras
R520 –1966	Cereals and pulses: Determination of the mass of 1000 grains
R521 –1966	Machine chucking reamers with parallel shanks or Morse taper shanks
R522 –1966	Special tolerances for reamers
R523 –1966	Recommended range of outside daimeters for milling cutters
R524 –1966	Hard metal wire drawing dies. Interchangeability dimensions of pellets and cases
R525 –1966	Bonded abrasive products — General factures (Designation — Ranges of dimensions — Profiles)
R525-Add. 1 –1969	Dimensions of the wheel holes special applications and tolerances
R526 –1966	Significance to purchasers of marks indicating conformity with standards
R527 –1966	Plastics. Determination of tensile properties
R528 –1966	Refractory products. Determination of pyrometric cone equivalent (Refractoriness)
R529 –1966	Short machine taps and hand taps
Erratum	Erratum of first printing, November 1966
R530 –1966	Dimensions for general purpose push-pull single-pole circuit-breakers for aircraft
R531 –1966	Cast iron sanitary pipes and fittings for waste water and ventilation
Erratum	Erratum of first printing, December 1966
R532 –1966	Method for calculating loudness level
R533 –1966	Rolling bearings. Double row cylindrical roller bearings, type RD with tapered bore 1:1. Special requirement: tolerance class 5
R534 –1966	Determination of the thickness of single sheets of paper
R535 –1966	Determination of the water absorption of paper or board (Cobb method)
R536 –1966	Determination of paper substance
R537 –1966	Testing of plastics with the torsion pendulum
Erratum	Erratum of first printing, January 1967
R538 –1966	Conventional signs. To be used in schemes for the installations of pipe-line systems in ships
R539 –1966	Dimensions and conductor resistance of heat-resisting (260 °C) electrical cables with copper conductors for aircraft
R540 –1966	Determination of fusibility of fuel ash
R541 –1966	Measurement of fluid flow by means of orifice plates and nozzles
R542 –1966	Oilseeds — Sampling
R543 –1966	Definition and marking of safety film for motion-picture uses (replacing Draft ISO Recommendation No. 83)
R544 –1966	Diameters and tolerances for electrodes for arc welding and filler metals for gas welding
R545 –1966	Lengths and tolerances for filler rods, other than drawn or extruded, for welding
R546 –1966	Lengths and tolerances for drawn or extruded filler rods for welding, supplied in straight lengths

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	Title
R547 –1966	Lengths and tolerances of electrodes for the welding of mild steel and low alloy high tensile steel
R548 –1966	Methods of chemical analysis of manganese ores. Determination of barium oxide content
R549 –1966	Methods of chemical analysis of manganese ores. Determination of combined water content
R550 –1966	Methods of chemical analysis of manganese ores. Determination of titanium content
R551 –1966	Methods of chemical analysis of manganese ores. Determination of zinc content
R552 –1966	Methods of chemical analysis of manganese ores. Determination of calcium oxide content and magnesium oxide content
R553 –1966	Methods of chemical analysis of manganese ores. Determination of vanadium content
R554 –1966	Standard atmospheres for conditioning and/or testing. Standard reference atmosphere. Specifications
R555 –1966	Liquid flow measurement in open channels. Dilution methods for measurement of steady flow. Part 1—Constant rate injection method
R556 –1967	Determination of the micum indices of coke
R557 –1967	Symbols, dimensions and layout for safety signs
R558 –1967	Conditioning atmosphere. Test atmosphere. Reference atmosphere. Definitions
R559 –1967	Steel pipes for gas and water, and for sewage, welded or seamless
R560 –1967	Cold drawn precision steel tubes. Metric series. Dimensions and masses per metre
R561 –1967	Graphical symbols for coal preparation plant
R562 –1967	Determination of the volatile matter of hard coal and of coke
R563 –1967	Knife sections of mower cutter bars
R564 –1967	Designations, diameters and breaking strengths of preformed stranded steel cables for aircraft controls
R565 –1967	Woven wire cloth and perforated plates in test sieves. Nominal sizes of apertures
R566 –1967	Common names for pesticides. Sixth list
R567 –1967	Determination of the bulk density of coke in a small container
R568 –1967	Heald frames for single or double row of healds
R569 –1967	Heald frames. Dimensions in relationship with pitch of the harness
R570 –1967	Heald carrying rods. Coordination with end loops of the healds
R571 –1967	Metal reeds with double-spring baulk
R572 –1967	Shuttles for pirn changing automatic looms
R573 –1967	Dobby lags and pegs in wood, metal or other suitable material
R574 –1967	Perforated parallel tubes for cheese dyeing. (Dimensions in millimetres)
R575 –1967	Transfer cones for dyeing purposes. Half-angle at top of cone 4°20′
R576 –1967	Paper patterns for dobbies
R577/I –1967	Tapered roller bearings. Tolerances. Metric series. Part I: Normal tolerances
R577/II –1968	Rolling bearings. Tapered roller bearings. Metric series. Tolerances. Part II—Tolerance classes 6 and 5
R578 –1969	Tapered roller bearings. Tolerances. Inch series. Normal tolerances. 2d edition
R579 –1967	Determination of total moisture in coke
R580 –1967	Oven test for moulded fittings in unplasticized polyvinyl chloride (PVC) for use under pressure
R581 –1967	Definition of weldability
R582 –1967	Rolling bearings. Tolerances. Metric series bearings. Chamfer dimension limits and maximum shaft and housing fillet radius
R583 –1967	Tolerances on the total thickness of conveyor belts and on the thicknesses of covers
R584 –1967	Plastics. Determination of the maximum temperature and the rate of increase of temperature during the setting of unsaturated polyester resins
R585 –1967	Plastics. Determination of the moisture content of non-plasticized cellulose acetate
R586 –1967	Determination of ash of coke
R587 –1967	Determination of chlorine in coal and coke using Eschka mixture
R588	(incorporated in R862–1968)
R589 –1967	Determination of total moisture in hard coal
R590 –1967	Oil of Brasilian sassafras
R591 –1967	Titanium dioxide for paints
R592 –1967	Determination of the optical rotation of essential oils
R593 –1967	Paper. Untrimmed stock sizes for the ISO-A series (Supplementary series)
Erratum	Erratum of first printing. May 1967
R594 –1967	Conical fittings for syringes, needles and other medical equipment. Definition and dimensional characteristics for conical fittings with a 6% and a 10% taper
R595 –1967	Syringes for medical use
R596 –1967	Hypodermic needles
R597 –1967	Definitions and terminology of cements
R598 –1967	Limitations of angles of slope and rotation for welding positions for straight manual arc welds made with covered electrodes of mild steel and low alloy high tensile steels
R599 –1967	Plastics. Determination of the percentage of extractable materials in polyamides
R600 –1967	Plastics. Determination of the viscosity ratio of polyamides in concentrated solution
R601 –1967	Determination of arsenic in coal and coke
R602 –1967	Determination of mineral matter in coal
R603 –1967	Bonded abrasive products. Grinding-wheel dimensions (Part 1)
Erratum	Erratum of first printing. August 1967
R604 –1967	Determination of compressive properties of plastics
R605 –1967	Pulses. Methods of test
R606 –1967	Short pitch transmission precision roller chains and chain wheels
R607 –1967	Surface active agents in powder form. Preparation of a reduced sample
R608 –1967	Lengths of classical V-belts (Sections Z, A, B, C, D, E)

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R609 –1967	Determination of carbon and hydrogen in coal and coke by the high temperature combustion method
R610 –1967	High-tensile steel chains (round link) for chain conveyors and coal ploughs
R611 –1967	Braking of motor vehicles and their trailers. Terminology
R612 –1967	Dimensions of motor vehicles and their trailers. Designations and definitions
R613 –1967	Magnetic compasses, binnacles and azimuth reading devices, class B, for use in sea navigation
R614 –1967	Shipbuilding details. Testing of toughened glasses for ships' side scuttles and fixed lights by the punch method
R615 –1967	Methods for determining the mechanical properties of the weld metal deposited by electrodes 3.15 mm or more in diameter
R616 –1967	Determination of the shatter indices of coke
R617 –1967	Calculation of rectangular symmetrical fillet welds statically loaded in such a way that the transverse section is not under any normal stress ($\sigma = 0$)
R618 –1967	Paper. Overall trimmed sizes of articles of stationery that include detachable sheets
R619 –1967	Methods of chemical analysis of manganese ores. Determination of chromium content
R620 –1967	Methods of chemical analysis of manganese ores. Determination of zinc content. (Polarographic method, for zinc content from 0.005 to 0.1% inclusive)
R621 –1967	Methods of chemical analysis of manganese ores. Determination of metallic iron content. (Photometric method for metallic iron content up to and including 2%)
R622 –1967	Determination of phosphorus in ash from coal
R623 –1967	Paper and board. Sizes of folders and files
R624 –1967	Cellulose pulps. Extraction from pulps of materials soluble in dichloromethane
R625 –1967	Determination of carbon and hydrogen in coal and coke by the Liebig method
R626 –1967	Strength calculation of butt welded joints
R627 –1967	Fundamental welding positions and definitions of rotation and slope for straight welds
R628 –1967	Common names for pesticides. Seventh list
R629 –1967	Chemical analysis of steels. Determination of manganese (Spectrophotometric method)
R630 –1967	Structural steels
R631 –1967	Mosaic parquet panels
R632 –1967	Methods of test for determining whether an electrode is a deep penetration electrode
R633 –1967	Cork. Glossary
R634 –1967	Methods of test for general purpose electrical cables with copper conductors for aircraft
R635 –1967	Code of symbols for covered electrodes for arc welding of mild steels and low alloy high tensile steels
R636 –1967	Code of symbols for filler rods for gas welding of mild steels and low alloy high tensile steels
R637 –1967	Methods of test for determining the mechanical properties of weld metal deposited by filler rods for gas welding mild steels and low alloy high tensile steels with Annex: Information concerning heat treatment
R638 –1967	Cellulose pulps. Determination of dry matter content of pulp
R639 –1967	Symbols for languages, countries and authorities
R640 –1967	Calibration of standardized blocks to be used for Vickers hardness testing machines
R641 –1968	Interchangeable spherical ground glass joints
R642 –1967	Hardenability test by end quenching steel (Jominy test)
R643 –1967	Micrographic determination of the austenitic grain size of steels
R644 –1967	Conventional signs to be used in schemes for the installations of ventilation systems in ships
R645 –1967	Statistical vocabulary and symbols. First series of terms and symbols. Part 1: Statistical vocabulary
R646 –1967	6 and 7 bit coded character sets for information processing interchange
R647 –1968	Determination of the yields of tar, water, gas and coke residue by low temperature distillation of brown coal and lignite
R648 –1968	One-mark pipettes
R649 –1968	Density hydrometers for general purposes
R650 –1968	Relative density 60/60 °F hydrometers for general purposes
R651 –1968	Solid-stem calorimeter thermometers
R652 –1968	Enclosed-scale calorimeter thermometers
R653 –1968	Long solid-stem thermometers for precision use
R654 –1968	Short solid-stem thermometers for precision use
R655 –1968	Long enclosed-scale thermometers for precision use
R656 –1968	Short enclosed-scale thermometers for precision use
R657/I –1968	Structural steel sections. Part I. Dimensions and sectional properties of hot-rolled equal-leg angles—Metric series
Erratum	Erratum of first printing April 1968
R657/II –1968	Structural steel sections. Part II. Dimensions and sectional properties of hot-rolled unequal-leg angles. Metric series
Erratum	Erratum of first printing April 1968
R657/III –1969	Structural steel sections. Part III. Dimensions and sectional properties of hot-rolled equal-leg angles—Inch series
R657/IV –1969	Structural steel sections. Part IV. Dimensions and sectional properties of hot-rolled unequal-leg angles—Inch series
R657/VII –1969	Dimensions of hot-rolled steel sections. Part VII. Parallel flange I-beams. Inch series. Dimensions and sectional properties
R657/IX –1969	Structural steel sections. Part IX. Dimensions and sectional properties of hot-rolled parallel flange column sections—Inch series

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R658 -1968	Oleaginous seeds. Determination of impurities
R659 -1968	Oleaginous seeds. Determination of oil content
R660 -1968	Crude vegetable oils and fats. Determination of acidity
R661 -1968	Crude vegetable oils and fats. Preparation of contract sample for analysis
R662 -1968	Crude vegetable oils and fats. Determination of moisture and volatile matter
R663 -1968	Crude vegetable oils and fats. Determination of insoluble impurities
R664 -1968	Oleaginous seeds. Reduction of contract samples to samples for analysis
R665 -1968	Oleaginous seeds. Determination of moisture and volatile matter
R666 -1968	Mounting of plain grinding wheels by means of hub flanges
R667 -1968	Determination of rate of cure of rubber compounds by the shearing disk viscometer
Erratum	Erratum of first printing February 1968
R668 -1968	Dimensions and ratings of freight containers
R669 -1968	Rating of resistance welding equipment
R670 -1968	Dimensions of straight resistance spot welding electrodes
R671 -1968	Chemical analysis of steel and cast iron. Determination of sulphur (Method after combustion in a current of oxygen and titration with sodium borate)
R672 -1968	Analysis of soaps. Determination of moisture and volatile matter
R673 -1968	Analysis of soaps. Determination of foreign matter of low solubility in ethanol
R674 -1968	Calibration of standardized blocks to be used for Rockwell B and C hardness scale testing machines
R675 -1968	Determination of dimensional change of woven fabrics subjected to laundering near the boiling point.
R676 -1968	Spices and condiments. Nomenclature. First list
R677 -1968	Basic rack of straight bevel gears for general engineering and heavy engineering
R678 -1968	Modules and diametral pitches of straight bevel gears for general engineering and heavy engineering
R679 -1968	Method of testing strength of cements
R680 -1968	Chemical analysis of cements. Main constituents of Portland cement
R681 -1968	Chemical analysis of cements. Minor constituents of Portland cement
R682 -1968	Chemical analysis of cements. Determination of sulphur as sulphide
R683/I -1968	Heat-treated steels, alloy steels and free cutting steels. Part I: Quenched and tempered unalloyed steels
R683/II -1968	Heat-treated steels, alloy steels and free cutting steels. Part 2: Wrought, quenched and tempered steels with 1% chromium and 0.2% molybdenum
R684 -1968	Analysis of soaps. Determination of total free alkali
R685 -1968	Analysis of soaps. Determination of total alkali
R686 -1968	35 mm Filmstrips. Dimensions and formats
R687 -1968	Determination of moisture in the analysis sample of coke
R688 -1968	Filler rods for braze welding. Methods of test for determining the characteristics of the deposited metal
R689 -1968	Microcopies. Legibility tests. Description and use of the ISO micromire (ISO micro test object) for checking a reading apparatus
R690 -1968	Bibliographical references. Essential and supplementary elements
R691 -1968	Tolerances on spanner gaps and sockets (Metric values for general use)
R692 -1968	Pulps. Determination of alkali solubility of pulp
R693 -1968	Dimensions of seam welding wheel blanks
R694 -1968	Positioning of magnetic compasses in ships
Erratum	Erratum of first printing March 1968
R695 -1968	Determination of the resistance of glass to attack by a boiling aqueous solution of mixed alkali
R696 -1968	Surface active agents. Measurement of foaming power
R697 -1968	Surface active agents. Determination of apparent density of washing powders before and after compaction
R698 -1968	Filler rods for braze welding. Methods of test for determining the conventional bond strength on steel, cast iron and other metals
R699 -1968	Pulps. Determination of alkali resistance
R700 -1968	Rating of manual arc welding equipment
R701 -1968	International gear notation. Symbols for geometrical data
R702 -1968	Spindle noses and face plates types A and Camlock. Sizes for interchangeability
R703 -1968	Troughability of conveyor belts. (Characteristic and method of test)
R704 -1968	Naming principles
R705 -1968	Method for the determination of density of latex
R706 -1968	Determination of coagulum content of latex
R707 -1968	Milk and milk products. Sampling
R707 -Add. -1969	Addendum to ISO/R 707-1968
R708 -1968	Filler rods for gas welding. Test to determine the compatibility of steel filler rods and the parent metal in the welding of steels
R709 -1968	Determination of ester value and calculation of ester content of essential oils
R710/I -1968	Graphical symbols for use on detailed maps, plans and geological cross sections. Part I: General rules of representation
R710/II -1968	Graphical symbols for use on detailed maps, plans and geological cross sections. Part II: Representation of sedimentary rocks
R711 -1968	Cereals and cereal products. Determination of moisture content (Basic reference method)
R712 -1968	Cereals and cereal products. Determination of moisture content (Routine method)
R713 -1968	Chemical analysis of zinc. Polarographic determination of lead and cadmium
R714 -1968	Chemical analysis of zinc. Photometric determination of iron

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R715 –1968	Chemical analysis of zinc. Polarographic determination of lead
R716 –1968	Verification of Rockwell B and C scale hardness testing machines
R717 –1968	Rating of sound insulation for dwellings
R718 –1968	Methods for thermal shock tests on laboratory glassware
R719 –1968	Determination of the hydrolytic resistance of glass grains at 98 °C
R720 –1968	Determination of the hydrolytic resistance of glass grains at 121 °C
R721 –1968	Rock drilling. Integral stems
R722 –1968	Rock drilling. Hollow hexagonal drill steels in bar form
R723 –1968	Rock drilling. Forged collared shanks and chuck bushings for hollow hexagonal drill steels
R724 –1968	ISO general purpose metric screw threads. Basic dimensions
R725 –1968	ISO inch screw threads. Basic dimensions
R726 –1968	Calibration of standardized blocks to be used for Brinell hardness testing machines
R727 –1968	Socket fittings for pipes under pressure. Unplasticized polyvinyl chloride (PVC) fittings with plain sockets. Metric series
R728 –1968	Size analysis of coke
R729 –1968	Oleaginous seeds. Determination of acidity of oils
R730 –1968	Three-point linkage of agricultural wheeled tractors for attachment of mounted implements
R731 –1968	Formic acid for industrial use. Methods of test
R732 –1968	Dimensions for 127, 120 and 620 roll film, backing paper and film spools
R733 –1968	Hexagon bolts and nuts. Metric series. Tolerances on widths across flats. Widths across corners
R734 –1968	Oilseed residues. Determination of oil content
R735 –1968	Oilseed residues. Determination of ash insoluble in hydrochloric acid
R736 –1968	Oilseed residues. Determination of diethyl ether extract
R737 –1968	Coniferous sawn timber. Sizes—Methods of measurement
R738 –1968	Coniferous sawn timber. Sizes—Tolerances and shrinkage
R739 –1968	Sodium carbonate for industrial use. Preparation and storage of test samples
R740 –1968	Sodium carbonate for industrial use. Determination of total soluble alkalinity. Volumetric method
R741 –1968	Sodium carbonate for industrial use. Determination of sodium hydrogen carbonate. Volumetric method
R742 –1968	Sodium carbonate for industrial use. Determination of chloride content. Volhard volumetric method
R743 –1968	Sodium carbonate for industrial use. Determination of sulphate content. Barium sulphate gravimetric method
R744 –1968	Sodium carbonate for industrial use. Determination of iron content. 2,2′-bipyridyl photometric method
R745 –1968	Sodium carbonate for industrial use. Determination of loss of mass and of nonvolatile matter at 250 °C
R746 –1968	Sodium carbonate for industrial use. Determination of matter insoluble in water at 50 °C
R747 –1968	Sodium carbonate for industrial use. Expression of test results
R748 –1968	Liquid flow measurement in open channels by velocity area methods
R749 –1968	Oilseed residues. Determination of total ash
R750 –1968	Fruit and vegetable products. Determination of titratable acidity
R751 –1968	Fruit and vegetable products. Determination of water-insoluble solids
R752 –1968	Zinc ingots
R753 –1968	Methods of test for acetic acid
R754 –1968	Methods of test for acetic anhydride
R755 –1968	Methods of test for n-butanol
R756 –1968	Methods of test for isopropyl alcohol
R757 –1968	Methods of test for acetone
R758 –1968	Method for the determination of density of liquids at 20 °C
R759 –1968	Method for the determination of residue on evaporation on a water bath
R760 –1968	Determination of water by the Karl Fischer method
R761 –1968	Method for the determination of bromine index
R762 –1968	Fruit and vegetable products. Determination of mineral impurities
R763 –1968	Fruit and vegetable products. Determination of ash insoluble in hydrochloric acid
R764 –1968	"Antimagnetic" watches for general purpose use
R765 –1968	Pesticides considered not to require common names. First list
R766 –1968	Fibre building boards. Determination of dimensions of test pieces
R767 –1968	Fibre building boards. Determination of moisture content
R768 –1968	Fibre building boards. Determination of bending strength
R769 –1968	Fibre building boards. Determination of water absorption and of swelling in thickness after immersion in water
R770 –1968	Oil of eucalyptus globulus
R771 –1968	Oilseed residues. Determination of moisture and volatile matter
R772 –1968	Vocabulary of terms and symbols used in connection with the measurement of liquid flow with a free surface
R773 –1969	Rectangular or square parallel keys and their corresponding keyways (Dimensions in millimetres)
R774 –1969	Taper keys with or without gib head and their corresponding keyways (Dimensions in millimetres)
R775 –1969	Cylindrical and 1/10 conical shaft ends
R776 –1968	Pulps. Determination of acid insoluble ash
R777 –1968	Pulps. Determination of calcium content
R778 –1968	Pulps. Determination of copper
R779 –1968	Pulps. Determination of iron

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R780 –1968	Pictorial markings for handling of goods (general symbols)
R781 –1968	Measurement of fluid flow by means of Venturi tubes
R782 –1968	Microcopy. Measurement of the screen luminance of microfilm readers
R783 –1968	Mechanical testing of steel at elevated temperatures. Determination of lower yield stress and proof stress and proving test
R784 –1968	Conventional signs to be used in schemes for the installations of sanitary systems in ships
R785 –1968	Common names for pesticides. Eighth list
R786 –1968	Units and symbols for refrigeration
R787 –1968	General methods of test for pigments
R788 –1968	Ultramarine pigments
R789 –1968	Test code for agricultural tractors
R790 –1968	Marking of freight containers. Series 1 and 2
R791 –1968	Chemical analysis of magnesium and its alloys. Gravimetric determination of aluminium in magnesium alloys (aluminium content between 1.5 and 12.0%)
R792 –1968	Chemical analysis of magnesium and its alloys. Photometric determination of iron (Orthophenanthroline method applicable to iron content between 0.002 and 0.05%)
R793 –1968	Chemical analysis of aluminium and its alloys. Photometric determination of iron (Orthophenanthroline method applicable to iron content between 0.05 and 2.50%)
R794 –1968	Chemical analysis of magnesium and its alloys. Photometric determination of copper (Oxalyldihydrazide method applicable to copper content between 0.002 and 0.4%)
R795 –1968	Chemical analysis of aluminium and its alloys. Photometric determination of copper (Oxalyldihydrazide method applicable to copper content between 0.002 and 0.8%)
R796 –1968	Chemical analysis of aluminium and its alloys. Electrolytic determination of copper in aluminium alloys (Copper content greater than or equal to 0.50%)
R797 –1968	Chemical analysis of aluminium and its alloys. Gravimetric determination of silicon (Silicon content greater than or equal to 0.30%)
R798 –1968	Chemical analysis of aluminium and its alloys. Gravimetric determination of zinc in aluminium alloys (Zinc content between 0.50 and 6.5%)
R799 –1968	Pilot ladders
R800 –1968	Plastics. Basis for specification for phenolic moulding materials
R801 –1968	Pulps. Determination of saleable mass, in lots, of pulp baled in sheet form
R802 –1968	Aluminium oxide primarily used for the production of aluminium. Preparation and storage of test samples
R803 –1968	Aluminium oxide primarily used for the production of aluminium. Determination of loss of mass at 300 °C (conventional moisture)
R804 –1968	Aluminium oxide primarily used for the production of aluminium. Preparation of sample solution for analysis
R805 –1968	Aluminium oxide primarily used for the production of aluminium. Determination of iron content—1,10-phenanthroline photometric method
R806 –1968	Aluminium oxide primarily used for the production of aluminium. Determination of loss of mass at 1000 °C and 1200 °C
R807 –1968	Chemical analysis of magnesium and magnesium alloys. Polarographic determination of zinc (Zinc content between 0.1 and 4%)
R808 –1968	Chemical analysis of aluminium and aluminium alloys. Photometric determination of silicon (Silicon content between 0.02 and 0.4%)
R809 –1968	Chemical analysis of magnesium and magnesium alloys. Photometric determination of manganese. Periodate method (Manganese content between 0.01 and 0.8%)
R810 –1968	Chemical analysis of magnesium and magnesium alloys. Photometric determination of manganese. Periodate method (Manganese content less than 0.01%)
R811 –1968	Method of test for resistance of fabrics to penetration by water (Hydrostatic head test)
R812 –1968	Method of test for temperature limit of brittleness for vulcanized rubbers
R813 –1968	Preparation of test piece and method of test of the adhesion of vulcanized rubber to metal where the rubber is assembled to one metal plate
R814 –1968	Preparation of test piece and method of test of the adhesion of vulcanized rubber to metal where the rubber is assembled to two metal plates
R815 –1968	Method of test for the compression set under constant deflection at normal and high temperatures of vulcanized rubbers
R816 –1968	Determination of tear strength of small test pieces of vulcanized rubbers (Delft test piece)
R817 –1968	Number designation of organic refrigerants
R818 –1968	Fibre building boards. Definition. Classification
R819 –1968	Fibre building boards. Determination of density
R820 –1968	Particle boards. Definition. Classification
R821 –1968	Particle boards. Determination of dimensions of test pieces
R822 –1968	Particle boards. Determination of density
R823 –1968	Particle boards. Determination of moisture content
R824 –1968	Household refrigerators. Part I—Performance requirements
R825 –1968	Household refrigerators. Part II—Special low-temperature compartments for the storage of frozen foodstuffs
R826 –1968	Mechanical property limits for rolled products of aluminium and aluminium alloys
R827 –1968	Mechanical property limits for extruded products of aluminium and aluminium alloys
R828 –1968	Mechanical property limits for rivet stock of aluminium and aluminium alloys

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	Title
R829 –1968	Mechanical property limits for aluminium alloy forgings
R830 –1968	Terminology relating to freight containers
R831 –1968	Rules for construction of stationary boilers
R832 –1968	Abbreviations of typical words in bibliographical references
R833 –1968	Abbreviations of generic names in titles of periodicals
R834 –1968	Fire resistance tests of structures
R835 –1968	Graduated pipettes (excluding blowout pipettes)
R836 –1968	Vocabulary for the refractories industry
R837 –1968	Aircraft seat rails and pins
R838 –1968	Paper. Holes for general filing purposes
R839 –1968	Milling machine arbors with 7/24 tapers and milling machine accessories
R840 –1968	Code for numerical control of machines (compatible with the ISO 7 bit character set)
R841 –1968	Axis and motion nomenclature for numerically controlled machines
R842 –1968	Sampling raw materials for paints and varnishes
R843 –1968	International system for the transliteration of Greek characters into Latin characters
R844 –1968	Plastics—Compression test of rigid cellular plastics
R845 –1968	Plastics—Determination of apparent density of cellular plastics
R846 –1968	Plastics—Recommended practice for the evaluation of the resistance of plastics to fungi by visual examination
R847 –1968	Phosphoric acid for industrial use—Determination of sulphate content—Volumetric method
R848 –1968	Phosphoric acid for industrial use—Determination of calcium content—Volumetric method
R849 –1968	Phosphoric acid for industrial use—Determination of iron content—2,2′-bipyridyl spectrophotometric method
R850 –1968	Sodium tripolyphosphate for industrial use—Determination of matter insoluble in water
R851 –1968	Sodium tripolyphosphate for industrial use—Measurement of pH potentiometric method
R852 –1968	Sodium tripolyphosphate and sodium pyrophosphate for industrial use—Determination of iron content—2,2′-bipyridyl spectrophotometric method
R853 –1968	Sodium tripolyphosphate and sodium pyrophosphate for industrial use—Determination of loss on ignition
R854 –1968	Requirements for 28-volt d.c. flat strip fuses for aircraft
R855 –1968	Oil of lemon, obtained by expression, Italy
R856 –1968	Oil of peppermint, United Kingdom, U.S.A., France and Italy
R857 –1968	Definitions of welding processes
R858 –1968	Netting yarns for fishing nets. Designation in the Tex system
R859 –1968	Testing and rating room air conditioners
R860 –1968	International unification of concepts and terms
R861 –1968	Hexagon socket head cap screws. Metric series
R862 –1968	Surface active agents. Glossary
R862/Add. 1 –1969	ISO/R 862—Addendum 1—Surface active agents—Vocabulary
R863 –1968	Pozzolanicity test for pozzolanic cements
R864 –1968	Solid wires for gas-shielded metal-arc welding of mild steel. Dimensions of wires, spools, rims and coils
R865 –1968	Dimensions and pitching of slots on platens for projection welding machines
R866 –1968	Centre drills for centre holes without protecting chamfers—Type A
R867 –1968	Spindle noses and face plates. Bayonet type. Sizes for interchangeability. Metric series
Erratum F R868 –1968	Plastics. Determination of indentation hardness of plastics by means of a durometer (Shore hardness)
R869 –1968	Plastics. Preparation of specimens for optical tests on plastics materials. Moulding method
R870 –1968	Plastics. Preparation of specimens for optical tests on plastics materials. Casting method
R871 –1968	Plastics. Determination of the temperature of evolution of flammable gases from plastics
R872 –1968	Plastics. Determination of ash of unplasticized cellulose acetate
R873 –1968	Peaches. Guide to cold storage
R874 –1968	Fresh fruits and vegetables. Sampling
R875 –1968	Determination of solubility of essential oils in ethanol
R876 –1968	Special method of mechanical testing to determine the coding for deep penetration electrodes
R877 –1968	Plastics. Determination of resistance of plastics to colour change upon exposure to daylight
R878 –1968	Plastics. Determination of resistance of plastics to colour change upon exposure to light of the enclosed carbon arc
R879 –1968	Plastics. Determination of resistance of plastics to colour change upon exposure to light of a xenon lamp
R880 –1968	Asbestos-cement pipes, joints and fittings for sewerage and drainage
R881 –1968	Asbestos-cement siding shingles
R882 –1968	Specification for cardamoms
R883 –1969	Throwaway carbide indexable inserts. Dimensions
R884 –1968	Pictorial marking of transit packages containing photographic materials sensitive to radiant energy
R885 –1968	Bolts and screws. Radii under the head for general purpose bolts and screws. Metric series
R886 –1968	Chemical analysis of aluminium and aluminium alloys. Photometric determination of manganese (Manganese contents between 0.005 and 1.5%)
R887 –1968	Washers for hexagon bolts and nuts. Metric series
R888 –1968	Nominal lengths for bolts, screws and studs. Thread lengths for general purpose bolts
R889 –1968	Test code for stationary steam generators of the power station type
R890 –1968	Location and width of the recording head for centre sound records on 16 mm perforated magnetic film

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R891 –1968	Location and width of the recording head for edge sound records on 16 mm perforated magnetic film
R892 –1968	Dimensions of projection reels for 8 mm motion-picture film
R893 –1968	Surface active agents. Technical sodium alkylsulphonates. Methods of analysis
R894 –1968	Surface active agents. Technical sodium primary alkylsulphates. Methods of analysis
R895 –1968	Surface active agents. Technical sodium secondary alkylsulphates. Methods of analysis
R896 –1968	Surface active agents. Scientific classification
R897 –1968	Identification of the emulsion side of edge-marked roll film for still picture cameras
R898/I –1968	Mechanical properties of fasteners. Part I. Bolts, screws and studs
R898/II –1969	Mechanical properties of fasteners. Part II. Nuts with specified proof load values
R898/III –1969	Mechanical properties of fasteners. Part III. Marking of bolts, screws, studs and nuts
R899 –1968	Determination of tensile creep of plastics
R900 –1968	Aluminium oxide primarily used for the production of aluminium. Determination of titanium content. Tiron photometric method
R901 –1968	Aluminium oxide primarily used for the production of aluminium. Determination of absolute density. Pyknometer method
R902 –1968	Aluminium oxide primarily used for the production of aluminium. Measurement of the angle of repose
R903 –1968	Aluminium oxide primarily used for the production of aluminium. Measurement of untamped density
R904 –1968	Hydrochloric acid for industrial use. Determination of total acidity. Volumetric method
R905 –1968	Hydrochloric acid for industrial use. Evaluation of hydrochloric acid concentration by measurement of density
R906 –1968	Hydrochloric acid for industrial use. Determination of sulphate content. Barium sulphate gravimetric method
R907 –1968	Hydrochloric acid for industrial use. Determination of sulphated ash. Gravimetric method
R908 –1968	Hydrochloric acid for industrial use. Determination of oxidizing or reducing substances. Volumetric method
R909 –1968	Hydrochloric acid for industrial use. Determination of iron content. 2,2′-bipyridyl spectrophotometric method
R910 –1968	Sulphuric acid and oleum for industrial use. Determination of total acidity and calculation of free SO_3 content of oleum. Volumetric method
R911 –1968	Sulphuric acid for industrial use. Evaluation of sulphuric acid concentration by measurement of density
R912 –1968	Sulphuric acid and oleum for industrial use. Determination of sulphur dioxide content. Barium sulphate gravimetric method
R913 –1968	Sulphuric acid and oleum for industrial use. Determination of residue on ignition. Gravimetric method
R914 –1968	Sulphuric acid and oleum for industrial use. Determination of total nitrogen content. Volumetric method
R915 –1968	Sulphuric acid and oleum for industrial use. Determination of iron content. 2,2′-bipyridyl spectrophotometric method
R916 –1968	Testing of refrigerating systems
R917 –1968	Testing of refrigerant compressors
R918 –1969	Test method for distillation (distillation yield and distillation range)
R919 –1969	Guide for the preparation of classified vocabularies (Example of method)
R920 –1969	Method of test for wool fibre length barbe and hauter using a comb sorter
R920/A1 –1969	Amendment to ISO/R 920–1969
R921 –1969	Nuclear energy glossary. First series of terms
R922 –1969	Plastics. Determination of soluble matter of crystalline polypropylene by boiling n-heptane
R923 –1969	Expression and presentation of results of coal cleaning tests
R924 –1969	Principles and conventions for flowsheets for coal preparation plant
R925 –1969	Determination of carbon dioxide in coal by the gravimetric method
R926 –1969	Determination of nitrogen, total sulphur, chlorine and phosphorus in coke
R927 –1969	Spices and condiments. Determination of extraneous matter
R928 –1969	Spices and condiments. Determination of total ash
R929 –1969	Spices and condiments. Determination of water-insoluble ash
R930 –1969	Spices and condiments. Determination of acid-insoluble ash
R931 –1969	Green bananas. Guide to storage and transport
R932 –1969	Animal fats. Determination of insoluble impurities
R933 –1969	Animal fats. Determination of moisture and volatile matter
R934 –1969	Animal fats. Determination of water (entrainment distillation method)
R935 –1969	Animal fats. Determination of solidification point of fatty acids (titre)
R936 –1969	Meat and meat products. Determination of ash
R937 –1969	Meat and meat products. Determination of nitrogen content
R938 –1969	Hand-operated stillage trucks. Principal dimensions
R939 –1969	Spices and condiments. Determination of moisture content (entrainment method)
R940 –1969	Spices and condiments. Determination of alcohol-soluble extract
R941 –1969	Spices and condiments. Determination of cold water soluble extract
R942 –1969	Whiteheart malleable cast iron
R943 –1969	Blackheart malleable cast iron
R944 –1969	Pearlitic malleable cast iron
R945 –1969	Designation of the microstructure of graphite in cast iron
R946 –1969	Beam unnotched impact test for grey cast iron

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R947 –1969	Recommended practice for radiographic inspection of fusion welded butt joints in steel pipes up to 50 mm (2 in) wall thickness
R948 –1969	Spices and condiments. Sampling
R949 –1969	Cauliflowers. Guide to cold storage
R950 –1969	Cereals. Sampling (as grain)
R951 –1969	Pulses. Sampling
R952 –1969	Tensile testing of light metal and light metal alloy tubes
R953 –1969	Drift expanding test on light metal and light metal alloy tubes
R954 –1969	Simple bend test for light metal and light metal alloy sheet and strip of thickness between 0.2 mm (0.008 in) and 7 mm (0.25 in)
R955 –1969	Flattening test on aluminum and aluminum alloy tubes
R956 –1969	Tensile test for light metal and light metal alloy wires
R957 –1969	Simple torsion test for aluminum and aluminum alloy wire
R958 –1969	Wrapping test for aluminum and aluminum alloy wire
R959 –1969	Spices and condiments. Black pepper and white pepper, whole and ground. Specification
R960 –1969	Plastics. Determination of the water content in polyamides
R961 –1969	Implementation of the 6 and 7-bit coded character sets on 7 track 12.7 mm (1/2 in) magnetic tape
R962 –1969	Implementation of the 7-bit coded character set on 9 track 12.7 mm (1/2 in) magnetic tape
R963 –1969	Guide for the definition of 4-bit character sets derived from the ISO 7-bit coded character set for information processing interchange
R964 –1969	Shipbuilding details. Mating dimensions for pipeline flanges for ships
R965/I –1969	ISO general purpose metric screw threads. Tolerances. Part 1. Principles and basic data
R965/II –1969	ISO general purpose metric screw threads. Tolerances. Part 2. Limits of sizes for commercial bolt and nut threads. Medium quality
R965/III –1969	ISO general purpose metric screw threads. Tolerances. Part 3. Deviations for constructional threads
R966 –1969	Seeds. Sampling and methods of test
R967 –1969	Common names for pesticides. Ninth list
R968 –1969	Common names for pesticides. Tenth list
R969 –1969	Common names for pesticides. Eleventh list
R970 –1969	Common names for pesticides. Twelfth list
R971 –1969	Common names for pesticides. Thirteenth list
R972 –1969	Spices and condiments. Chillies, whole and ground. Specification
R973 –1969	Spices and condiments. Pimento (Allspice) whole and ground. Specification
R974 –1969	Plastics. Method of determining the brittleness temperature by impact
R975 –1969	Determination of the yield of benzenesoluble extract in brown coals and lignites
R976 –1969	Method for the determination of pH of latex
R977 –1969	Sodium hydroxide for industrial use. Preparation and storage of test sample
R978 –1969	Sodium hydroxide for industrial use. Preparation of sample solution
R979 –1969	Sodium hydroxide for industrial use. Determination of alkalinity. Volumetric method
R980 –1969	Sodium hydroxide for industrial use. Determination of the carbon dioxide content, expressed as sodium carbonate. Gas—volumetric method
R981 –1969	Sodium hydroxide for industrial use. Determination of chloride content. Volhard volumetric method
R982 –1969	Sodium hydroxide for industrial use. Determination of sulphate content. Barium sulphate gravimetric method
R983 –1969	Sodium hydroxide for industrial use. Determination of iron content. 2,2′-bipyridyl spectrophotometric method
R984 –1969	Sodium hydroxide for industrial use. Determination of silica content. Gravimetric method by insolubilization
R985 –1969	Sodium hydroxide for industrial use. Determination of silica content. Gravimetric method by precipitation of the quinolinesilicomolybdic complex
R986 –1969	Sodium hydroxide for industrial use. Determination of calcium. EDTA complexometric method
R987 –1969	Sodium hydroxide for industrial use. Determination of water-insoluble matter
R988 –1969	Potassium hydroxide for industrial use. Preparation and storage of test sample
R989 –1969	Potassium hydroxide for industrial use. Preparation of sample solution
R990 –1969	Potassium hydroxide for industrial use. Determination of alkalinity. Volumetric method
R991 –1969	Potassium hydroxide for industrial use. Determination of the carbon dioxide content, expressed as potassium carbonate. Gas—volumetric method
R992 –1969	Potassium hydroxide for industrial use. Determination of chloride content. Volhard volumetric method
R993 –1969	Potassium hydroxide for industrial use. Determination of sulphate content. Barium sulphate gravimetric method
R994 –1969	Potassium hydroxide for industrial use. Determination of iron content. 2,2′-bipyridyl spectrophotometric method
R995 –1969	Potassium hydroxide for industrial use. Determination of silica content. Gravimetric method by insolubilization
R996 –1969	Potassium hydroxide for industrial use. Determination of silica content. Gravimetric method by precipitation of the quinolinesilicomolybdic complex
R997 –1969	Potassium hydroxide for industrial use. Determination of calcium. EDTA complexometric method
R998 –1969	Potassium hydroxide for industrial use. Determination of water-insoluble matter
R999 –1969	Index of a publication

TABLE 13. Numerical List — ISO Recommendations — Continued

Ref.	Title
R1000–1969	Rules for the use of units of the international system of units and a selection of the decimal multiples and sub-multiples of the SI units
R1001–1969	Magnetic tape labelling and file structure for information interchange
R1002/I –1969	Rolling bearings. Airframe bearings. Part 1: Introduction, General, Boundary dimensions, Tolerances, Permissible load
R1003–1969	Spices and condiments. Ginger, whole, in pieces and ground. Specification
R1004–1969	Print specifications for magnetic ink character recognition
R1005/I –1969	Railway rolling stock material — Part 1 — Tyres for trailer stock
R1005/II –1969	Railway rolling stock material — Part 2 — Rough tyres for trailer stock: Dimensions and tolerances
R1005/III –1969	Railway rolling stock material — Part 3 — Axles for trailer stock
R1005/IV –1969	Railway rolling stock material — Part 4 — Rolled or forged wheel centres for tyred wheels for trailer stock
R1005/V –1969	Railway rolling stock material — Part 5 — Cast wheel centres in non-alloy steel for tyred wheels for trailer stock
R1005/VI –1969	Railway rolling stock material. Part 6. Solid wheels for trailer stock
R1005/VII –1969	Railway rolling stock material. Part 7. Wheel sets for trailer stock
R1006–1969	Modular co-ordination. Basic module
R1007–1969	Dimensions for 35 mm film magazines for still picture use and test for film pullout force
R1008–1969	Photographic black-and-white papers for general use. Preferred sizes of sheet material
R1009–1969	Photographic black-and-white paper for roll paper printers. Preferred sizes of rolls
R1010–1969	Photographic colour paper for general use. Preferred sizes of sheet material
R1011–1969	Photographic colour paper for roll paper printers. Preferred sizes of rolls
R1012–1969	Photographic colour film for general use. Preferred sizes of sheet material
R1013–1969	Determination of the bulk density of coke in a large container
R1014–1969	Determination of the true relative density, the apparent relative density and the porosity of coke
R1015–1969	Determination of moisture in brown coals and lignites by the direct volumetric method
R1016–1969	Determination of ash of brown coals and lignites
R1017–1969	Benzene extract from brown coals and lignites — Determination of acetone-soluble material ("Resinous substances")
R1018–1969	Determination of the moisture-holding capacity of hard coals
R1019–1969	Cinematography. Dimensions of daylight loading spools for 16 mm motion-picture film
R1020–1969	Cinematography. Dimensions of daylight loading spools for double-8 mm motion-picture film
R1021–1969	Aircraft engine nacelle fire-extinguisher doors
R1022–1969	Gaseous oxygen replenishment couplings for aircraft
R1023–1969	High pressure air charging valves for aircraft
R1024–1969	Rockwell superficial hardness test (N and T scales) for steel
R1025–1969	Sectional beams for warp knitting machines. Terminology and dimensions
R1026–1969	Fruit and vegetable products. Determination of total solids
R1027–1969	Radiographic image quality indicators. Principles and identification
R1028–1969	Flowchart symbols for information processing
R1029–1969	Coniferous sawn timber defects: Classification
R1030–1969	Coniferous sawn timber defects: Measurement
R1031–1969	Coniferous sawn timber defects: Terms and definitions
R1032–1969	Coniferous sawn timber sizes: Terms and definitions
R1033–1969	Dimensions for general purpose push-pull three-pole circuit-breakers for aircraft
R1034–1969	Aircraft connections for ground air-conditioning
R1035/I –1969	Dimensions of hot-rolled steel bars. Part I. Round bars. Metric series
Erratum	Erratum of first printing March 1969
R1035/II –1969	Dimensions of hot-rolled steel bars. Part 2. Square bars. Metric series
R1035/III –1969	Dimensions of hot-rolled steel bars. Part 3. Flat bars. Metric series
Erratum	Erratum of first printing March 1969
R1036–1969	Dyeing and finishing machines. Definition of left and right sides
R1037–1969	Beams for dyeing fibres and yarn
R1038–1969	Rolling bearings. Cylindrical roller bearings. Radial internal clearance
R1039–1969	Dimensions of cores for motion-picture and magnetic films
R1040/I –1969	Modular co-ordination. Horizontal multi-modules. 1st part
R1041–1969	Determination of freezing point of essential oils
R1042–1969	One-mark volumetric flasks
R1043–1969	Abbreviations (symbols) for plastics
R1044–1969	Industrial trucks. Voltages of traction batteries for electric trucks
R1045–1969	Dimensions of straight resistance spot welding electrodes (for loads greater than 1500 kgf)
R1046–1969	Architectural and building drawings. Definitions and nomenclature
R1047–1969	Architectural and building drawings. Presentation of drawings. Scales
R1048–1969	Identification of exposed colour roll film
R1049–1969	Continuous mechanical handling equipment for loose bulk materials. Vibrating conveyors and feeders with rectangular or trapezoidal trough
R1050–1969	Continuous mechanical handling equipment for loose bulk materials. Screw conveyors
R1051–1969	Rivet shank diameters (Diameter range 1 to 36 mm)
R1052–1969	Steels for general engineering purposes
R1053–1969	Chemical analysis of zinc. Photometric determination of copper

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R1054–1969	Chemical analysis of zinc. Polarographic determination of cadmium in zinc
R1055–1969	Chemical analysis of zinc and zinc alloys. Photometric determination of iron
R1056–1969	Punched tape block formats for the numerical control of machines. Coding of preparatory functions G and miscellaneous functions M
R1057–1969	Interchangeable punched tape variable block format positioning and straight-cut numerically controlled machines
R1058–1969	Punched tape variable block format for positioning and straight-cut numerically controlled machines
R1059–1969	Punched tape fixed block format for positioning and straight-cut numerically controlled machines
R1060–1969	Plastics. Designation of polyvinyl chloride resins
R1061–1969	Plastics. Determination of free acidity of unplasticized cellulose acetate
R1062–1969	Common names for pesticides. Fourteenth list
R1063–1969	Surface active agents. Determination of stability in hard water
R1064–1969	Surface active agents. Determination of apparent density of pastes on filing
R1065–1969	Surface active agents. Determination of the cloud point temperature (cloud point) of non-ionic surface active agents obtained from ethylene oxide
R1066–1969	Analysis of soaps. Determination of glycerol
R1067–1969	Analysis of soaps. Determination of unsaponifiable and unsaponified matter
R1068–1969	Plastics. PVC resins. Determination of the compacted apparent bulk density
R1069–1969	Magnetic compasses and binnacles for sea navigation. Vocabulary
R1070–1969	Liquid flow measurement in open channels by slope area method
R1071–1969	Code of symbols for covered electrodes for manual metal-arc welding of cast iron
R1072–1969	General manufacturing characteristics of solid wood parquet strips with rectangular face
R1073–1969	Alphanumeric character sets for optical recognition
R1074–1969	Stability of counterbalanced lift trucks—Basic tests
R1075–1969	Performance requirements for heat-resisting (190 °C) electrical cables with copper conductors for aircraft
R1076–1969	General purpose electrical cables with aluminium or aluminium alloy conductors for aircraft
R1077–1969	Dimensions of elastomeric toroidal sealing rings for pipe-fittings in aircraft (inch series—Class 1 tolerances)
R1078–1969	Dimensions of elastomeric toroidal sealing rings for aircraft (inch series—Class 1 tolerances)
R1079–1969	Verification of Rockwell superficial N and T scale hardness testing machines
R1080–1969	Cotter slots with 5% taper keys for boring machine tapers
R1081–1969	Terms and definitions relating to drives using V-belts and grooved pulleys
R1082–1969	Shackle type connector units for high tensile steel chain for conveyors
R1083–1969	Spheroidal graphite or nodular graphite cast iron
R1084–1969	Industrial tractors—Definition and nominal rating
R1085–1969	Combinations of double ended wrench gaps
R1086–1969	Title-leaves of a book
R1087–1969	Vocabulary of terminology
R1088–1969	Collection of data for determination of errors in measurement of liquid flow by velocity area methods
R1089–1969	Dimensions of tubular electrode holders for spot welding machines
R1090–1969	Function key symbols on typewriters
R1091–1969	Layout of printing and function keys on typewriters
R1092–1969	Numeric section of ten-key keyboards for adding machines and calculating machines
Erratum	Erratum of first printing June 1969
R1093–1969	Keytop and printed or displayed symbols for adding machines and calculating machines
R1094–1969	Classification of adding machines and calculating machines
R1095–1969	Shipbuilding details—Toughened glasses for ships' side scuttles and fixed lights
R1096–1969	Plywood—Classification
R1097–1969	Plywood—Measurement of dimensions of panels
R1098–1969	Plywood—Veneer plywood for general use—General requirements
R1099–1969	Axial load fatigue testing
R1100–1969	Liquid flow measurement in open channels—Establishment and operation of a gauging station and determination of the stage-discharge relation
R1101–1969	Tolerances of form and of position—Part 1: Generalities, symbols, indications on drawings
R1102–1969	Mechanical connections between prime movers and trailers—Interchangeability
R1103–1969	Ball couplings for caravans and light trailers
R1104–1969	Surface active agents—Technical sodium alkylsulphonates—Method of analysis
R1105–1969	Pesticides considered not to require common names—Second list
R1106–1969	Recommended practice for radiographic inspection of fusion welded butt joints for steel plates up to 50 mm (2 in) thick
Annex to ISO-R 947, 1027, 1106	Explanations on the significance of the principal radiographic terms used in ISO Recommendations concerning welding
R1107–1969	Netting for fishing—Basic terms and definitions
R1108–1969	Spices and condiments—Determination of non-volatile ether extract
R1109–1969	Classification of dense refractory products
R1110–1969	Plastics—Accelerated conditioning of test specimens of polyamide 66, 610 and 6
R1111–1969	Cold-reduced tinplate and cold-reduced blackplate—Part 1—Sheet

TABLE 13. Numerical List—ISO Recommendations—Continued

Ref.	*Title*
R1112–1969	Horology—Functional and non-functional jewels
R1113–1969	Representation of 6 and 7 bit coded character sets on punched taped
R1114–1969	Cocoa beans—Cut test
R1115–1969	Finishes with external screw thread for glass containers and gauges for the inspection of screw closures
R1116–1969	35 mm and 16 mm microfilms, spools and reels
R1117–1969	Bonded abrasive products—Grinding wheel dimensions—Part 2
R1118–1969	Chemical analysis of aluminum and aluminum alloys—Determination of titanium (Spectrophotometric method with chromotropic acid)
R1119–1969	Series of conical tapers and taper angles
R1120–1969	Strength of mechanical fastenings for conveyor belts (Static test method)
R1121–1969	List of characteristics which may be required of conveyor belts according to their use
R1122–1969	Glossary of gears—Geometrical definitions
R1123–1969	Rolling bearings—Tapered roller bearings——Inch series—Chamfer dimension limits
R1124–1969	Sampling bulk shipments of carbon black for the rubber industry
R1125–1969	Determination of ash content of carbon black for the rubber industry
R1126–1969	Determination of loss on heating of carbon black for the rubber industry
R1127–1969	Stainless steel tubes—Dimensions, tolerances and conventional masses per unit length
R1128–1969	Steel tubes—Butt welding bends 5 D (90° and 180°)
R1129–1969	Boiler tubes—Dimensions, tolerances and conventional masses per unit length
R1130–1969	Methods of fiber sampling for testing
R1131–1969	Weft pirns for box loaders for automatic looms—Dimensions of pirn tip
R1132–1969	Rolling bearings—Tolerances—Definitions
R1133–1969	Plastics—Determination of the melt flow rate of thermoplastics
R1134–1969	Pears—Guide to cold storage
R1135–1969	Transfusion equipment for medical use
R1136–1969	Air permeability methods for measuring the mean diameter of wool fibres
R1137–1969	Plastics—Method of test for the determination of the behaviour of plastics in a ventilated tubular oven
R1138–1969	Determination of total sulphur content of carbon black for the rubber industry
R1139–1969	Textiles—Designation of yarns
R1140–1969	Three-strand polyamide multifilament ropes
R1141–1969	Three-strand polyester multifilament ropes
R1142–1969	Sampling and conditioning of ropes for testing
R1143–1969	Rotating bar bending fatigue testing
R1144–1969	Textiles—Universal system for designating linear density (Tex system) (Replacing ISO/R 138 and ISO/R 271)
R1145–1969	Dimensions of refactory arch bricks
R1146–1969	Pyrometric reference cones
R1147–1969	Plastics—Aqueous dispersions of polymers and copolymers—Freezethaw cycle stability test
R1148–1969	Plastics—Polymer and copolymer water dispersions—Determination of pH
R1149–1969	Layout of multilingual classified vocabularies
R1150–1969	Closed-end drop wires (electrical and mechanical) for automatic drawing-in machines
R1151–1969	Symbols for flight dynamics—Part I—Aircraft motion relative to the air
R1152–1969	Symbols for flight dynamics—Part II—Motions of the aircraft and the atmosphere relative to the earth
R1153–1969	Symbols for flights dynamics—Part III—Derivatives of forces, moments and their coefficients
R1154–1969	Dimensions for punched paper tape for data interchange
R1155–1969	The use of longitudinal parity to detect errors in information messages
R1156–1969	Shipbuilding details—Wrought aluminum alloys for use in shipbuilding

17. STEEL

ISO Technical Committee on Steel, ISO/TC 17, has developed 70 ISO Recommendations (counting each part as a separate document) including 17 that are dimensional standards. The dimensional standard (ISO/R388) for thicknesses of sheet metal and diameters of wire summarized in table 6 and discussed in 11.4.1 is applicable to all metals including steel and hence was developed by another technical committee. Likewise, pipe dimensions (ISO/R65) in table 8 and 11.5.2 is under the cognizance of ISO/TC 5 which deals with pipe and fittings made from any material. ISO/R65 and other pipe standards are discussed more fully in a subsequent section of this survey.

Most ISO Recommendations for steel are specifications for chemical composition and/or physical properties, or are test methods for steel. Chemical composition is generally expressed in percentages. Therefore, measurement units are not involved. Test methods for chemical composition usually employ customary metric units. Measurements units are generally involved in the specifications and test methods for physical properties, but they are easily translated into other units.

The American (ASTM), British (BS), French (AFNOR), German (DIN), Italian (UNI), Japanese (JIS), and Indian (IS) national standards corresponding to the 70 ISO Recommendations for steel are listed in table 14. Prior to 1962, the U.S. apparently expressed little interest in international steel standards since the U.S. did not vote on 21 of the first 27 ISO Recommendations listed in table 14. From 1964 through 1969, there were 43 ISO Recommendations issued of which the U.S. approved 25, and disapproved 13. The ISO Recommendations approved by the U.S. generally differ from the corresponding ASTM standards. The U.S. Committee for International Standardization of Steel is part of ASTM Committee A-1 on Steel. In view of the greater interest recently in international standardization, this Committee may take steps to bring ASTM standards in accord with ISO Recommendations approved by the U.S.

Of the 17 dimensional standards for steel products, five are metric series, four are inch series, seven are for railway rolling stock and one includes both metric and inch products. The U.S. disapproved only those for railway rolling stock. Thus, the disapprovals of dimensional standards are not based on measurement units per se, but on more basic differences in engineering practices. On the other hand, approval of the metric dimensional standards does not make them part of U.S. practices. In order to do so, it is necessary to adopt new national standards or revise existing ones and industry must use them in their manufactures.

TABLE 14. International Steel Standards

ISO Rec.	U.S. (ASTM)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
79	A370, E10	*240	*A03–152	*50351		Z2243	*1500
80	A370	*891	*A03–153	*50103	*5550	Z2245	*1586
81	E92	*427	*A03–154	*50133		Z2244	*1501
82	A370	*18	A03–151	*50145		(1)	*1608
83	A370	*131	*A03–156	*50115		(2)	*1499
84	A370	*131		*50115		(3)	*1598
85	A370	*1639	A03–157	1605		(4)	*1599
86	E8	*18	A03–160	*50114	*5547	Z2241	*1663
87	A370	*1639	A03–158	1605	*5548	Z2248	*1962
88		*1639	A03–159	*50153	*5549	Z2550	*1403
89	A318		A03–701	*51210		(5)	*1521
136	A318		A03–701	*51212		(6)	*1717
144		*2803	A03–701	51211		(7)	*1716
145	A326		A03–701	51215		(8)	*1755
146	E92	427	A03–504			B7725	*1754
147	A370	*82	A03–501	51300	*6326	B7721	*1828
148	A370	*131	A03–161	*50115	*4713	(9)	*1757
149		*3855	A03–652	*50101		B7777	*1756
156	A370	*240	*A03–502			B7724	*2281
165	A370		A03–855	*50139	*5467	(10)	*2330
166		*1775	A03–856	*50135	*5466	(11)	*2335
167	A370		A03–852	*50136	*5469	(12)	*2329
202	A370	*1775	A03–853	*50136	*5468	(13)	*2328
203		*3500		50118	*5111	Z2271	*3407
204	E139	*3500	A03–352	50118	*5111	Z2271	*3408
205		*3688	A03–351	50112	*3918		
206	E150	*3500	A03–353		*5111	Z2272	*3409
373		*3518		50100			
374	A370			*50137		G3461–3	
375	A370	*18	A49–851	*50140	*5465	(14)	*1894
376	E74	*1610		51301		B7728	
377	A370		A03–111	50125	*6453	G0303	3711
404	A6		*A03–115			G0303	1387
437	E30	*1221	*A06–301		*6454	G1211	228
439	E30	*1121	*A06–302		*6442		228
442	A370	*1310		*51222		B7722–3	*3766
629	E212		*A06–303			G1213	

422-764 OL - 71 - 7

TABLE 14. International Steel Standards—Continued

ISO Rec.	U.S. (ASTM)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
630	A36	*4360	A35-501	17100		G3101	226, 1977
640	A370	*427	A03-507				
642	A255	*4437	A04-303	50191		G0561	*3848
643	E112		A04-102			G5551	*2853
657/I	A575		A45-009	1028		G3192	
657/II	A575		A45-010	1029		G3192	
657/III							
675/IV							
657/VII							
657/IX							
671	E30		A06-304		*6460	G1215	*228
674	A370	*891	A03-506	51303			*3754
683/I		*970	A35-562	17200		G4051	
683/II	A542			17200		G4051	
716	E18	*891	A03-503				*3804
726	E10	*240	A03-505				*4132
783		*3688	A03-351	50112			*4713
1005/I							
1005/II							
1005/III							
1005/IV							
1005/V							
1005/VI							
1005/VII							
1024			A03-170				*5072
1035/I			A45-003	*1013	*6012	G3191	*1732
1035/II			A45-004	*1014	*6013		*1732
1035/III			A45-005	1017	*6014	G3194	*1731
1052			A35-501	17100			
1079							*5073
1099				50100			*5074
1111			A36-150				*1993
1143							*5075

[1] Z2201, Z2241.
[2] Z2202, Z2242.
[3] Z2202, Z2242.
[4] Z2204, Z2248.
[5] Z2201, Z2241.
[6] G3521, G3536, G3530, G3560.
[7] C2506, C3126.
[8] G3521, G3530, G3560.
[9] Z2202, Z2242.
[10] G3437, G3461.
[11] G3437, G3454, G3452, G3456, G3461, G3463.
[12] G3444, G3452, G3454.
[13] G3441, G3444, G3452, G3458, G3460.
[14] Z2201, Z2241.

*Essentially in agreement with ISO Recommendations; agreement with Japanese (JIS) standards was not determined.

18. NONFERROUS METALS

ISO Recommendations for nonferrous metals are developed by three technical committees: TC 18 Zinc and Zinc Alloys, TC 26 Copper and Copper Alloys and TC 79 Light Metals and their Alloys. These committees developed 61 ISO Recommendations which were issued from 1959 through 1969. Only one (ISO/R431) is a dimensional standard. Other dimensional standards are in draft recommendation stage. Dimensional standard for thicknesses of sheet metal and diameters of wire (ISO/R388) and dimensional standards for pipe and tubing developed by other committees are also applicable to nonferrous metal products.

The American (ASTM), British (BS), French (AFNOR), German (DIN), Italian (UNI), Japanese (JIS), and Indian (IS) national standards corresponding to the 61 ISO Recommendations on nonferrous metals are listed in table 15. There are ASTM Standards corresponding to 52 of the 61 but there may be substantive differences. There appears to have been little or no effort made to revise ASTM Standards to be in essential agreement with the ISO Recommendations that have been approved by ANSI. Generally, SI units have not been included, other than the inclusion of a conversion table added as an appendix to the standard.

ASTM Committee B-2 on Nonferrous Metals and Alloys, B-5 on Copper and Copper Alloys and B-7 on Light Metals and Alloys have the U.S. advisory committees for ISO/TC 18, 26, and 79, respectively. The activity of the three ISO committees and the U.S. participation on them is reflected in the following tabulation of voting by ANSI on the 61 ISO Recommendations for Nonferrous Metals.

Number of ISO Recommendations

Committee	Approved	Dis-approved	No vote	Total
18	6	1	1	8
26	4	7	5	16
79	30	3	4	37
	40	11	10	61

Thus, about 65 percent of these ISO Recommendations appear to conform sufficiently well with U.S. practice to warrant approval, even though they may differ to some extent from ASTM Standards. Measurement units do not appear to underlie either the approval or disapproval votes of ANSI.

TABLE 15. International Standards for Nonferrous Metals

ISO Rec.	U.S. (ASTM)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
114	B92	*2970		*17800	*5537	H2150	
115	B179		A57-101	*1712			2590
121	B94	*2970		*1729		H5203	
122	B93	*2970		*1729		H2221	
164	B85	1490	A57-702	*1725	*5470	H5202	617
190	E8	*18		*50145		Z2241	*1816
191	E10	*240		*50351			*1790
192	E92	*427		*50133			*1810
195	B153	[8]		*50135		[1]	*2348
196	B154	[9]		*50911	*3669	H3422-5	*2305
197	B224		A53-100	*1718	*5649		
207	B92			*17800	*5537		
208	B85	*1490	A57-702	*1725		H5202	617
209	B221	[10]		*1712			737
301	B240	*1004	A55-102	*1743		H2207	713
397		*2873		51212			*3388
398		*1639				[2]	*3260
399	E92	*427		*50133			*2866
400	E8	*18		*50145		[3]	*2654
401	E8	*18				[3]	*2655
402	E8	*18		51210		[3]	*2656
403	E10	*240		50351			*3054
426	[16]	[11]	A53-403	*17660		[4]	
427	B103	[12]	A53-012	*17662		[5]	
428	B150	[13]		*17665		H3441	
429	B151	[14]		*17664		[6]	
430	B151	[15]		*17663			
431	B712	*1036		1708		H4121-2	191
503	B107	3370		1729		H4201-4	
713	E68		*A06-814				*406
714	E40	*3630	*A06-813				*406
715		*3630	*A06-814			H2107	*2600
752			A55-101	*1706			*209

TABLE 15. International Standards for Nonferrous Metals — Con.

ISO Rec.	U.S. (ASTM)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
791	E35	*3907	*A06-591				
792	E35	*3907	*A06-593		*5893		
793	E34	*1728	*A06-571				*504
794	E34	*3907	*A06-592		*5895		
795	E34		*A06-572				
796	E34		*A06-572		*5894		
797	E34	*1728	*A06-570		*5892		*504
798	E34	*1728	A06-573		*5896		*504
807			*A06-594		*6137		
808	E35		A06-570				*504
809	E35	*3907	*A06-597				
810		*3907	*A06-597				
826	B209			1745		([7])	*736-7
827	B221			1746		H4172-3	*1285
828	B316			59675		H4465-7	*740
829	B247			1749		H2103	
886	E34		*A06-576				*504
952	E8						*2657
953	B210						*4599
954	E290						*4598
955							*4177
956	E8						*2658
957	E143						*4176
958	B230						*4168
1053			*A06-801				*2600
1054	E68		*A06-814				*2600
1055			*A06-823				406, 2600
1118	E34		*A06-574				504

[1] H3631, 3641, 3651, 3661.
[2] Z2204, 2248.
[3] Z2201, 2241.
[4] H3201-3, 3220, 3321-2, 3325, 3422-5, 3521, 3523, 3631.
[5] H3731-2, 3741-2.
[6] H3701-2, 3711, 3721.
[7] H4101, 4104-6, 4111, 4121-3, 4161, 4163-7, 4181-3.
[8] Agrees with BS378, 659, 885, 1386, 1464, 2017, 2871.
[9] Agrees with BS250-2, 378, 885, 1464, 1867, 1948, 2579, 2871, 2874.
[10] Agrees with BS1470-1477.
[11] BS218, 249-52, 265-67, 378, 409, 711-13, 885, 1464, 1541, 1949, 2579, 2786, 2870-75.
[12] BS369, 407, 2870-1, 2873-5.
[13] BS378, 1067, 1464, 2032-3, 2579, 2870-5.
[14] BS374, 378, 1464, 2579, 2870-1, 2875.
[15] Agrees with BS790, 2870, 2873.
[16] ASTM B36, B121, B140, B453, B455.
*Essentially in agreement with ISO Recommendation; agreement with Japanese (JIS) standards was not determined.

19. PLASTICS

There have been 69 ISO Recommendations issued through 1969 that were developed by ISO/TC 61 on Plastics. This committee is one of the most active in ISO. The secretariat is held by the American National Standards Institute. U.S. participation in this committee is through a National Committee under the cognizance of Committee D-20 on Plastics of the American Society for Testing and Materials.

The 69 Recommendations on plastics pertain to methods of test, terminology, symbols, etc. There is no quality specification or dimensional standard among the 69 so far issued. However, there are dimensional standards for plastic pipe which were developed by another ISO committee and which are discussed in a subsequent section of this survey.

The American (ASTM), British (BS), French (AFNOR), German (DIN), Italian (UNI), Japanese (JIS), and Indian (IS) standards corresponding to the 69 ISO Recommendations on plastics are listed in table 16. Twenty-three of them are essentially equivalent to corresponding ASTM standards and seven are similar. It is evident from table 16 that some other countries have more national standards in accord with the ISO Recommendations than the U.S. has even though the Secretariat of ISO/TC 61 is in the U.S. These countries generally had few national standards for plastics and they adopt the ISO Recommendations for the national standards as they are issued. ASTM standards for plastics generally include metric equivalents of U.S. customary units. However, most standards do not permit easy use in laboratories having equipment calibrated in metric measurement units.

TABLE 16. International Standards for Plastics

ISO Rec.	U.S. (ASTM)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
59	D494	*2782	*T51–004	*53700	*4273		*867
60	*D1895	*2782	*T51–003	*53468	*4267	K6911	*867, *2221
61	*D1895	*2782	*T51–003	*53467	*4268	K6911	
62	*D570	*2782	*T51–002	*53475	*4292	K6790	[1]
75	*D648	*2782	*T51–005	*53461	*5641		*867
117	*D570	*2782	*T51–011	*53471	*4293	K6911	*2221
118		*2782	*T51–006	*53718			
119		*2782	*T51–010	*53704	*4297		*867
120		*2782	T51–009	*53707	*4299		*867
171	*D1895	*2782	*T51–012	*53466	*4270	K6911	*867, *2221,
172			*T51–008	*53708	*4298		
173		*2782	*T51–007	*53719			
174	D1243	*2782	*T51–013	*53726		K6721	*4669
175	*D543		*T51–029	*53476	*6059	K6761	*2798
176	D1203			*53407	*5636	K6733	
177			*T51–025	*53405	*5638		
178	*D790	*2782	*T51–001				
179	*D256	*2782	T51–035	*53453	*6062	K6911	
180	*D256				*6323	K6911	[1]
181	*D757	*2782	*T51–015	*53459	*5639		
182	D793			*53381			*4669
183		*2782	*T51–028	*53415	*6064		*2076
194				*7730	*5806	K6900	
291	*D618	**	*T51–014	50014	*4301		[2]
292	*D1238		*T51–016	53735		K6760	*2530
293	D2292						*2530
294	D1897						
295	D796			*53451			
305				*53381	*5637		
306	*D1525	*2782	*T51–021	*53460	*5642		*2530
307		*2782	T51–019	*53727		K6810	
308		*2782	*T51–020	*53710	*4296		*867
458	*D1043		T51–102	*53447	*5635		
462	*D543		T51–023	*53476	*6060		
472	D883	*1755			*4266	K6900	
483	*E104	3718					
489	*D542		T51–064	53491		K6714	
527	*D638		T51–034	*53445	*5819	K6911	[3]
537	*D2236		T51–104	*53445			
584	D1043		*T51–022	*16945	*5814	K6901	
585			T51–350	*53723	*5644	K6791	
599						K6810	
600	*D789		T51–032	*53728		K6810	
604	*D695		T51–101			K6911	
800						K6915	1300
844	D1621		*T56–101	*53421		K6967	
845	D1895		*T56–107	*53420		K6767	
846	D1924		X41–513				
868	*D2240					K6888	

TABLE 16. International Standards for Plastics—Continued

ISO Rec.	U.S. (ASTM)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
869							
870							
871	D1929						
872			T51-351	*53724			
877	E187		T51-055	*53388	*6063	K7101	
878	D1499		T51-057			K7102	
879	D2565		T54-012	*53389			
899	D674		T51-103	*53444			
922					*5817		
960						K6810	
974	D746				*5812		
1043				*7728			
1060			*T53-001	*7746		K6720	
1061			T51-352	*53729			
1068			*T51-042	*53194		K6721	
1110			*T51-051	*53714			
1133	D1238				*5640		
1137			T51-161				
1147			*T51-053				
1148			*T51-052				

* Essentially in agreement with ISO Recommendation; agreement with Japanese (JIS) standards was not determined.
** No separate standard, British Standards generally are in agreement.
[1] Agrees with IS867, 2221, 2267.
[2] Agrees with IS867, 1998, 2267.
[3] Agrees with IS867, 1998, 2221, 2530.

20. RUBBER

ISO/TC 45 on Rubber has developed 35 ISO Recommendations through 1969. They are either sampling procedures or methods of test. Dimensional and quality specifications are to be issued soon. As indicated in table 7 and 11.4.2, the rubber industry has adopted preferred numbers for bore sizes of rubber hose, but manufacture of such hoses has not yet been implemented since ISO Recommendation R1307 was approved in late 1970.

The American (ASTM), British (BS), French (AFNOR), German (DIN), Italian (UNI), Japanese (JIS), and Indian (IS) national standards corresponding to the 35 ISO Recommendations for rubber are listed in table 17. There are ASTM standards essentially equivalent to 29 of them. This number exceeds the number issued by other countries that are in agreement with the ISO Recommendations listed in table 17. The high degree (over 80%) of agreement between ASTM standards and ISO Recommendations for rubber exceeds that for any other ISO Committee including those whose Secretariat is held by the American National Standards Institute.

The acceptance of ASTM standards for rubber internationally stems from policies early established by ASTM Committee D-11 on Rubber and Rubber-Like Materials, the sponsor of the U.S. Committee advising ANSI and representing the U.S. on ISO/TC 45. Committee D-11 encourages the development of new methods with metric measurement units and early included metric units in existing methods. Perhaps of more significance, Committee D-11 has modified many ASTM standards for rubber to permit their use in both metric and nonmetric laboratories. These standards could be readily edited for use by ISO and metric countries. In line with ASTM policy, Committee D-11 is currently including SI units or changing customary metric units to SI units in standards that already include metric units.

TABLE 17. International Rubber Standards

ISO Rec.	U.S. (ASTM)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
33	D394	903A9	*T46-012	53516	*5254		*3400
34	D624	903A3	*T46-007	*53515		K6301	
35	*D1076	*1672-2	*T42-012	*53567	*4902	K6381	*3708
36	*D413	*903A12	*T46-008	*53530		K6301	*3400
37	*D412	*903A2	*T46-002	*53504	*4915	K6301	*3400
48	*D1415	*903A7 *903A20	*T46-003	*53519	4046	K6301	*3400
123	*D1076 *D1417	1672-1 3397	*T42-001	53562	*4901	K6381	
124	*D1076 *D1417	1672-1 3397	*T42-003	53563	*4903	K6381	*3708
125	*D1076	*1672-1	*T42-005	53565	*4904	K6381	*3708
126	*D1076	*1672-1	*T42-004	*53564	*5255	K6381	*3708
127	*D1076	*1672-2	*T42-013	*53566	*5256		*3708
132		*903A10	T46-015	*53522			
133	*D713	*903A11	T46-016	*53522			
188	*D572 *D573 *D865	*903A19	*T46-004 *T46-005 *T46-006	*53508	*5408 *5409	K6301	*3400
247	*D1278	*1673-2	*T43-105	53568		K6352	*3660
248	*D1278	*1673-2	*T43-104	*53526		K6352	*3660
249	*D1278	*1673-2	*T43-109	*53527		K6352	*3660
250	*D1278	1673-1	*T43-003	*53525		K6352	
289	*D1646	*1673-3	*T43-005	*53523		K6300	*3660
471	*D1349	**	*T40-101		*4905	K6301	3400
498		*1672-2	T42-002	*53591	*5874		
506	*D1076	*1672-2	*T42-016	*53590	*5614		*3708
667	D1646	*1673-3	*T42-004	*53524		K6300	
705	*D1076	1672-2	T42-015		*5615		
706	*D1076 *D1417	1672-2 3387	*T42-010		*5875	K6381 K6387	
812	*D746	*903A25	T42-018	*53546		K6301	
813	*D429B	903A21B	*T46-017		*5405	K6301	
814	*D429A	903A21A	*T46-017		*5406	K6301	
815	*D395B	*903A6A	*T46-011	*53517	*4913	K6301	
816				*53515		K6301	
976	*D1076 *D1417	*3397	*T42-009				
1124	*D1900		*T42-102				
1125	*D1506		*T45-132			K6221	
1126	*D1509		*T45-131		*6070	K6221	
1138	*D1619		*T45-133				

*Essentially in agreement with ISO Recommendations; agreement with Japanese (JIS) standards was not determined.
**No separate standard, but individual British Standards generally are in agreement.

21. ANTI-FRICTION BEARINGS

21.1 BACKGROUND

A bearing is a mechanical device used to reduce friction between parts of a machine where movement occurs. Anti-friction bearings are bearings that employ rolling elements to minimize friction, such as spherical balls, cylindrical rollers, spherical rollers, and conical rollers. The bearing dimensions are critical with respect to dimensions of parts of the machine in which they are in contact. The use of bearings conforming to standardized dimensions provides benefits both for the user and the manufacturer. The user benefits from alternate sources of supply, greater availability of replacement bearings, and lower cost. The manufacturer benefits from a smaller number of items to be manufactured and kept in inventory. The standardization is confined to external dimensions and tolerances which are essential for interchangeability, generally as completely assembled bearings. Internal design and dimensions are manufacturer's choice except in bearings assembled by the user from standardized parts.

21.2 STANDARDS FOR ANTI-FRICTION BEARINGS

National standards issued by the American National Standards Institute are based on AFBMA industry standards developed by the Anti-Friction Bearing Manufacturers Association. International standards are developed by ISO Technical Committee 4 on Rolling Bearings. Through 1969, this Committee developed the 30 ISO Recommendations listed in table 18. They are mostly dimensional specifications for boundary dimensions and tolerances of radial and thrust ball bearings, radial and thrust cylindrical roller bearings, tapered roller bearings, and accessories for bearing installation.

TABLE 18. International Standards for Antifriction Bearings

ISO Rec.	U.S. (ANSI)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
15	B3.6	*292	*E22–300	*616	*4259	B1512	*2513
76	*B3.11		*E22–391	*622		B1519	*3823
104	B3.6		*E22–300	*616	*6033	B1512, B1532	2513
113	B3.9		*E22–308	736–9			
199/I	B3.5	*292	E22–359	620		B1514	2513
199/II	B3.6						
200	B3.7			*620		B0104	2513
201	B3.5	*292	*E22–316	620		B1521	2513
246			*E22–308	5412		B1533	
281	*B3.11		*E22–392	622		B1518	*3824
300/I	*B54.1		*E22–395		*5417	B1516	*2398
300/II	*B54.1					B1516	
300/III							
355/I	B3.6		*E22–300	616	*6034	B1512	*3697
355/II			E22–300	616		B1534	
355/III		3134	E22–300	616			
355/IV							*3697
355/V			E22–300				
464	B3.6		*E22–302	616	*6046	B1509	*2513
465	B3.6		E22–316	*620			
492	B3.5		E22–316	*620	*4505	B1514	*2513
533	B3.5						
577/I			*E22–335	*620	4223	B1514	*3697
577/II						B1514	
578	B3.5	3134					
582	B3.5			620	4597	B1566	*3697
1002							
1038				*620			
1123							
1132						B0104	

* Essentially in agreement with ISO Recommendation; agreement with Japanese Standards (JIS) was not determined.

The American (ANSI), British (BS), French (AFNOR), German (DIN), Italian (UNI), Japanese (JIS), and Indian (IS) national standards corresponding to the 30 ISO Recommendations are listed in table 18. The U.S. approved 23, disapproved one, approved one in part, and did not vote on five. The U.S. and ISO standards for identification code and load ratings are in complete agreement. The dimensional specifications for metric ball bearings are in accord except for the chamfer. The AFBMA chamfers are consistent with the ISO chamfers, but some bearings conforming to the ISO chamfer would not meet the chamfer requirement in the ANSI Standard. Although the preponderance of ball bearings made in the U.S. conforms to the ISO metric series, there are many ball bearings made in an inch series, such as airframe bearings, and some even made in mixed inch and metric dimensions. For example, the bore may be a multiple of 1/16 inch and the outside diameter may be a whole number of millimeters or the bore and outside diameter may be a whole number of millimeters and the width a multiple of 1/16 inch. There are also proprietary ball bearings of nonstandard dimensions made for use by equipment manufacturers who desire to restrict trade.

Dimensional specifications for cylindrical roller bearings are similar to those for ball bearings. The metric series conform to the ISO Recommendations except for chamfer. Cylindrical roller bearings classified as needle bearings, those used in airframes, and proprietary cylindrical roller bearings are made in inch series.

There is no U.S. standard for metric series of tapered roller bearings. Production of a metric series has started in the U.S., but the dimensions do not conform to ISO Recommendations for tapered roller bearings. The inch series of tapered roller bearings include many more sizes in the U.S. standards than in the ISO Recommendations. This situation exists because the bearing manufacturers make special sizes at the request of equipment manufacturers using tapered roller bearings. The change to a metric series should eliminate the numerous inch sizes developed over the years and reduce cost of manufacture and inventory.

ISO Recommendations for spherical roller and instrument precision ball bearings are under development.

The Anti-Friction Bearing Manufacturers Association estimates that 60 percent of the anti-friction bearings made in the U.S. are in metric series conforming to ISO Recommendations. Now that tapered roller bearings are being made in metric series, this percentage made in metric sizes should be increasing. The U.S. is an active participant in ISO/TC 4 on Rolling Bearings and U.S. standards are generally in essential agreement with the ISO Recommendations. The dual inch and metric series increase the number of bearings manufactured and inventoried in the U.S. and hence cause a needless increase in cost.

22. BUILDING CONSTRUCTION AND MATERIALS

ISO Recommendations pertaining to building construction and materials originate in many technical committees. General purpose products such as pipe and structural steel are used much more widely than in buildings and are discussed in other sections of this report. The following technical committees are concerned primarily with building construction or materials for buildings:

55 Sawn timber
59 Building construction
77 Products in asbestos cement
89 Boards made from wood or other ligno-cellulosic fibrous materials
92 Fire tests on building materials and structures
99 Semi-manufactures of timber
116 Performance testing of space heating appliances

Some activities of other committees, such as TC 43 on Acoustics and TC 74 on Hydraulic Binders, also pertain to buildings. The combined activities of the technical committees dealing exclusively or in part with building construction and materials has resulted in 60 ISO Recommendations through 1969. Sixteen of these ISO Recommendations relate to pipe and structural steel. The remaining 44 are listed in table 19 together with corresponding American (ASTM), British (BS), French (AFNOR), German (DIN), Italian (UNI), Japanese (JIS), and Indian (IS) national standards. The U.S. approved seven, disapproved four, and did not vote on 33 of these 44 ISO Recommendations. The 11 votes pertained to ISO Recommendations developed by technical committees 43, 74 and 77. Among the other six committees mentioned above, U.S. participates only in 59 and 92 but did not

TABLE 19. International Standards for Building Construction and Materials

ISO Rec.	U.S. (ASTM)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
140	[1]	*2750	S31-002	*52210		Z8106	
160			P41-302	*19800	4372	A5301	*1592
390			P08-001				
391	C428			19830	6159		
392	C428			19831	6159		
393			P33-301	274	3949	A5403	
394							
395			P33-302	274	3948	A5410	
396				274	3948	A5410	*2096
597	C219		P15-101	*1164			
631		*4050	B54-008	280	4373		
679	C109		P15-451	1164	6132-3		*4031
680			P15-461	*1164			
681	C114			*1164			
682	C114						
717			S31-010	4109			
737				68250			2179
738	[2]			68251			1331
766	D1037		B51-101	52350	*5064		1658
767	D1037		B51-102	52351	*5066		2380
768	D1037		B51-107	52352	*5067		2380
769	D1037		B51-104	52351	*5068		2380, 1658
818	D1554		B51-100	68750	*5062		1658
819	D1554		B51-103	52350	*5065		1658, 2380
820	D1554		B51-200	52360	4867		3087, 3097, 3478
821	D1037		B51-201	52361	4866		2380
822	D1037		B51-203	52361	4870		2380
823	*D1037		B51-202	52361	4871		2380
834	*E119		P92-201	*4102			*3809
863	C340		P15-462	1164			*4032
880				247	3948		
881			P16-403	19830	5341		
1006	[3]		P01-001	4172			*1233
1029			B50-002				707
1030	[2]						*3364
1031			B50-002				3364
1032			B50-002				
1040	[3]			4172			
1046			P02-001	1356			*962
1047			P02-002	1356			*962
1072			*B54-150	280	4373-5		
1096			B51-340		6469		
1097			*B54-155		6470		
1098					6472		

[1] ANSI Standard Z24.19.
[2] Commerce Standard PS 20.
[3] ANSI Standards A62.1 and A62.5.
* Agrees substantially with ISO Recommendations; agreement with Japanese Standards (JIS) was not determined.

vote on the ISO Recommendations developed by any of these committees. In view of this small participation, it is not surprising that U.S. standards for building construction and materials are generally not in accord with the ISO Recommendations. U.S. indifference toward international standardization in the building industry may stem from the fragmentation of standardization within the U.S. among some 6,000 local building codes and regulations.

A basic ISO Recommendation for building construction is R1006 which establishes a basic module of 10 centimeters. For countries using the yard-foot-inch system, the basic module is 4 inches. ISO Recommendation R1006 was issued in 1969 and is beginning to be incorporated into national standards. It is being supplemented by other recommendations establishing multimodules for horizontal and vertical dimensions of buildings. If these recommendations are followed in countries approving them, they would become the foundation for standardization of building construction that should result in substantial reduction of building costs. Present trends indicate that the basic module of 4 inches is not likely to be used except in the U.S.

23. PIPE AND TUBING

23.1 BACKGROUND

Tubing having outside diameters conforming to one of the sizes listed in ANS B36.10 issued by the American National Standards Institute is generally called pipe. Other sizes retain the designation tubing. The agreement noted in table 8 for outside diameters of U.S. and ISO pipe sizes (with two exceptions previously noted) reflects international standardization occurring many years ago. Present outside diameters of pipe can be traced to the English tube trade during the period 1820 to 1840. In 1886, the Committee on Standard Pipe and Pipe Threads of the American Society of Mechanical Engineers published (Transactions ASME, Vol. 8, p. 40) the dimensions for standard wall pipe that are now in ANS B36.10. Since all pipe was originally threaded, standardization of outside diameters was critical. The wall thickness was not critical provided it was sufficient to permit threading and still have adequate strength. As a consequence, there has not been universal agreement on wall thickness.

Standardizing committees have used at least four equations for relating wall thickness (T), outside pipe diameter (D), pressure (P), and stress (S). Currently, the following equations for determining thickness of pipe appear in various standards:

$$T = 0.1 + DP/1.75S \qquad (1)$$

$$T = DP/2S \qquad (2)$$

$$T = DP/(2S + 0.8P) \qquad (3)$$

$$T = DP/(2S + P) \qquad (4)$$

These equations are arranged in descending order of wall thickness; that is, eq (1) gives the greatest thickness and eq (4) gives the least. Equation (1) applies only when the inch unit is used; the other equations are applicable when any unit is used consistently. The actual values specified in most standards for wall thickness are not consistent with values calculated from the given equation. The specified wall thicknesses usually give pressure ratings for the pipe which decrease with increasing diameter. The notable exceptions are some relatively recent standards for plastic pipe having a constant ratio of D/T (Standard Dimension Ratio).

The diverse practices used in developing standards for pipe and tubing stems from independent committees in the U.S. and most countries for pipes and tubing made from different materials. Within ISO, a single technical committee deals with pipe and tubing regardless of the material. Fittings are also the responsibility of this committee, ISO/TC 5 on Pipes and Fittings. (Note: In 1970, Subcommittee 6 became ISO/TC 138 Plastic Pipe and Fittings).

23.2 SPECIFICATIONS

Table 20 lists the 25 ISO Recommendations developed through 1969 by ISO/TC 5 and the corresponding American (ANSI), British (BS), French (AFNOR), German (DIN), Italian (UNI), Japanese (JIS) and Indian (IS) national standards. The U.S. did not vote on 23 of the 25 ISO Recommendations, and disapproved two. Table 20 includes ISO Recommendations R7 and R228 on pipe threads which are discussed in section 24 on screw threads and fasteners.

Pipe and tubing dimensions are prescribed in the following ways in domestic and international standards:

1. ISO Recommendations and most domestic standards specify the outside diameter and wall thickness with tolerances on each.
2. A few domestic standards specify the inside diameter and wall thickness with tolerances on each.
3. A few domestic standards specify the outside diameter with tolerances, the minimum inside diameter and the minimum wall thickness.

The outside diameter corresponding to a given nominal size may have any one of the following values:

1. For pipe sizes up to 12 inches, the outside diameters are larger than the nominal sizes and have the values indicated in table 8.
2. The outside diameter of some tubing, particularly that for water service, is 1/8 inch larger than the nominal size.
3. Pipe sizes over 12 inches and most tubing have outside diameters equal to the nominal sizes.
4. Tubing having inside diameter and wall thickness specified has an outside diameter dependent on these dimensions.

The tolerance on pipe and tubing vary widely. Table 21 gives the minimum and maximum limits for outside diameter of five sizes of pipe given

TABLE 20. International Standards for Pipe and Tubing

ISO Rec.	U.S. (ANSI)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
7	B2.1	*[1]	E03-004	*2999	*339	B0203	*554
13	B16.1	*1211		28501	*5336	G5523	*1536-8
49	B16.3	*143, 1256		*2950	*5192	B2301	*1879
50	B16.5	*1387, 1740	*E29-029	*2886	*349	B2302	
64	B36.10	*[2]	*A49-004	*[3]	*4991	G3452	*1161
65	B36.10	*1387		*2440-1	*3824	G3452	*1161, 1239
134	B36		*A49-004	*[3]	*4992	G3444	3601
161		3867	T54-002	*[4]			
221		[2]		*[3]	*4991	G3452	*1161
228		*2779	E03-005	*259	*358	B0202	*2232, 2643
264				*8063-8			
265			T54-017	*19531		K6743	
274			A68-201	*LN9494		[5]	*2501
285	B16.9	*1965	E29-043	*2605	*5788	B2304	
330						K6741-2	*3076
336		536, 5601	*A49-004	*[3]	*4991	[6]	1161
508		1710		2403	5634	Z9102	*2379
531		416					3989
559	I336.1				*6363	[7]	3589
560			*A48-003	*2391	*2898	[8]	
580				*8063			
727			T54-029	*8063			
1127			*A48-051			G3459	
1128			*E29-045				
1129						G3461-2	

[1] BS 21, 143, 1256 and 1740.
[2] BS534, 778, 1965, 3601 and 3602.
[3] DIN 2448 and 2458.
[4] DIN 8061, 8062, and 8702-5.
[5] JIS H3601, 3620, 3631, 3641, and 3651.
[6] JIS G3452, 3454, 3455-7, 3461-2, 3464, 3437, and 3444.
[7] JIS G3452, 3457.
[8] JIS G3452, 3454-6.
*Essentially in agreement with ISO Recommendation; agreement with Japanese (JIS) standards was not determined.

in ISO Recommendation R65 for steel pipe and in various ASTM standards. The letter in the designation signifies the material; i.e., A-ferrous, B-nonferrous, and D-plastic. This table represents only a portion of the domestic standards for pipe, but it is typical of the various limits specified for a critical dimension required to be maintained for both nonthreaded and threaded fittings. The tolerances on outside diameter of tubing range from 0.001 to 0.023 inch for 3/4-inch tubing and from 0.002 to 0.031 inch for 3-inch tubing. An occasional standard permits only plus tolerances or greater plus than minus tolerance. Plus tolerances, particularly of different magnitudes, makes the standardization of fittings difficult for either pipe or tubing.

Table 8 shows that wall thickness is the principal difference between ISO and U.S. pipe. This dimension is also the principal difference among domestic standards. Table 22 lists the wall thicknesses specified for 6-inch

TABLE 21. Limits on Outside Diameter of Pipe

Nominal size inch / mm		¾ / 20	1½ / 40	3 / 80	6 / 150	12 / 300
Outside Diameter (inch)						
ISO/R65*	max	1.075	1.921	3.524	6.555	....
	min	1.043	1.886	3.465	6.453	....
ASTM Standard:						
Note 1	max	1.066	1.916	3.535	6.691	12.878
	min	1.019	1.869	3.465	6.559	12.622
A524, B337	max	1.065	1.916	3.531	6.687	12.843
	min	1.019	1.869	3.469	6.594	12.719
B42, B43, B315	max	1.050	1.900	3.500	6.625	12.750
	min	1.044	1.894	3.490	6.609	12.726
B161, B165	max	1.055	1.905	3.510	6.640	....
	min	1.045	1.895	3.490	6.610	....
B188, B302	max	1.050	1.900	3.500	6.625	12.750
	min	1.045	1.894	3.492	6.611	12.732
Note 2	max	1.058	1.908	3.510	6.645	....
	min	1.042	1.892	3.490	6.605	....
B466, B467	max	1.053	1.904	3.505	6.634	12.765
	min	1.047	1.896	3.495	6.616	12.735
Note 3	max	1.054	1.906	3.508	6.636	12.765
	min	1.046	1.894	3.492	6.614	12.735
D2310, D2517	max	1.065	1.915	3.515	6.640	12.775
	min	1.035	1.885	3.485	6.610	12.725
D2661	max	....	1.915	3.520	....	....
	min	....	1.900	3.500	....	....
D2680	max	....	....	....	....	14.13
	min	....	....	....	....	14.01
D2729, D2751	max	....	....	3.258	6.286	12.518
	min	....	....	3.242	6.264	12.482

*Medium and heavy series, two sets of other tolerances are given for light series I & II.

Note 1. ASTM A53, A72, A120, B241, B345, and B429 (Tolerances in some Standards are smaller by 0.001 inch).

Note 2. ASTM B167, B407, B423, B444, and B445.

Note 3. ASTM D1503, D1527, D1785, D2241, D2282, D2446, D2447, D2513, D2665, and D2672.

pipe in ASTM standards. Over 30 nominal thicknesses are specified in the range from 0.109 to 0.884 inch. Because of differences in specifying tolerances, this number is increased to about 50. The thicknesses for steel pipe specified in ISO Recommendation R65 (0.192 inch for Medium and 0.212 inch for Heavy) correspond approximately to the two thinnest wall thicknesses in ANS B36.10 (0.188 and 0.219 inch). These thicknesses are not commonly used in the U.S. and are not specified in the ASTM Standards. On the other hand, ISO pipe apparently is being used successfully in threaded application. It therefore appears that considerable economic benefit could result from a reevaluation of the thickness requirements for standard wall pipe.

The wall thickness of tubing specified in many standards can be traced to the Stubs gage numbers for steel sheets (Birmingham wire gage). The wall thicknesses in standards for plastic tubing and some metal tubing do not cor-

TABLE 22. Wall Thicknesses of 6-Inch Pipe

Material	Code	Maximum inch	Nominal inch	Minimum inch	ASTM Standards
Iron	XXS		.884	.774	A72
Steel	XXS		.864	.756	A53, A120, A524
Steel	160		.719	.629	A53, A524
Aluminum	160		.718	.628	B241, B345
Plastic	SDR 11	.675	.603	.603	D2446
Plastic	120	.629	.562	.562	D1785
Steel, Aluminum	120		.562	.492	A53, A524, B241, B345
Steel			.500	.438	A523
Plastic	SDR13.5	.550	.491	.491	D2241, D2282, D2513
Plastic	SDR13.5	.540	.481	.481	D2446
Cu, Ni		.494	.457	.420	B466
Iron	XS		.441	.386	A72
Cu, Brass	XS	.464	.437	.410	B42, B43
Cu-Ni	XS	.472	.437	.402	B466
Cu, Cu-Si	XS		.437	.415	B188, B135
Plastic	80	.484	.432	.432	D1527, D1785, D2447
Ni, Ti	80	.486	.432	.378	B161, B165, B337
Steel, Aluminum	80, XS		.432	.378	A53, A120, A312, A524, B317, B241, B345
Plastic	SDR 17	.437	.390	.390	D2241, D2282, D2446, D2513
Steel			.375	.328	A523
Steel			.344	.301	A523
Plastic	SDR 21	.354	.316	.316	D2241, D2282, D2446, D2513
Plastic	Class T	.353	.315	.315	D2241, D2282
Steel			.312	.273	A523
Steel	Std		.286	.250	A72
Ni, Ti	40	.315	.280	.245	B161, B165, B167, B337, B407, B423, B444, B445
Plastic	40	.314	.280	.280	D1503, D1527, D1785, D2447
Steel, Aluminum	40, Std		.280	.245	A53, A120, A312, A523, A524, B317, B241, B345
Cu-Ni		.277	.259	.241	B466
Cu-Ni		.265	.259	.253	B467
Plastic	SDR 26	.286	.255	.255	D2241, D2282, D2513
Cu-Ni	Regular	.268	.250	.232	B466
Cu, Brass	Regular	.264	.250	.236	B42, B43
Cu, Cu-Si	Regular		.250	.238	B188, B315
Steel			.250	.219	A523
Steel			.219	.192	(ANSI B36.10)
Plastic	SDR32.5	.228	.204	.204	D2241
Steel			.188	.165	(ANSI B36.10)
Plastic			.180	.180	D2751
Plastic	SDR 41	.182	.162	.162	D2241
Copper	TP	.168	.158	.148	B302
Al, Ti	10	.151	.134	.117	B241, B345, B337
Ni, Cu-Ni	10	.147	.134	.121	B161, B165, B466
Cu-Ni		.139	.134	.129	B467
Steel	10S		.134	.117	A312
Al-Ti	5	.123	.109	.095	B241, B345, B337
Steel	5S		.109	.095	A312
Plastic	SDR 64	.124	.104	.104	D2241
Plastic			.100	.100	D2729

respond to these gage numbers, but there does not appear to be a rational basis for most of the values specified. For example, the ratio of outside diameter to wall thickness should be constant for a particular pressure rating and material. This ratio for copper tubing in water service ranges from 10.2 to 32.0 for Type K, from 12.5 to 43.7 for Type L, and from 20 to 50 for Type M. Therefore, the pressure rating for a particular type varies with the diameter by a factor of about 3.

23.3 STANDARDIZATION NEEDS

The lack of agreement among domestic standards and between U.S. national standards and ISO Recommendations indicates the need for better coordination of pipe and tubing standards, possibly assigning the responsibility for standardizing dimensions to a single U.S. Committee as in ISO. Further, there has been a trend for some time away from threaded couplings to other means for joining pipe and tubing, such as welding, soldering, cementing, and various types of connectors. Nonthreaded fastenings have permitted the use of pipe or tubing with thinner walls and hence they have conserved materials. As previously noted, standards for plastic pipe and tubing have used the standard dimension ratio (SDR) or ratio of outside diameter to wall thickness as a more rational basis for selecting wall thicknesses of different sizes of tubing. The use of SDR and preferred numbers could further simplify the standardization of tubing dimensions and facilitate engineering calculations since the internal cross-sectional areas of all tubing would be related mathematically. Table 23 gives the outside diameters and wall thicknesses in millimeters for various standard dimension ratios from 6.3 to 125. The R10 series of preferred numbers is used for the three quantities (outside diameters, wall thickness, and SDR). Additional sizes for special purposes could be added by the use of the R20 or R40 series and the table could be extended to higher or lower values for any quantity. However, the 28 sizes covering the range from 2 to 1000 mm outside diameter and the 14 wall thicknesses corresponding to the 14 values of SDR should suffice for nearly all tubing whether made from plastics or the strongest metal.

The pressure rating for tubing made from a particular material depends on the allowable fiber stress and its SDR. Thus, in table 23, the pressure rating is increased 25 percent in going from one SDR to the next lower SDR. For a particular SDR, metal tubing having an allowable fiber stress of 110 MN/m^2 (about 16,000 psi) would have a pressure rating 10 times that of plastic tubing having an allowable fiber stress of 11 MN/m^2 (about 1,600 psi). Conversely, tubing of this metal having an SDR of 100 would have the same pressure rating as tubing of this plastic having an SDR of 10; i.e., the wall thickness of the plastic tubing would have to be 10 times that of the metal for the same pressure rating.

There are of course limitations for thin tubing. The wall thickness must be sufficient to provide the structural strength necessary for the application. The maximum thickness is limited by the equipment used to fabricate the tubing. For this reason, the thicknesses in table 23 have been arbitrarily

TABLE 23. Illustrative Tubing Dimensions Based on Preferred Numbers

[millimeters]

Outside diameter	Wall thickness for standard dimension ratio of–													
	6.3	8	10*	12.5	16	20*	25	31.5	40*	50	63	80*	100	125
2.0	0.32													
2.5	.40	0.32												
3.2	.50	.40	0.32											
4.0	.63	.50	.40	0.32										
5.0	.80	.63	.50	.40	0.32									
6.3	1.00	.80	.63	.50	.40	0.32								
8.0	1.25	1.00	.80	.63	.50	.40	0.32							
10.0	1.60	1.25	1.00	.80	.63	.50	.40	0.32						
12.5	2.00	1.60	1.25	1.00	.80	.63	.50	.40	0.32					
16.0	2.50	2.00	1.60	1.25	1.00	.80	.63	.50	.40	0.32				
20.0	3.15	2.50	2.00	1.60	1.25	1.00	.80	.63	.50	.40	0.32			
25.0	4.00	3.15	2.50	2.00	1.60	1.25	1.00	.80	.63	.50	.40	0.32		
31.5	5.00	4.00	3.15	2.50	2.00	1.60	1.25	1.00	.80	.63	.50	.40	0.32	
40.0	6.30	5.00	4.00	3.15	2.50	2.00	1.60	1.25	1.00	.80	.63	.50	.40	0.32
50.0	8.00	6.30	5.00	4.00	3.15	2.50	2.00	1.60	1.25	1.00	.80	.63	.50	.40
63.0	10.0	8.00	6.30	5.00	4.00	3.15	2.50	2.00	1.60	1.25	1.00	.80	.63	.50
80.0	12.5	10.0	8.00	6.30	5.00	4.00	3.15	2.50	2.00	1.60	1.25	1.00	.80	.63
100	16.0	12.5	10.0	8.00	6.30	5.00	4.00	3.15	2.50	2.00	1.60	1.25	1.00	.80
125	20.0	16.0	12.5	10.0	8.00	6.30	5.00	4.00	3.15	2.50	2.00	1.60	1.25	1.00
160	25.0	20.0	16.0	12.5	10.0	8.00	6.30	5.00	4.00	3.15	2.50	2.00	1.60	1.25
200	31.5	25.0	20.0	16.0	12.5	10.0	8.00	6.30	5.00	4.00	3.15	2.50	2.00	1.60
250	40.0	31.5	25.0	20.0	16.0	12.5	10.0	8.00	6.30	5.00	4.00	3.15	2.50	2.00
315	50.0	40.0	31.5	25.0	20.0	16.0	12.5	10.0	8.00	6.30	5.00	4.00	3.15	2.50
400	63.0	50.0	40.0	31.5	25.0	20.0	16.0	12.5	10.0	8.00	6.30	5.00	4.00	3.15
500		63.0	50.0	40.0	31.5	25.0	20.0	16.0	12.5	10.0	8.00	6.30	5.00	4.00
630			63.0	50.0	40.0	31.5	25.0	20.0	16.0	12.5	10.0	8.00	6.30	5.00
800				63.0	50.0	40.0	31.5	25.0	20.0	16.0	12.5	10.0	8.00	6.30
1000					63.0	50.0	40.0	31.5	25.0	20.0	16.0	12.5	10.0	8.00

*Internal diameters are preferred numbers in R10, R20, R40 and R80 series, respectively.

restricted to the range of 0.32 to 63 mm. This range could be made larger or smaller as required.

In order to facilitate compatibility between tubing and fittings, it is desirable that standards for tubing have only minus tolerances and standards for fittings have only plus tolerances. The use of preferred numbers for tolerances is advantageous for either a decreasing percentage with increasing values or a constant percentage. Table 24 illustrates both cases. For outside diameters in the R10 series of preferred numbers, tolerances are given in the R20 series for three cases designated small, medium, and large in the proportion of 1:4:16, respectively. This proportion could be changed and starting values for the small tolerance could be shifted up or down. The important feature is that the tolerance increases in a rational manner tenfold for an increase of hundredfold in outside diameter. A single set of tolerances would be chosen for any one type of tubing.

For illustrative purposes, the R10 series of preferred numbers is chosen for both wall thicknesses and their tolerances in table 24. Thus, the tolerance is a fixed percentage of the wall thickness; small, medium, and large values are selected to be 5, 10, and 20 percent, respectively. These values are in-

TABLE 24. Illustrative Tolerances on Tubing Dimensions

[millimeters]

Outside diameter	Tolerance*			Wall Thickness	Tolerance**		
	Small	Medium	Large		Small	Medium	Large
2.0	0.016	0.063	0.250	0.32	0.016	0.032	0.063
2.5	.018	.071	.280	.40	.020	.040	.080
3.2	.020	.080	.315	.50	.025	.050	.100
4.0	.022	.090	.355	.63	.032	.063	.125
5.0	.025	.100	.400	.80	.040	.080	.160
6.3	.028	.112	.450	1.00	.050	.100	.200
8.0	.032	.125	.500	1.25	.063	.125	.250
10.0	.036	.140	.560	1.60	.080	.160	.315
12.5	.040	.160	.630	2.00	.100	.200	.400
16.0	.045	.180	.710	2.50	.125	.250	.500
20.0	.050	.200	.800	3.15	.160	.315	.630
25.0	.056	.224	.900	4.00	.200	.400	.800
31.5	.063	.250	1.00	5.00	.250	.500	1.00
40.0	.071	.280	1.12	6.30	.315	.630	1.25
50.0	.080	.315	1.25	8.00	.400	.800	1.60
63.0	.090	.355	1.40	10.0	.500	1.00	2.00
80.0	.100	.400	1.60	12.5	.630	1.25	2.50
100	.112	.450	1.80	16.0	.800	1.60	3.15
125	.125	.500	2.00	20.0	1.00	2.00	4.00
160	.140	.560	2.24	25.0	1.25	2.50	5.00
200	.160	.630	2.50	31.5	1.60	3.15	6.30
250	.180	.710	2.80	40.0	2.00	4.00	8.00
315	.200	.800	3.15	50.0	2.50	5.00	10.00
400	.224	.900	3.55	63.0	3.15	6.30	12.5
500	.250	1.00	4.00				
630	.280	1.12	4.50				
800	.315	1.25	5.00				
1000	.355	1.40	5.60				

*Tolerances are all minus; plus tolerance is zero. R20 series of preferred numbers is used for tolerances on outside diameters of the R10 series. Small, medium and large are in the proportion 1:4:16. Other proportions could be used or values for tolerances could be shifted up to down as required.

**Tolerances are all plus; minus tolerance is zero. R10 series of preferred numbers is used for both tolerances and outside diameters. Therefore, tolerances are constant percentages of diameters. Small, medium and large are 5, 10, and 20 percent, respectively. Other percentages could be used.

dicated to be plus tolerances to assure adequate strength of the tubing. The percentages in table 24 are arbitrarily chosen. For a particular type of tubing, a single percentage from the R10 series of perferred numbers would be chosen.

Although the use of preferred numbers could be used for dimensions and tolerances of tubing based on the inch unit, the greatest advantage would be achieved by using SI units and international standardization. Present outside diameters of pipe used in threaded applications would probably not be changed in view of their standardization internationally for most sizes. However, wall thicknesses and tolerances could be based on preferred numbers and standardized internationally.

24. SCREW THREADS AND FASTENERS

24.1 BACKGROUND

The first known practical application of the screw was developed by Archimedes over 2,000 years ago, but the screw did not become important in commerce until the industrial revolution. The most important part of a screw is the thread. A screw thread is a ridge in the form of a helix on the external or internal surface of a cylinder or cone. It is essentially a spiral inclined plane or wedge whose mechanical advantage is used to increase the applied force. Screw threads serve many functions such as connectors or couplings, fasteners, gas and liquid seals and translators of motion or power. Thus, they are important elements of the nation's technology. Most screw threads are used for fastening. In a real sense, they are the "nails" of the metal age. Although adhesive bonding and welding are increasingly used in permanent fastening, threaded fasteners are unmatched in coupling and fastening parts that require future disassembly.

The screw is one of six simple machines; the others being the lever and fulcrum, wheel and axle, pulley, inclined plane, and wedge. Of these, the screw is the most complex and difficult to standardize dimensionally in order to achieve interchangeability. The standardization problem stems from the numerous forms or shapes of screw threads in use. The Robertson Guide to World Screw Thread Series Symbols, issued by W. H. A. Robertson and Company, Ltd., Bedford, England in 1962, lists 180 thread forms or shapes. Most of them are modifications of the 55 degree V-thread proposed in 1841 by Sir Joseph Whitworth in England and the 60 degree V-thread proposed by Mr. William Sellers of the Franklin Institute, Philadelphia in 1864.

The Whitworth thread was adopted as a British Standard in 1905 and its use became widespread in countries that adopted British technology. The

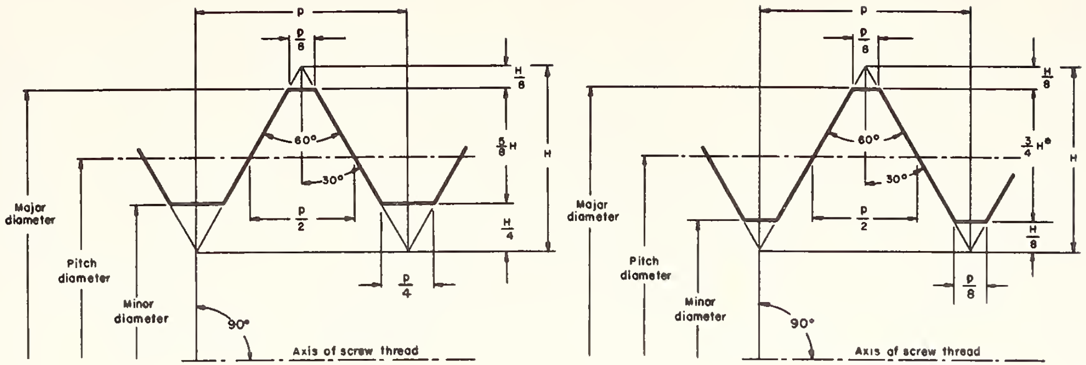
Sellers thread was adopted by many industries in the United States, but it had not been standardized nationally when World War I started. The need for interchangeability of parts in the mass production of war material led to passage of Public Law No. 201 in July 1918 creating a commission for the standardization of screw threads. The National Screw Thread Commission consisted of representatives from the Commerce, Navy and War Departments, the Society of Automotive Engineers, and the American Society of Mechanical Engineers. The Director of the National Bureau of Sandards served as Chairman. Congress underestimated the Commission's task since its tenure was authorized initially for 6 months. After four short extensions, the time limit was dropped. The Commission issued reports in 1921, 1925, 1929, and 1933 (NBS Miscellaneous Publications 42, 61, 89, and 141, respectively). The Commission was abolished by Executive Order in March 1933 as part of an economy reorganization during the depression. The Commission Reports included standards for the American National threads based on the Sellers thread form, Acme threads, hose threads, threads for electric lamps and sockets, and threads for wood screws. They also included methods for gaging threads.

The threat of World War II led the Secretary of Commerce to establish with the Secretaries of War and Navy the Interdepartmental Screw Thread Committee in 1939. This Committee issued NBS Handbook H25, *Screw Thread for Federal Services* in 1939. It was revised in 1942 and issued as NBS Handbook H28. New editions or supplements of NBS Handbook H28 were issued in 1944, 1950, 1957, 1963 and 1969. Although the screw thread standards in NBS Handbook H28 are mandatory only for Federal Agencies, they have in fact become national standards since ANS B1.1 and B1.2 issued by the American National Standards Institute are identical with corresponding standards in Handbook H28.

24.2 INTERNATIONAL STANDARDIZATION

The use of different national standards by the Allied Nations during World War II, particularly the Whitworth thread in the United Kingdom and the American National thread in the United States led to a series of conferences after the War which were attended by representatives of Canada, United Kingdom and United States. These conferences resulted in the Declaration of Accord on November 18, 1948 establishing the standards for the Unified Screw Threads. These standards were based on those for American National Threads. The basic profile of the Unified Thread was adopted by ISO for both metric and inch general purpose screw threads. The Unified (ISO) and the American National Thread forms are illustrated in figure 5.

The first technical committee established by ISO was on screw threads. This committee has developed through 1969 the nine ISO recommendations on screw threads listed in table 25. ISO Recommendation R68 gives the basic profile. The inch screw threads in ISO Recommendations R263 and R725 are the Unified Threads. The other six recommendations pertain to



Unified Thread ISO basic profile inch and metric series thread height = 5H/8

American National Thread Sellers symmetrical profile inch series thread height = 3H/4

Figure 5. Basic thread forms; ISO (Unified) and American National Threads P signifies pitch and H signifies fundamental triangle height.

metric screw threads. These metric threads are being adopted as national standards by most countries and are tending to replace the inch threads and over 20 different metric thread systems used in these countries.

TABLE 25. International Standards for Screw Threads and Fasteners

ISO Rec.	U.S. (ANSI)	U.K. (BS)	France (AFNOR)	Germany (DIN)	Italy (UNI)	Japan (JIS)	India (IS)
Screw Threads:							
68	B1.1, 1.10	(2)	E03-001	13/30	*4533	(7)	*1330, 1362
261	B1.10	*3643	E03-013	13/12	*4534-5	(8)	*4218
262		*3643	E03-014	*13/33	*4536	(9)	*4218
263	*B1.1	*1580				(10)	
724		*3643	E03-052	*13/1	*5535	(8)	*4218
725	*B1.1	*1580					
965/I			E03-051	*13/32	*5541-2		*4218
965/II			E03-053		*5546		*4218
965/III							*4218
Fasteners:							
225		(3)*			*5624	(11)	*1367
272	(1)	(4)*	*E27-311	(5)	*5625-7	(12)	*1363-4, 2389
273/I		*4186	E27-040	*69	1728	B1001	*1821
273/II			E27-040	*69		B1001	*1821
288/I		*3692	E27-414	*935	*5593-5	B1170	*2232
288/II			E27-414	*935		B1170	
733		(4)	E27-024	*475/1			
861				*912	*5931-2	B1176	*2269
885			E27-028	*267		(13)	*4172
887				*125, 126		B1256	*2016
888			E27-025	(6)	*5626	(14)	*4206
898/I				*267/3			*1367
898/II			*E27-005	*267/4			*1367
898/III			*E27-005	*267/7, 8			*1367

[1] ANS B18.2.1, 18.2.2, 18.6.3.
[2] BS 1580, 3369, 3643.
[3] BS 3692, 4168, 4183, 4190.
[4] BS 3692, 4190.
[5] DIN 555, 558, 601, 931, 934, 960, 961.
[6] DIN 558, 601, 603-8, 912, 931, 960, 6912, 7984.
[7] JIS B0205, 0206, 0207, 0208.
[8] JIS B0205, 0207.
[9] JIS B0205, 0207, 1180, 1181.
[10] JIS B0206, 0208.
[11] JIS B1101, 1173, 1180.
[12] JIS B1002, 1180, 1181
[13] JIS B1101, 1180.
[14] JIS B1101, 1111, 1173, 1176, 1179, 1180, 1182.
*Essentially in agreement with ISO Recommendation; agreement with Japanese (JIS) standards was not determined.

24.3 DYNAMICS OF SCREW THREAD TECHNOLOGY

The 180 thread forms currently used throughout the world and the activity within ISO indicate two opposing movements; one tends to proliferate the sizes and shapes of threaded forms, and the other is directed toward standardization and reduction in thread sizes and shapes. These two movements are occurring simultaneously. Standardization of screw thread dimensions nationally and internationally fosters efficiency and economy in production. On the other hand, rigid adherence to an existing thread system or an overly conservative acceptance policy for new thread systems, interferes with the application of new technology and hinders development of new markets. A balance of the two movements is essential for a healthy and vigorous economy.

For a particular application, the thread may be any one of innumerable combinations of diameter, pitch and profile. The particular design used may be chosen for economic reasons, to stifle competition, to gain proprietary advantage, or to be consistent with customary units of measurement and engineering standards of related products. Whatever the motivation, this freedom in design provides the innovations and new concepts in thread technology. However, without restraint it results in chaos and the advantages of interchangeability and mass production are lost. Innumerable bolts, nuts, taps, dyes, and gages have to be produced and kept in inventory with an attendant increase in cost.

In addition to the economy of mass production, standardization is fostered by the reduction in engineering data that must be generated regarding strength, fatigue life, tolerances, etc. and in the number of gages and gaging practices that must be developed. Currently, the movement toward standardization of screw threads tends to be predominant and opportunities for introducing new thread series are becoming less frequent, particularly when it is to replace a screw thread series that has been standardized and widely accepted internationally.

The Industrial Fasteners Institute recognizes that innovation in screw thread design is becoming more difficult, and that a change from inch-base to metric-base fasteners may provide a rare opportunity for improving screw thread and fastener technology. The Institute is sponsoring the development of an optimum fastener system based on current knowledge and technology. (See sec. 24.15.)

24.4 SPECIFICATIONS FOR SCREW THREADS AND FASTENERS

The complexity of the thread is responsible for separate standards for the screw thread and for the fastener exclusive of the thread. This complexity can be seen by the following comparison of requirements that must be specified in the two cases:

Screw thread	*Threaded fastener*
Major diameter	Thread series
Pitch diameter	Thread sizes
Minor diameter	Overall length
Direction of thread	Threaded length
Included angle of thread	Nonthreaded diameter
Leading flank angle of thread	Head shape or type
Following flank angle of thread	Dimensions of head
Lead or helix angle of thread	Material
Thread ridge thickness	Working strength
Thread groove thickness	Surface coating or treatment
Fundamental triangle height	Radius at head-body junction
Crest truncation and contour	Number of incomplete threads at start
Root truncation and contour	
Tolerances for class of fit	
Taper of thread	
Depth of thread engagement	
Length of thread engagement	
Method of gaging	

The numerous parameters listed above that can be varied in a screw thread make the clearances and tolerances critical in order to have interchangeability. Three classes of fit are provided in the Unified Thread Series designated 1A, 2A, and 3A for external threads and 1B, 2B, and 3B for internal threads. ISO Recommendation R965/I prescribes a more elaborate system of tolerances. For an external thread, seven tolerance grades and three tolerance positions are permitted for pitch diameter, and three tolerance grades and three tolerance positions are permitted for major diameter. For an internal thread, five tolerance grades and two tolerance positions are permitted for both pitch and minor diameters. Among the 189 possible tolerance combinations classes for external threads, only 13 tolerance classes are recommended. Similarly, among the 100 possible combinations for internal threads, 13 tolerances classes are recommended. Nevertheless, the 13 recommended ISO tolerance classes apparently are many more than necessary since three classes suffice for Unified Threads. The designation of the ISO metric thread is also more complex. For example, the thread of a fine 6 mm diameter, 0.75 mm pitch bolt and nut with minimum tolerances might be designated: M6 × 0.75 − 4H/3h4h for the ISO metric thread. The corresponding Unified extra fine thread for a 0.25-inch diameter, 32 threads per inch bolt and nut is designated: 1/4 − 32 UNEF − 3A/3B.

Table 25 lists the 23 ISO Recommendations issued through 1969 by TC 1 on Screw Threads and TC 2 on Bolts, Nuts and Accessories together with corresponding American (ANSI), British (BS), French (AFNOR), German (DIN), Italian (UNI), Japanese (JIS), and Indian (IS) national standards. U.S. approved 13, disapproved six and did not vote on four. These recommendations pertain to metric threads and fasteners except for ISO Recommendation R263 and R725 which pertain to the Unified inch thread and R68 which gives the basic profile for both metric and inch threads.

24.5 GAGING PRACTICES

Section 6 of NBS Handbook H28 deals with Gages and Gaging for Unified Screw Threads. It is the largest and one of the most important sections in these screw-thread standards. The numerous parameters in a standard screw-thread makes the development of gaging practice difficult. On the one hand, the practice must assure interchangeability and compliance with the standard. On the other hand, the practice must be suitable for inspection of the tremendous production of threaded fasteners which has a value of nearly 2 billion dollars per year.

The diverse national practices have made international standardization of gaging practices more difficult than standardization of profile and sizes of screw threads. In the development of the Unified Screw Thread in 1948, the difference in gaging practice used in the United Kingdom and the United States was not resolved and each country continues to use its own practice. As a result, a borderline screw thread might be placed in different classes of fit in the two countries.

The objective of a gaging practice is to accept all screw threads within tolerance limits and to reject all threads outside those limits. Measuring methods are practices directed toward determining actual magnitude of individual dimensions of the thread; whereas, gaging utilizes functional processes that test whether the resultant of all errors in the thread elements provide a thread form within material tolerances.

In measurement of pitch diameter, U.S. practice differs from that in other countries in two respects: (1) In the U.S., measurements are made only on external threads; internal threads are judged on the basis of fit to the measured external threads. (2) The U.S. does not follow the practice of the countries that apply corrections to pitch diameter measurement for deformations resulting from the measurement process and corrections for lead angle contribution. The U.S. chooses to follow a simplified practice, accepting a small inaccuracy that does not exceed 8 percent of the most critical tolerances for pitch diameter of standard threads.

ISO Recommendation on gaging issued in 1970 follows closely the British gaging practice. The following differences exist between U.S. and British gaging practices:

(1) The U.S. utilizes adjustable split ring gages in testing external threads. British Standard specifies solid ring gages which requires many more plug gages to monitor the ring gages. Wear on the solid ring gages results in a very limited service life.

(2) The British "not go" plug gage has a greater truncation of thread crest than the U.S. gage, since the British believe that greater truncation provides a more critical test for detecting defective thread form. U.S. practice allows for greater entry than the British practice in "not go" gaging tests.

(3) U.S. tolerances for external thread (ring) gages are slightly more stringent than British tolerances. On the other hand, U.S. tolerances for internal thread (plug) gages are considerably more liberal than the British tolerances. Both British and U.S. tolerances for ring and plug gages allow departures

greater than the tolerance allowed for pitch diameter of class 3 thread products.

In general the U.S. philosophy in standards favors simplified gaging and measurement procedures to serve the needs of mass production. U.S. practice uses fewer gages, less complicated mathematics and measurement practices, and less sophisticated measuring equipment. This simplification sacrifices some accuracy in determining actual size of screw thread and generates the basic disagreement between U.S. and British practice. British measurement practices are accurate to about 1.3μm (0.00005 in) as compared to about 3.8μm (0.00015 in) in U.S. practice.

24.6 THREAD FORM

The form or profile of screw threads is as critical to compatibility as dimensions of thread elements. Since threads can be scaled up or down in size without change in profile, incompatibility in thread form is not caused by basing design on different measurement units. Specifications for the following thread forms have been or are being developed by ISO or IEC:

(1) Unified Form—an equilateral triangular form of thread (apex angle 60 degrees) truncated at crest and root. The root is generally rounded and the crest is sometimes also rounded. This form is used for general purpose threads, both inch and metric and is the most extensively used of all forms. The miniature thread and the rounded root (UNJ) threads have a modified Unified thread form in which the root of external thread is more rounded and the thread is smaller in height. The largest use is in fasteners such as bolts, nuts, screws, and tapped holes.

(2) Whitworth Form—a triangular form of thread with a 55 degree apex angle, rounded at crest and root. This form is used in tapered and straight pipe threads except in the U.S. Its principal application is in threaded pipe couplings, fittings, valves, and similar pressure tight connections.

(3) Trapezoidal Form—an extensively truncated triangular form of thread with a 30 degree apex angle. In the U.S., a 29 degree apex angle is used. This form is used primarily for traversing components of machines and mechanical tools.

(4) Edison Form—a thread form composed of two circular segments tangent to each other and of equal radii. This form is used for electric lamp screw bases and sockets.

(5) Glass Form—a special thread form for glass containers having screw closures based on British Standard 1918.

Thusfar, ISO has not undertaken standardization of threads for aircraft fasteners, microscopes, and photographic equipment, and of Acme and Buttress threads. U.S. standards for the following threads are not compatible in shape with comparable international standards: pipe threads, gas cylinder valve outlet and inlet threads, and hose coupling threads.

24.7 COMPARISON OF THREADS OF UNIFIED FORM

Different forms of root truncation and rounding have attracted sufficient proponents so that three forms of Unified Thread with different roots now exist. For automotive and most industrial fasteners, the thread form in ISO Recommendation R68 is being accepted. The aerospace industries favor a more truncated (reduced thread height) and controlled root radius of external thread designated as the UNJ thread form (Mil Std 8879), which is not interchangeable with the UN form. The miniature screw thread has a form intermediate between the UN and UNJ forms. The ISO metric thread and the Unified inch thread have the same form. The two thread systems differ only in choice of diameters and pitch lengths for standard sizes. Thus, it is possible for metric and inch threads to be compatible if the tolerances for the two threads overlap. To be compatible, the pitch and pitch diameter of both external and internal threads must meet requirements given in appendix IV.

A comparison of pitch lengths for both Unified inch and ISO metric screw threads indicates that the following seven combinations are the only ones potentially compatible:

Threads/inch	*mm*
72	0.35
64	0.4
56	0.45
44	0.6
36	0.7
32	0.8
20	1.25

A comparison of pitch diameters for these pitch lengths indicates the following six combinations are potentially compatible:

*Unified Thread**	*Metric Thread***
UNF 0.73 –72	M 1.8 × 0.35
UNF .086 –56	M 2.2 × 0.45
UNF .099 –56	M 2.5 × 0.45
UNF .164 –36	M 4.0 × 0.7
UNF .190 –32	M 5.0 × 0.8
UN .3125–20	M 8.0 × 1.25

*UNF signifies Unified fine thread, the first number indicates major diameter in inch unit, and the second number indicates the number of threads per inch.

**M signifies metric, the first number indicates major diameter in millimeters and the second number indicates the pitch (distance between thread centers) in millimeters.

Assuming a Class 2 tolerance for the Unified Thread and an ISO grade 6 tolerance for the metric thread, the first three combinations are compatible if manufacturing tolerances be asymmetric to the basic pitch diameter and limited to approximately 50 percent of the magnitude of Class 2 tolerances for pitch diameter. The fourth and fifth combinations are compatible only near the tolerance limits, and the last one is not compatible within Class 2 tolerances and allowances.

422-764 OL - 71 - 9

While it is not recommended to combine a metric and inch thread, the combinations noted above show that the ISO metric and Unified threads are very similar. Either series could satisfy the needs of a general purpose screw thread system for most fastener applications.

There are 319 thread sizes listed in the U.S. standards for Unified Threads covering a range in diameters from 0.06 in (1.5 mm) to 6 in (152 mm) and pitches from 80 to 4 threads per inch, (0.3175 to 6.35 mm pitch). Each thread size is manufactured in at least two classes of fit. The metric series of general purpose screw threads includes 332 thread sizes covering a range from 1 to 300 mm in diameter and 0.2 to 6 mm in pitch. Each size may be manufactured in a number of tolerance grades. *Thus, the U.S. faces the prospect of doubling the number of thread sizes if the current trend to use both inch and metric thread sizes expands.* Such a course is inefficient and costly. The trend should be in the opposite direction; that is, the number of thread sizes should be reduced to promote efficiency and economy.

24.8 MINIATURE SCREW THREADS

Screw thread diameters below 0.06 in (1.5 mm) have a Unified form with a more truncated root. The U.S. standards for these threads are based on metric dimensions so that measurement units are not responsible for any incompatibility. The proposed ISO Recommendation differs from the U.S. Standards with respect to tolerances. For external threads, the U.S. standards are more stringent; whereas, for internal threads, the proposed ISO Recommendation is more stringent.

There are 14 thread sizes in the miniature thread series listed in NBS Handbook H28. They are all inherently compatible with those in the proposed ISO Recommendation. The differences in tolerances between U.S. and ISO specifications are annoying in manufacture and may cause confusion. A manufacturer making miniature screw threads for international commerce must adhere to smaller tolerances than one manufacturing for domestic trade only.

24.9 EDISON SCREW THREADS

There are five sizes of thread used for electric lamp bases and sockets. They are designated Miniature, Candelabra, Intermediate, Medium and Mogul. The dimensions of these threads in NBS Handbook H28 are similar in form and essentially identical in pitch to corresponding threads in IEC Recommendation No. 61-1. However, there are significant differences in major and minor diameters of the threads specified in the two documents; mainly, (1) The U.S. Intermediate Thread is not interchangeable with the IEC thread, (2) Lamps with IEC E27 threads, will fit U.S. Medium lamps sockets, but not all lamps with U.S. Medium threads fit IEC E27 sockets, and (3) Lamps with IEC E40 threads fit U.S. Mogul lamp sockets, but lamps with U.S. Mogul lamp threads do not fit IEC E40 sockets since the minor diameter of U.S. threads is too large to be interchangeable. The U.S. and IEC threads are not identical in shape, since the radii specified for the rolled threads generally differ.

24.10 PIPE THREADS

NBS Handbook H28 Part II, gives specifications for the following pipe threads:

NPI — American Standard taper pipe threads for general use
NPSC — American Standard straight pipe threads in pipe couplings
NPTR — American Standard taper pipe threads in railing joints
NPSM — American Standard straight pipe threads for free-fitting mechanical joints for fixtures
NPSL — American Standard straight pipe threads for loose-fitting mechanical joints with locknuts.
NPTF — Dryseal American Standard taper pipe thread
PTF-SAE SHORT — Dryseal SAE short taper pipe thread
NPSF — Dryseal American Standard fuel internal straight pipe thread
NPSI — Dryseal American Standard intermediate internal straight pipe thread
UNS — Threads for use on thin-wall tubing, 27 threads per inch.
NGT — National gas taper threads
SGT — Special gas taper threads
NGS — National gas straight threads
NGO — National gas cylinder valve outlet threads
NPSH — American National hose coupling threads
NH — American National fire-hose coupling threads
— American National hose connections for welding and cutting equipment.

In addition to the pipe threads listed in NBS Handbook H28, there are several standards issued by the American Petroleum Institute giving specifications for pipe threads used in the oil industry. These standards include 12 thread forms which have tapers of 1:4, 1:6, 1:16, 1:32 and straight. These pipe threads are used throughout the world in the oil industry. However, they have not been adopted by either ANSI or ISO.

All U.S. pipe and hose threads have an equilateral triangular form, differing from the Unified Thread form generally in a smaller extent of truncation. Pipe threads also differ in pitch and diameter from the Unified inch and ISO metric thread sizes and most are tapered.

Since the pipe threads in NBS Handbook H28 have an apex angle of 60 degrees, they are not compatible with those in ISO Recommendations R 7 and R 228 which are based on the Whitworth form having an apex angle of 55 degrees. On the other hand, the outside diameters of most sizes of U.S. and ISO pipe are the same. Hence the incompatibility results from differences in thread design and not from measurement units. Because of the incompatibility in thread forms, couplings, fittings and valves are also incompatible. It should be noted that the incompatibility between U.S. and ISO pipe threads does not result from the use of metric dimensions, but is inherited from past incompatibility of British and U.S. Standards for pipe threads.

For threads used in hose couplings and connections to gas cylinders, there is no ISO Recommendation at present. If ISO chooses to base a future recommendation for thread used in these applications on the Whitworth form, they will be incompatible with U.S. Standards also because of design.

American Standard taper pipe threads are used in Canada and Venezuela, but the ISO pipe thread is used throughout the rest of the world. New technology with more efficient and economic design for joining pipe and fittings is probably required to achieve world wide standardization.

24.11 TRAPEZOIDAL SCREW THREADS

The trapezoidal form of thread used in the U.S. has a thread height equal to one-half of the pitch and is known as an Acme thread. It is used extensively in machines and mechanical tools to convert rotary into linear motion or to transmit power. The apex angle of the thread is 29 degrees. Currently, there is no ISO Recommendation, but a proposed Draft Recommendation is sufficiently developed to indicate that an angle of 30 degrees will be specified. If so, the Acme and ISO trapezoidal threads will not be compatible. ISO is also considering a proposal for the Acme thread. The U.S. is not represented on the ISO Working Group for Trapezoidal Screw Threads so that the U.S. Standards may not receive adequate consideration. There are also U.S. standards for trapezoidal threads having smaller thread heights than the Acme thread; namely, 0.375, 0.3 and 0.25 of the pitch value. They are known as Stub Acme Threads and are used where the Acme threads are not suitable. There is currently no comparable ISO Recommendation, but the ISO Working Group for Trapezoidal Screw Threads has been requested to develop a proposed specification for them.

24.12 BUTTRESS THREAD

This thread is used in application where high stresses are involved in a direction along the thread axis. The pressure flank is nearly perpendicular to the thread axis so as to reduce radial components of thrust to a minimum. Typical applications are the breach mechanisms of large guns and airplane propeller hubs. NBS Handbook H28 specifies a pressure flank of 7 degrees from the normal to the thread axis and a clearance flank of 45 degrees. The thread height is 0.6 of the pitch value. Several other national standards exist, but there has been no attempt toward international standardization.

24.13 THREADS FOR MICROSCOPES

NBS Handbook H28 specifies a truncated Whitworth thread form with apex angle of 55 degrees for microscope objective and nosepiece threads. The major diameter is 0.8 inch and there are 36 threads per inch. This thread is completely interchangeable with the RMS thread developed by the Royal Microscopical Society of Great Britain and is almost universally accepted. However, it lacks formal recognition as an international standard.

24.14 OTHER THREADS

NBS Handbook H28 describes several threads for the following special applications:

American tripod to American camera fastener
American tripod to European camera fastener
Attachment of mounted lenses to photographic equipment
Attachment of lens accessories to lens mount
Attachment of shutter cable release to American camera
Attachment of shutter cable release to European camera
Dairy sanitary fittings
Glass containers
Plastic containers
Metal containers
Modified square thread for machines
60 degree Stub thread for machines

Most of these threads are not compatible with other national standards and an ISO Recommendation has been issued only for the threads used in screw closures on glass containers. British Standard 1918 is used in the U.S. for these screw threads and is the basis for ISO Recommendation R1115. However, BS 1918 and ISO/R1115 are not compatible in all specification requirements, but BS 1918 is likely to be revised to conform with ISO/R1115. Some of the threads for these special applications are used to some extent in other countries. In fact, some are used specifically as interface adapters between American and European products. Such adapters are one means of resolving the incompatibility between U.S. practices and those in other countries. However, international standardization is a preferable solution.

24.15 FUTURE TRENDS

The current trend toward increasing use of metric fasteners in the U.S. doubles the number of sizes that must be manufactured and inventoried. This evolutionary process of metrication can double inventory costs without compensating benefits and can place the U.S. at an economic disadvantage compared to a country using metric fasteners practically exclusively. In addition, the continued use of two series causes confusion and error in the replacement market indefinitely. Individual manufacturers are free to use only one series, but the consumer is burdened with the costs and disadvantages of maintaining a dual system.

Recognizing the current trend, the Industrial Fasteners Institute has undertaken a study to develop an optimum metric fastener system. The first progress report on this study is given in appendix V. The study shows how the adverse impact of metrication can be minimized and the benefits maximized. Instead of adding 57 ISO metric sizes to the existing 59 inch sizes of screw threads, the study proposes a new series of only 25 sizes to replace both. The new series is based on the UNJ thread form used for aircraft which has been found to have superior fatigue resistance. The sizes from 1 to 25 mm in diameter are rationalized by means of the R10 series of preferred numbers. Thus, a metrication program could provide the rare opportunity and incentive for changing screw thread standards taking advantage of current knowledge and technology. Such a drastic change in standards is possible with inch screw threads, but it is not likely since the incentive for change does not exist. Metrication requires change. In any metrication program, advantage can and should be taken of such a change to simplify and improve engineering standards, not only for screw threads and fasteners, but for all industrial products conforming to national standards.

25. DISCUSSION

It is apparent from this study that a large proportion of engineering standards either do not have measurement units or use such units only as a language. This fact attests to the separate identities and purposes of standards and units. Yet in the domain of dimensional specifications, the two are so intimately intertwined through custom that the compatibility of these standards is related to the units. However, compatibility does not depend on the units alone. For all standards including dimensional specifications, the entire engineering practice must be the same to achieve compatibility. Thus, dimensional specifications in both metric and nonmetric countries are compatible if the engineering practice is the same, even though one expresses dimensions in millimeters and the other in inches. On the other hand, corresponding dimensional specifications expressed in the same unit are incompatible if the engineering practices differ.

Apart from the role of units in dimensional specifications, the use of the same units in all engineering standards facilitates communication. The traditional use in the U.S. of metric units in biological and chemical standards reflects their worldwide use in these sciences for communication purposes. The International System of Units[1] (SI) adopted by the General Conference on Weights and Measures simplifies the measurement units and communication. The current trend throughout the world, including the U.S., is to include or use SI units in engineering standards. ISO, ASTM, and other organizations now require the inclusion of SI units in addition to or in place of customary metric or inch-pound units. As these units become incorporated into more and more standards, resistance to standards which do not use them is likely to grow in international forums.

The findings of this study indicate that the inclusion of SI units into U.S. standards is not sufficient to promote their use internationally. The standards must be drafted in such form that they can be used easily in both metric and nonmetric countries. For example, the standards should permit tests to be made with equipment graduated in either U.S. customary or SI units and with specimens having either customary inch or metric dimensions. Standards drafted in this way standardize the essential features of engineering practices without restricting their use by nonessential provisions.

In addition to the inclusion of SI units and the drafting of U.S. standards to permit their use easily in other countries, participation in international forums on standardization is necessary to promote them. The study indicates that currently the U.S. participates in less than 50 percent of the working groups which draft the proposals for IEC and ISO Recommendations. Even the current level of participation is primarily the result of a growing awareness during the past 10 years of the need for participation. In many instances, U.S. participation starts after the issuance of several recommendations which are not in accord with U.S. engineering practices. By this time, other recommendations have been drafted and well on their way to approval. It is only on recommendations issued some 3 or more years after participation begins that U.S. representatives can be effective in having U.S. practices considered. In view of the increasing rate at which IEC and ISO Recommendations are being issued, immediate steps need to be taken for U.S. participation in the other working groups if U.S. engineering practices are to be considered in drafting the IEC and ISO Recommendations still needed for international trade. Although only 10 percent of the necessary 15 to 20 thousand IEC and ISO Recommendations have been issued, it appears from current interest in international standardization that most of the remainder will be drafted during the next 10 years and issued within 15 years. Thus, the next 10 years are critical, and provide a last chance for U.S. participation to be effective.

The cost of full participation is substantial. Travel costs for delegates alone may be nearly two million dollars per year. The salaries of delegates and others for their time devoted to international standardization can not be easily estimated, but these costs may be 10 or more times the travel costs. In addition, consideration needs to be given to the administrative organization and cost for processing the increasing number of standards at both the domestic and international levels. The diversity of standards making activities may in some respects within the U.S. be desirable, but it is not conducive to effective U.S. representation in *international* forums. The organization representing the U.S. in IEC, ISO and other international standardizing activities would be more effective if it embraced the entire repertoire of standards and assured adequate representation of the interests of consumers, producers and government.

The current worldwide interest in international standardization and harmonization of national standards provides a unique opportunity to review traditional practices and develop rational standards based on latest knowledge and technology. The national standards of metric countries reflect different practices just as British and U.S. standards frequently reflect different practices. Therefore, the present period when international recommendations are being developed in IEC and ISO enables optimum standards to be developed which will reduce the number of sizes of standard parts and products, conserve materials by their more efficient use, and improve the quality of product. The study on optimum metric fasteners initiated by the Industrial Fasteners Institute (app. V) needs to be emulated in other industries. In the past, individual companies have revised their own standards to accomplish these objectives, but the difficulty in changing national standards for parts and products used throughout industry have prevented full benefits to be achieved. A principal objective of international standardization should be to develop from the experiences of all countries engineering standards that are superior to existing national standards and which will conserve the worlds resources. After international standards are established, there is not likely to be another opportunity for making changes of the magnitude required to achieve these goals.

As new practices and technologies are developed in the future, the need for standardization beyond the company level should be considered. Practices that require development of national standards generally require international standardization also. Therefore, development of such standards should proceed simultaneously at the national and international levels, to the extent that this would be practical to do. Failure to do so may result in national standards that are not in harmony and may establish practices that are prohibitive in cost to change.

In summary, this study shows that engineering standards can be harmonized internationally without the U.S. changing its measurement units. To achieve international standardization, all countries including the U.S. have to change many, if not most, of their engineering practices. The extent of change may be little or great, depending on the practice. The impact of change can be mimimized by full participation in the international forum. The measurement units in international standards are mixed at present, but eventually they will be the International System of Units. Those involved with the development or use of standards will have to be adept with these units. Other parts of the U.S. Metric Study are directed to the wider use of these units in the U.S.

Public Law 90-472

An Act

82 STAT. 693

To authorize the Secretary of Commerce to make a study to determine the advantages and disadvantages of increased use of the metric system in the United States.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the Secretary of Commerce is hereby authorized to conduct a program of investigation, research, and survey to determine the impact of increasing worldwide use of the metric system on the United States; to appraise the desirability and practicability of increasing the use of metric weights and measures in the United States; to study the feasibility of retaining and promoting by international use of dimensional and other engineering standards based on the customary measurement units of the United States; and to evaluate the costs and benefits of alternative courses of action which may be feasible for the United States. Metric system. Study.

Sec. 2. In carrying out the program described in the first section of this Act, the Secretary, among other things, shall— Investigation and appraisal requirements.

(1) investigate and appraise the advantages and disadvantages to the United States in international trade and commerce, and in military and other areas of international relations, of the increased use of an internationally standardized system of weights and measures;

(2) appraise economic and military advantages and disadvantages of the increased use of the metric system in the United States or of the increased use of such system in specific fields and the impact of such increased use upon those affected;

(3) conduct extensive comparative studies of the systems of weights and measures used in educational, engineering, manufacturing, commercial, public, and scientific areas, and the relative advantages and disadvantages, and degree of standardization of each in its respective field;

(4) investigate and appraise the possible practical difficulties which might be encountered in accomplishing the increased use of the metric system of weights and measures generally or in specific fields or areas in the United States;

(5) permit appropriate participation by representatives of United States industry, science, engineering, and labor, and their associations, in the planning and conduct of the program authorized by the first section of this Act, and in the evaluation of the information secured under such program; and

(6) consult and cooperate with other government agencies, Federal, State, and local, and, to the extent practicable, with foreign governments and international organizations.

Sec. 3. In conducting the studies and developing the recommendations required in this Act, the Secretary shall give full consideration to the advantages, disadvantages, and problems associated with possible changes in either the system of measurement units or the related dimensional and engineering standards currently used in the United States, and specifically shall— Results of changes in measurement system.

(1) investigate the extent to which substantial changes in the size, shape, and design of important industrial products would be necessary to realize the benefits which might result from general use of metric units of measurement in the United States;

(2) investigate the extent to which uniform and accepted engineering standards based on the metric system of measurement units are in use in each of the fields under study and compare the extent to such use and the utility and degree of sophistication of such metric standards with those in use in the United States; and

(3) recommend specific means of meeting the practical difficulties and costs in those areas of the economy where any recommended change in the system of measurement units and related dimensional and engineering standards would raise significant practical difficulties or entail significant costs of conversion.

Sec. 4. The Secretary shall submit to the Congress such interim reports as he deems desirable, and within three years after the date of the enactment of this Act, a full and complete report of the findings made under the program authorized by this Act, together with such recommendations as he considers to be appropriate and in the best interests of the United States. Report to Congress.

Sec. 5. From funds previously appropriated to the Department of Commerce, the Secretary is authorized to utilize such appropriated sums as are necessary, but not to exceed $500,000, to carry out the purposes of this Act for the first year of the program. Funds.

Sec. 6. This Act shall expire thirty days after the submission of the final report pursuant to section 3. Expiration date.

Approved August 9, 1968.

UDC 53.081 : 003.62 : 004.1

Ref. No. : ISO/R 1000-1969(E)

ISO

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

ISO RECOMMENDATION

R 1000

RULES FOR THE USE OF UNITS OF THE INTERNATIONAL SYSTEM OF UNITS AND A SELECTION OF THE DECIMAL MULTIPLES AND SUB-MULTIPLES OF THE SI UNITS

1st EDITION
February 1969

For each individual country the only valid standard is the national standard of that country.

Printed in Switzerland

Also issued in French and Russian. Copies to be obtained through the national standards organizations.

BRIEF HISTORY

The ISO Recommendation R 1000, *Rules for the use of units of the International System of Units and a selection of the decimal multiples and sub-multiples of the SI units*, was drawn up by Technical Committee ISO/TC 12, *Quantities, units, symbols, conversion factors and conversion tables*, the Secretariat of which is held by the Dansk Standardiseringsraad (DS).

Work on this question led, in 1967, to the adoption of a Draft ISO Recommendation.

In March 1968, this Draft ISO Recommendation (No. 1557) was circulated to all the ISO Member Bodies for enquiry. It was approved, subject to a few modifications of an editorial nature, by the following Member Bodies :

Australia	Hungary	Poland
Austria	India	Romania
Belgium	Iran	South Africa, Rep. of
Brazil	Iraq	Switzerland
Canada	Ireland	Thailand
Chile	Israel	Turkey
Czechoslovakia	Italy	U.A.R.
Denmark	Japan	United Kingdom
Finland	Korea, Dem. P. Rep. of	U.S.S.R.
France	Netherlands	
Germany	New Zealand	

Two Member Bodies opposed the approval of the Draft :

Norway
Sweden

Since the publication of this Draft was a particularly urgent matter, the ISO Council decided, at its 1967 meeting, that the document be published as an ISO RECOMMENDATION after its approval by the ISO Member Bodies.

ISO/R 1000-1969(E)

ISO Recommendation R 1000 February 1969

RULES FOR THE USE OF UNITS OF THE INTERNATIONAL SYSTEM OF UNITS AND A SELECTION OF THE DECIMAL MULTIPLES AND SUB-MULTIPLES OF THE SI UNITS

1. SCOPE

This ISO Recommendation gives rules for the use of units of the International System of Units and for forming and selecting decimal multiples and sub-multiples of the SI units for application in the various fields of technology.

2. GENERAL

2.1 The name Système International d'Unités (International System of Units), with the abbreviation SI, was adopted by the 11th Conférence Générale des Poids et Mesures in 1960.
The coherent units are designated "SI units".

2.2 The International System of Units is based on the following six base-units :

metre (m)	ampere (A)
kilogramme (kg)	kelvin (K)
second (s)	candela (cd)

as units for the base-quantities : length, mass, time, electric current, thermodynamic temperature, and luminous intensity.

2.3 The SI units for plane angle and solid angle, the radian (rad) and the steradian (sr) respectively, are called supplementary units in the International System of Units.

2.4 The expressions for the derived SI units are stated in terms of base-units; for example, the SI unit for velocity is metre per second (m/s).

For some of the derived SI units special names and symbols exist; those approved by the Conférence Générale des Poids et Mesures are listed below :

Quantity	Name of SI unit	Symbol	Expressed in terms of basic or derived SI units
frequency	hertz	Hz	$1\ Hz = 1\ s^{-1}$
force	newton	N	$1\ N = 1\ kg{\cdot}m/s^2$
work, energy, quantity of heat	joule	J	1 J = 1 N·m
power	watt	W	1 W = 1 J/s
quantity of electricity	coulomb	C	1 C = 1 A·s
electric potential, potential difference, tension, electromotive force	volt	V	1 V = 1 W/A
electric capacitance	farad	F	1 F = 1 A·s/V
electric resistance	ohm	Ω	1 Ω = 1 V/A
flux of magnetic induction, magnetic flux	weber	Wb	1 Wb = 1 V·s
magnetic flux density, magnetic induction	tesla	T	$1\ T = 1\ Wb/m^2$
inductance	henry	H	1 H = 1 V·s/A
luminous flux	lumen	lm	1 lm = 1 cd·sr
illumination	lux	lx	$1\ lx = 1\ lm/m^2$

It may sometimes be advantageous to express derived units in terms of other derived units having special names; for example, the SI unit of electric dipole moment (A·s·m) is usually expressed as C·m.

2.5 Decimal multiples and sub-multiples of the SI units are formed by means of the prefixes given below

Factor by which the unit is multiplied	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deca	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

The symbol of a prefix is considered to be combined with the unit symbol to which it is directly attached, forming with it a new unit symbol which can be raised to a positive or negative power and which can be combined with other unit symbols to form symbols for compound units.

Examples $1\ \text{cm}^3 = (10^{-2}\text{m})^3 = 10^{-6}\text{m}^3$

$1\ \mu\text{s}^{-1} = (10^{-6}\text{s})^{-1} = 10^{6}\text{s}^{-1}$

$1\ \text{mm}^2/\text{s} = (10^{-3}\text{m})^2/\text{s} = 10^{-6}\text{m}^2/\text{s}$

Compound prefixes should not be used; for example, write nm (nanometre) instead of mμm.

3. RULES FOR THE USE OF SI UNITS AND THEIR DECIMAL MULTIPLES AND SUB-MULTIPLES

3.1 The SI units are *preferred*, but it will not be practical to limit usage to these; in addition, therefore, their decimal multiples and sub-multiples, formed by using the prefixes, are required.

In order to avoid errors in calculations it is essential to use coherent units. Therefore, it is strongly recommended that in calculations only SI units themselves be used, and not their decimal multiples and sub-multiples.

3.2 The use of prefixes representing 10 raised to a power which is a multiple of 3 is especially recommended.

NOTE. – In certain cases, to ensure convenience in the use of the units, this recommendation cannot be followed; column 5 of the tables in the Annex gives examples of these exceptions.

3.3 It is recommended that only one prefix be used in forming the decimal multiples or sub-multiples of a derived SI unit, and that this prefix be attached to a unit in the numerator.

NOTE. – In certain cases convenience in the use requires attachment of a prefix to both the numerator and the denominator at the same time, and sometimes only to the denominator. Column 5 of the tables in the Annex gives examples of these exceptions.

4. NUMERICAL VALUES

4.1 When expressing a quantity by a numerical value and a certain unit it has been found suitable in most applications to use units resulting in numerical values between 0.1 and 1000.

The units which are decimal multiples and sub-multiples of the SI units should therefore be chosen to provide values in this range; for example,

observed or calculated values	can be expressed as
12 000 N	12 kN
0.003 94 m	3.94 mm
14 010 N/m^2	14.01 kN/m^2
0.0003 s	0.3 ms

4.2 The rule according to clause 4.1 cannot, however, be consistently applied. In one and the same context the numerical values expressed in a certain unit can extend over a considerable range; this applies especially to tabulated numerical values. In such cases it is often appropriate to use the same unit, even when this means exceeding the preferred value range 0.1 to 1000.

4.3 Rules for writing symbols for units are given in ISO Recommendation R 31, Part . . . * : *General principles concerning quantities, units and symbols.*

5. LIST OF UNITS

For a number of commonly used quantities, examples of decimal multiples and sub-multiples of SI units, as well as of some other units which may be used, are given in the Annex to this document.

* At present at the stage of draft proposal.

ANNEX

List of SI units and a selection of recommended decimal multiples and sub-multiples of the SI units together with other units or other names of units which may be used

Item No. in ISO/R 31	Quantity	SI unit	Selection of recommended decimal multiples and sub-multiples of SI unit	Other decimal multiples and sub-multiples of SI unit	Other units or other names of units which may be used	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
PART 1 : SPACE AND TIME						
1-1.1	plane angle	rad (radian)	mrad μrad		degree (...°), $1° = \frac{\pi}{180}$ rad minute (...'), $1' = \frac{1°}{60}$ second (...''), $1'' = \frac{1'}{60}$ grade (...^{g}), $1^g = \frac{\pi}{200}$ rad	The units degree and grade, with their decimal subdivisions, are recommended for use when the unit radian is not suitable.
1-2.1	solid angle	sr (steradian)				
1-3.1...7	length	m (metre)	km mm μm nm	dm cm		1 nautical mile = 1852 m
1-4.1	area	m^2	km^2 mm^2	dm^2 cm^2	hectare (ha), 1 ha = 10^4 m^2 are (a), 1a = 10^2 m^2	

(1)	(2)	(3)	(4)	(5)	(6)	(7)
1-5.1	volume	m^3	mm^3	dm^3 cm^3	hectolitre (hl), 1 hl $= 10^{-1}$ m^3 litre (l), 1 l $= 10^{-3}$ m^3 $= 1$ dm^3 centilitre (cl), 1 cl $= 10^{-5}$ m^3 millilitre (ml), 1 ml $= 10^{-6}$ m^3 $= 1$ cm^3	In 1964 the Conférence Générale des Poids et Mesures adopted the name litre (l) as the synonym for cubic decimetre (dm^3) but discouraged the use of the name litre for precision measurements.
1-6.1	time	s (second)	ks ms μs ns		day (d), 1 d = 24 h hour (h), 1 h = 60 min minute (min), 1 min = 60 s	Other units such as week, month and year (a) are in common use.
1-8.1	angular velocity	rad/s				
1-10.1	velocity	m/s			kilometre per hour (km/h) 1 km/h $= \frac{1}{3.6}$ m/s	1 knot = 0.514 444 m/s
PART II : PERIODIC AND RELATED PHENOMENA						
2-3.1	frequency	Hz (hertz)	THz GHz MHz kHz			
2-3.2	rotational frequency	s^{-1}			revolution per minute revolution per second	

Item No. in ISO/R 31	Quantity	SI unit	Selection of recommended decimal multiples and sub-multiples of SI unit	Other decimal multiples and sub-multiples of SI unit	Other units or other names of units which may be used	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
PART III : MECHANICS						
3-1.1	mass	kg (kilogramme)	Mg g mg μg		tonne (t), 1 t = 10^3 kg	The metric carat (1 metric carat = 2 × 10^{-4} kg) is used for commercial transactions in diamonds, fine pearls and precious stones.
3-2.1	density (mass density)	kg/m^3	Mg/m^3	1 kg/dm^3 = 1 g/cm^3	1 t/m^3 = 1 kg/l = 1 g/ml g/l	For litre (l) see item 1-5.1.
3-5.1	momentum	kg·m/s				
3-6.1	moment of momentum, angular momentum	$kg{\cdot}m^2/s$				
3-7.1	moment of inertia	$kg{\cdot}m^2$				
3-8.1 3-8.2	force and weight	N (newton)	MN kN mN μN	daN		

(1)	(2)	(3)	(4)	(5)	(6)	(7)
3-10.1	moment of force	N·m	MN·m kN·m μN·m	daN·m		
3-11.1 3-11.2	pressure and stress	N/m^2	GN/m^2 MN/m^2 kN/m^2 mN/m^2 $\mu N/m^2$	daN/mm^2 N/mm^2 N/cm^2	1 hbar = 10^7 N/m^2 1 bar = 10^5 N/m^2 1 mbar = 10^2 N/m^2 1 μbar = 10^{-1} N/m^2	The hectobar (hbar) is used in certain fields in some countries. The name "pascal" is given to the newton per square metre in a certain number of countries.
3-19.1	viscosity (dynamic)	$N{\cdot}s/m^2$	$mN{\cdot}s/m^2$		centipoise (cP) 1 cP = 10^{-3} $N{\cdot}s/m^2$	
3-20.1	kinematic viscosity	m^2/s	mm^2/s		centistokes (cSt) 1 cSt = 10^{-6} m^2/s	
3-21.1	surface tension	N/m	mN/m			
3-22.1	energy, work	J (joule)	GJ MJ kJ mJ		kilowatt hour (kWh) 1 kWh = 3.6 × 10^6 J = 3.6 MJ electronvolt (eV) 1 eV = (1.602 10 ± 0.000 07) × 10^{-19} J	The units Wh, kWh, MWh, GWh and TWh are used in the electrical industry. The units keV, MeV and GeV are used in accelerator technology.
3-23.1	power	W (watt)	GW MW kW mW μW			

Item No. in ISO/R 31	Quantity	SI unit	Selection of recommended decimal multiples and sub-multiples of SI unit	Other decimal multiples and sub-multiples of SI unit	Other units or other names of units which may be used	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	impact strength	J/m²	kJ/m²	daJ/cm² J/cm²		
PART IV : HEAT						
4-1.1	thermodynamic temperature	K (kelvin)				
4-2.1	Celsius temperature				degree Celsius (°C)	
4-1.1 4.2.1	temperature interval	K			°C	1 °C = 1 K
4-3.1	linear expansion coefficient	K^{-1}			$°C^{-1}$	
4-4.1	heat, quantity of heat	J	TJ GJ MJ kJ mJ			
4-5.1	heat flow rate	W	kW			
4-6.1	density of heat flow rate	W/m²	MW/m² kW/m²			

(1)	(2)	(3)	(4)	(5)	(6)	(7)
4-7.1	thermal conductivity	W/(m·K)			W/(m·°C)	
4-8.1	coefficient of heat transfer	$W/(m^2 \cdot K)$			$W/(m^2 \cdot °C)$	
4-10.1	heat capacity	J/K	kJ/K		kJ/°C J/°C	
4-11.1	specific heat capacity	J/(kg·K)	kJ/(kg·K)		kJ/(kg·°C) J/(kg·°C)	
4-13.1	entropy	J/K	kJ/K			
4-14.1	specific entropy	J/(kg·K)	kJ/(kg·K)			
4-16.1	specific energy	J/kg	MJ/kg kJ/kg			
4-18.1	specific latent heat	J/kg	MJ/kg kJ/kg			

Item No. in ISO/R 31	Quantity	SI unit	Selection of recommended decimal multiples and sub-multiples of SI unit	Other decimal multiples and sub-multiples of SI unit	Other units or other names of units which may be used	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
PART V : ELECTRICITY AND MAGNETISM *) **)						
5-1.1	electric current (intensity of electric current)	A (ampere)	kA mA μA nA pA			
5-2.1	electric charge quantity of electricity	C (coulomb)	kC μC nC pC			
5-3.1	volume density of charge, charge density	C/m^3	MC/m^3 kC/m^3	C/mm^3 C/cm^3		
5-4.1	surface density of charge	C/m^2	MC/m^2 kC/m^2	C/mm^2 C/cm^2		
5-5.1	electric field strength	V/m	MV/m kV/m mV/m μV/m	V/mm V/cm		

* In electricity and magnetism the SI units assume the rationalized form of the equations between the quantities. See ISO/R 31, Part V.

** The IEC has not considered the rules given in this Recommendation, nor the arrangement and the content of the list. In order to give guidance to ISO, IEC/TC 24 has made a list of multiples and sub-multiples used here, but without division into columns.

(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-6.1 5-6.2 5-6.3	electric potential and potential difference, tension and electromotive force	V (volt)	MV kV mV μV			
5-7.1	displacement	C/m^2	kC/m^2	C/cm^2		
5-9.1	electric flux, flux of displacement	C	MC kC mC			
5-11.1	capacitance	F (farad)	mF μF nF pF			
5-12.1	permittivity	F/m	μF/m nF/m pF/m			
5-17.2	electric polarization	C/m^2	MC/m^2 kC/m^2	C/cm^2		
5-18.1	electric dipole moment	C·m				

Item No. in ISO/R 31	Quantity	SI unit	Selection of recommended decimal multiples and sub-multiples of SI unit	Other decimal multiples and sub-multiples of SI unit	Other units or other names of units which may be used	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-19.1	current density	A/m²	MA/m² kA/m²	A/mm² A/cm²		
5-20.1	linear current density	A/m	kA/m	A/mm A/cm		
5-21.1	magnetic field strength	A/m	kA/m	A/mm A/cm		
5-23.1	magnetic potential difference	A	kA mA			
5-24.1	magnetic flux density, magnetic induction	T (tesla)	mT μT nT			
5-25.1	flux of magnetic induction, magnetic flux	Wb (weber)	mWb			
5-26.1	magnetic vector potential	Wb/m	kWb/m	Wb/mm		

(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-27.1 5-27.2	self inductance and mutual inductance	H (henry)	mH μH nH pH			
5-29.1	permeability	H/m	μH/m nH/m			
5-34.1	electromagnetic moment, magnetic moment	$A \cdot m^2$				
5-35.1	magnetization	A/m	kA/m	A/mm		
5-36.1	magnetic polarization	T	mT			
–	magnetic dipole moment	$N \cdot m^2/A$ Wb·m				
5-41.1	resistance	Ω (ohm)	GΩ MΩ kΩ mΩ μΩ			
5-42.1	conductance	Ω^{-1}			kS S (siemens) mS μS	$1\ S = 1\Omega^{-1}$ The name "siemens" and the symbol "S" are adopted by IEC and ISO, but not so far by CGPM.

ISO/R 1000-1969 (F)
ANNEX

Item No. in ISO/R 31	Quantity	SI unit	Selection of recommended decimal multiples and sub-multiples of SI unit	Other decimal multiples and sub-multiples of SI unit	Other units or other names of units which may be used	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-43.1	resistivity	Ω·m	GΩ·m MΩ·m kΩ·m mΩ·m μΩ·m nΩ·m	Ω·cm		$\mu\Omega\cdot cm = 10^{-8}\,\Omega\cdot m$ $\frac{\Omega\cdot mm^2}{m} = 10^{-6}\,\Omega\cdot m = \mu\Omega\cdot m$ are also used.
5-44.1	conductivity	1/(Ω·m)			MS/m kS/m S/m	
5-45.1	reluctance	H^{-1}				
5-46.1	permeance	H				
5-49.1 5-49.2 5-49.3	impedance and modulus of impedance and reactance	Ω	MΩ kΩ mΩ			
5-51.1 5-51.2 5-51.3 5-51.4	admittance and modulus of admittance and susceptance and conductance	Ω^{-1}			kS S mS μS	

(1)	(2)	(3)	(4)	(5)	(6)	(7)
5-52.1	active power	W	TW GW MW kW mW μW nW			
5-53.1	apparent power	VA				See also ISO/R 31, Part V.
5-54.1	reactive power				var	See also ISO/R 31, Part V.
PART VIII : PHYSICAL CHEMISTRY AND MOLECULAR PHYSICS*						
8-3.1	amount of substance				mol** kmol	
8-5.1	molar mass				kg/mol g/mol	
8-6.1	molar volume				m^3/mol 1 m^3/kmol = 1 l/mol	For litre (l) see item 1-5.1.
8-7.1	molar internal energy				J/mol J/kmol	
8-8.1	molar heat capacity				J/(mol·K); J/(mol·°C) J/(kmol·K); J(kmol·°C)	

* At present Draft ISO Recommendation No. 1777.

** In physical chemistry and molecular physics, the introduction of the additional unit the mole (mol), corresponding to the quantity "amount of substance", is recommended by IUPAP, IUPAC and ISO/TC 12. In this document the mole is not listed in column 3 (SI unit) because it has not so far been approved by the CGPM.

1 mol is an amount of substance of a system which contains as many elementary units as there are carbon atoms in 0.012 kg (exactly) of ^{12}C. The elementary unit must be specified and may be an atom, a molecule, an ion, an electron, etc., or a specified group of such particles.

ISO/R 1000-1969 (E)
ANNEX

Item No. in ISO/R 31	Quantity	SI unit	Selection of recommended decimal multiples and sub-multiples of SI unit	Other decimal multiples and sub-multiples of SI unit	Other units or other names of units which may be used	Remarks
(1)	(2)	(3)	(4)	(5)	(6)	(7)
8-9.1	molar entropy				J/(mol·K)	
8-13.1	molarity				mol/m^3 kmol/l 1 kmol/m^3 = 1 mol/l = 1 mol/dm^3	For litre (l) see item 1-5.1.
8-15.1	molality				mol/kg kmol/kg	
8-36.1	diffusion coefficient	m^2/s				
8-38.1	thermal diffusion coefficient	m^2/s				

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METRIC PRACTICE GUIDE

(A Guide to the Use of SI — the International System of Units)

ASTM Designation: E 380 - 70

AMERICAN SOCIETY FOR TESTING AND MATERIALS

1916 Race St., Philadelphia, Pa., 19103

Prepared by Committee on Metric Practice:

A. G. Cook, Chairman
Coordinator of Product Specifications, Allegheny Ludlum Steel Corp.

R. P. Lukens, Secretary
Standards Editor, ASTM

R. B. Belford
Technical Director, Industrial Fasteners Institute

R. P. Destito
Manager, Specifications & Standards Section, Revere Copper & Brass Inc.

K. C. Ford
Professional Engineer, Canadian Standardization Association Testing Laboratories

J. D. Graham
Manager, Engineering Research, International Harvester Co.

R. R. Heldenfels
Chief, Structures Research Div., Langley Research Center, National Aeronautics and Space Administration

A. A. Jones
Chief Engineer — Administrative, Anaconda Wire and Cable Co.

A. F. Jones
Chief, Research and Engineering Support Div., Army Materials and Mechanics Research Center

J. A. Liska
Chief, Division of Wood Engineering Research, U. S. Forest Products Laboratory

Bryant Mather
Chief, Concrete Div., U. S. Army Engineers, Waterways Experiment Station

A. G. McNish
National Bureau of Standards Manager, Metric Study Program, Office of Invention and Innovation

R. D. Stiehler (alternate to Mr. McNish)
National Bureau of Standards Manager, Standards Survey, U. S. Metric Study

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AMERICAN SOCIETY FOR TESTING AND MATERIALS

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Standard
METRIC PRACTICE GUIDE*
(A Guide to the Use of SI — the International System of Units)

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Foreword

To continue to serve the best interests of the public through science and industry the American Society for Testing and Materials is actively cooperating with other standardization organizations in the development of simpler and more universal metrology practices. In some industries both here and abroad, the U.S. customary units are gradually being replaced by those of a modernized metric[1] system known as the International System of Units (SI). Recognizing this trend, the Society considers it important to prepare for broader use of SI units through coexistence of these two major systems. This policy involves no change in standard dimensions, tolerances, or performance specifications.

Contents

* This guide is under the jurisdiction of the ASTM Committee on Metric Practice. A list of members may be found in the ASTM Yearbook.

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[1] An Act of Congress in 1866 declared that "it shall be lawful throughout the United States of America to employ the weights and measures of the metric system." In 1893 an Executive Order directed that "the office of weights and measures . . . will in the future regard the international prototype meter and kilogram as fundamental standards, and the customary units, the yard and the pound, will be derived therefrom in accordance with the act of July 28, 1866."

E 380

1. Scope

1.1 This Metric Practice Guide deals with the conversion, from one system of units to another, of quantities that are in general use, and includes the units most frequently used in the various fields of science and industry. The conversion factors given are from U.S. customary units[2] to those of the International System of Units[3] which is officially abbreviated as SI in all languages.

1.2 The recommendations contained herein[4] are based upon the following premises, which are believed to represent the broadest base for general agreement among proponents of the major metrology systems:

1.2.1 That for most scientific and technical work the International System of Units is generally superior to other systems; and that this system is more widely accepted than any other as the common language in which scientific and technical data should be expressed. This is particularly true for the fields of electrical science and technology since the common electrical units (ampere, volt, ohm, etc.) are SI units.

1.2.2 That various U.S. customary units, particularly the inch and the pound, will continue to be used for some time.

1.2.3 That unit usage can and should be simplified; that one means toward such simplification is the elimination of obsolete and unneeded units; and that another is a better understanding of the rational links between SI units and units of other systems.

2. SI Units and Symbols

2.1 The SI system consists of six base units, two supplementary units, a series of derived units consistent with the base and supplementary units, and a series of approved prefixes for the formation of multiples and submultiples of the various units.

2.1.1 *Base Units:*[5]

Quantity	Unit	SI Symbol	Formula
length	meter	m	...
mass	kilogram	kg	...
time	second	s	...
electric current	ampere	A	...
thermodynamic temperature	kelvin	K	...
luminous intensity	candela	cd	...

2.1.2 *Supplementary Units:*[5]

plane angle	radian	rad	
solid angle	steradian	sr	

2.1.3 *Derived Units:*[6]

acceleration	meter per second squared	...	m/s^2
activity (of a radioactive source)	disintegration per second	...	(disintegration/s)
angular acceleration	radian per second squared	...	rad/s^2
angular velocity	radian per second	...	rad/s
area	square meter	...	m^2
density	kilogram per cubic meter	...	kg/m^3
electric capacitance	farad	F	A · s/V
electric field strength	volt per meter	...	V/m
electric inductance	henry	H	V · s/A
electric potential difference	volt	V	W/A
electric resistance	ohm	Ω	V/A

[2] This and other terms are defined in Appendix A1.
[3] The International System of Units (Système International d'Unités) (SI) is described in Appendix A2.
[4] This section is adapted from IEEE Recommended Practice for Units in Published Scientific and Technical Work, IEEE Spectrum, March 1966, pp. 169–173.
[5] The six base and two supplementary units are defined in Appendix A2. In chemistry a further base unit has been considered necessary. The use of the mole (symbol-mol) for this purpose corresponding to the base quantity "amount of substance," is recommended by the ISO.
[6] These units will be used in the International System of Units (SI) without prejudice to other units that may be added in the future.
The Advisory Committee on Units of the International Committee of Weights and Measures has recommended the pascal (Pa) as the name for the unit of pressure or stress instead of the newton per square meter; thus the unit for viscosity becomes the pascal-second. The Committee also recommended the name siemens (S) as the name for the unit of electrical conductance instead of the reciprocal ohm or the ampere per volt.

422-764 OL - 71 - 11

E 380

Quantity	Unit	SI Symbol	Formula
electromotive force	volt	V	W/A
energy	joule	J	N · m
entropy	joule per kelvin	...	J/K
force	newton	N	$kg \cdot m/s^2$
frequency	hertz	Hz	(cycle)/s
illumination	lux	lx	lm/m^2
luminance	candela per square meter	...	cd/m^2
luminous flux	lumen	lm	cd · sr
magnetic field strength	ampere per meter	...	A/m
magnetic flux	weber	Wb	V · s
magnetic flux density	tesla	T	Wb/m^2
magnetomotive force	ampere	A	...
power	watt	W	J/s
pressure[6]	newton per square meter	...	N/m^2
quantity of electricity	coulomb	C	A · s
quantity of heat	joule	J	N · m
radiant intensity	watt per steradian	...	W/sr
specific heat	joule per kilogram-kelvin	...	J/kg · K
stress[6]	newton per square meter	...	N/m^2
thermal conductivity	watt per meter-kelvin	...	W/m · K
velocity	meter per second	...	m/s
viscosity, dynamic	newton-second per square meter	...	$N \cdot s/m^2$
viscosity, kinematic	square meter per second	...	m^2/s
voltage	volt	V	W/A
volume[7]	cubic meter	...	m^3
wavenumber	reciprocal meter	...	(wave)/m
work	joule	J	N · m

2.1.4 *Multiple and Submultiple Units* (*see 3.2*):

Multiplication Factors	Prefix	SI Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
100 = 10^{2}	hecto*	h
10 = 10^{1}	deka*	da
0.1 = 10^{-1}	deci*	d
0.01 = 10^{-2}	centi*	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

* Not recommended but occasionally used.

3. Rules for SI Style and Usage

3.1 *General*—The established SI units—base, supplementary, derived, and combinations thereof (see Section 2, SI Units and Symbols) with appropriate multiple or submultiple prefixes—should be used. To maintain the coherence of the system, multiples or submultiples of SI units should not be used in combinations to form derived units or in equations.

3.1.1 *Mixed Units*—The use of mixed units, especially those compounded from different systems, should be avoided. For example,

use kilogram per cubic meter (kg/m^3), not kilogram per gallon (kg/gal),

use 0.1789 rad or 10.25 deg, not 10 deg 15 min, and

use 12.75 lbm, not 12 lb 12 oz.

3.2 *Application of Prefixes:*

3.2.1 *General*—Approved prefixes (2.1.4)

[7] In 1964 the General Conference on Weights and Measures adopted the name liter as a special name for the cubic decimeter but discouraged the use of the name liter for volume measurement of extreme precision.

should be used to indicate orders of magnitude, thus eliminating insignificant digits and decimals, and providing a convenient substitute for writing powers of 10 as generally preferred in computation. For example,

12 300 m or 12.3 × 10^{3} m becomes 12.3 km, and

0.0123 μA or 12.3 × 10^{-9} A becomes 12.3 nA.

3.2.2 *Selection*—Multiple and submultiple prefixes representing steps of 1000 are recommended. For example, show force in mN, N, kN, and length in mm, m, km, etc. The use of centimeters should be avoided unless a strong reason exists. An exception is made in the case of area and volume used alone (see 3.2.5).

3.2.3 Double prefixes and hyphenated prefixes should not be used. For example,

use GW (gigawatt), not kMW, and
use pF (picofarad), not μμF.

3.2.4 *Combination Units*—Prefixes should not be used in the denominator of compound units, except for the kilogram (kg). Since the kilogram is a base unit of SI, this particular multiple is not a violation and should be used in place of the gram; for example, use 200 J/kg, not 2 dJ/g. Prefixes may be applied to the numerator of a combination unit, thus, meganewton per square meter (MN/m^2) or for greater clarity, mega(newton per square meter), but *not* newton per square centimer (N/cm^2) *nor* newton per square millimeter (N/mm^2).

3.2.5 With SI units of higher order such as m^2 and m^3, the prefix is also raised to the same order; for example, mm^3 is $10^{-9}m^3$ not $10^{-3}m^3$. In such cases, the use of cm^2, cm^3, dm^2, dm^3, and similar non-preferred prefixes is permissible.

3.3 *Non-SI Units*—Certain metric units that are not SI (such as kilogram-force) have been widely used in engineering practice. Consequently, certain deviations from SI may be used during a transition period, but should definitely be discouraged. These deviations are discussed below.

3.4 *Usage for Selected Quantities:*

3.4.1 *Mass, Force, and Weight:*

3.4.1.1 The principal departure of SI from the more familiar form of metric engineering units is the use of the newton as the unit of force instead of the kilogram-force. Likewise, the newton instead of kilogram-force is used in combination units including force; for example, pressure or stress (N/m^2), energy (N · m = J), and power (N · m/s = W).

3.4.1.2 The term "mass" (unit = kilogram) is used to specify the quantity of matter contained in material objects and is independent of their location in the universe. The term "weight" (unit = newton) is used as a measure of gravitational force acting on a material object at a specified location and generally varies as the object changes location (see Fig. 1). Although a constant mass has an approximately constant weight on the surface of the earth, the pound-force and the kilogram-force are, to high accuracy, not the forces exerted by the earth's gravitation on a pound-mass or a kilogram-mass in locations that depart significantly from mean sea level. The gravitational force varies by about 0.5 percent over the Earth's surface. Therefore, the variation of gravity must be taken into account when greater accuracy is required. For convenience, the precise expression of forces on a gravitational basis is related to the International standard gravity value ("standard acceleration") 9.80665 m/s^2. For example: a man of 72.5 kg mass in Washington, D.C., which is near sea level, would weigh, at standard gravity, 72.5 kg × 9.806 65 m/s^2 or 711 N, whereas the same man at an elevation such as that of Denver, Colorado, would weigh only 72.5 kg × 9.796 12 m/s^2 or 710 N.

3.4.1.3 The term *mass* or *unit mass* should be used to indicate the quantity of matter in an object, and the previous practice of using weight in such cases should be avoided. The term *weight* should be used only when specification of the gravitational forces requires it, and then it should be accompanied by a statement specifying the location and gravitational acceleration at that point.

3.4.1.4 If non-SI units are used for force and mass, a distinction should be made between (*1*) force or load and (*2*) mass, both of which have traditionally been termed weight. For force or load, gf, kgf, or lbf should be used; for mass, g, kg, lbm (preferred), or lb.

3.4.1.5 Certain physical quantities involving force and mass units may cause confusion due to the use of the same name for the units of both quantities. The newton was introduced as a unit of force to avoid this confusion, and

E 380

such problems are avoided if force and mass units are identified and converted accordingly. For example, the combination unit foot-pound-force per pound-mass used to measure efficiency could be considered (erroneously) to have the dimension of feet and might be converted to meters; however, considering the definition of the units, it should be converted to newton-meters per kilogram (N · m/kg) or joules per kilogram (J/kg) in SI units. In many cases, the relationship between newtons, seconds, and kilograms given by the first law of motion ($F = ma$) should be used to simplify units (that is, the newton is equal to a kilogram-meter per second per second, N = kg · m/s^2).

3.4.2 *Length:*

3.4.2.1 Nominal dimensions name the item; no SI equivalent is required (see Appendix A1 for definition of "nominal"). For example, there is nothing 1 in. about a nominal "1-in. pipe," the dimensions of which should be converted as follows:

Nominal Size, in.	Outside Diameter, in. (mm)	Wall Thickness, in. (mm)		
		Sch 40	Sch 80	Sch 160
1	1.315 (33.40)	0.133 (3.38)	0.179 (4.55)	0.250 (6.35)

Likewise, a "2 by 4" is that in name only and refers to the approximate dimensions in inches of a rough-sawn, green piece of timber, the finished dimensions of which are considerably less. A $^1/_4$-20 NC screw thread should continue to be identified in this manner. However, the controlling dimensions of the part, such as the pitch, major, and minor diameters of a screw thread, should be converted to SI values in accordance with 3.1 and 3.2. Threads per inch should be converted to millimeter pitch.

3.4.2.2 When a dimension such as wire diameter or thickness of sheet and strip is expressed by a gage number, the appropriate gage system (for example, American Wire Gage or Awg) and the corresponding SI value should be given.

3.4.2.3 Surface finish expressed in microinch should be converted to nanometer (nm).

3.4.3 *Temperature*—The SI temperature scale is the International Thermodynamic Temperature Scale, and the SI unit used is the kelvin; therefore kelvins should be used to express temperature and temperature intervals as the preferred unit. However, wide use is made of the degree Celsius, particularly in engineering and in non-scientific areas, and it will be permissible to use the Celsius scale where considered necessary. The Celsius scale (formerly called the centigrade scale) is related directly to the kelvin scale as follows:

One degree Celsius equals one kelvin, exactly.

A Celsius temperature (t) is related to a kelvin temperature (T) as follows:

$$T = 273.15 + t, \text{ exactly}$$

In using temperature information of extreme precision, the International Practical Temperature Scale must be recognized, because much available data are based upon it. This consists of international agreement on certain fixed points to permit calibration of instruments. Some of these fixed points are known to contain errors, but the differences between the Thermodynamic and the Practical scales are of no consequence in almost all temperature considerations. The basis of the practical scale is given in Footnote 13.

3.4.4 *Time*—The preferred SI unit for time rates or total time is the second. However, because of practical advantages in the use of hours, minutes, and days, etc. for certain purposes, these units are permissible.

3.4.5 *Angles*—The radian is the preferred SI unit. Decimal multiples of the radian or degree are preferred; however, the arc degree, arc minute, and arc second may be used for the measurement of plane angles. Solid angles should be measured in steradians.

3.4.6 *Stress and Pressure*—The correct unit for pressure and stress is the newton per square meter. Prior to the adoption of SI, the units kilogram-force per square centimeter or kilogram-force per square millimeter were commonly used in engineering in metric countries. These units may be used in addition to, but not in place of, N/m^2 as an interim procedure in order to maintain communication with engineering groups in metric countries during their transition to SI units. Where the kilogram is used as a unit of force, it shall be so designated (kgf) to distinguish it clearly from the unit of mass (kg).

3.4.7 *Other Quantities*—Other units that have been widely used in engineering may continue to be used in addition to, but not in place of, the SI units. Such units include the horsepower to measure mechanical power and the torr to measure air pressure. These exceptions are interim procedures during the transition to SI units and are not intended to be permanent protection for irregular practices. Such practices should be eliminated as rapidly as possible.

3.5 *Style:*

3.5.1 *Capitalization*—Symbols for SI units are not capitalized unless the unit is derived from a proper name; thus, Hz for H. R. Hertz, but m for meter. Unabbreviated units are not capitalized, for example, hertz, newton, and kelvin. Numerical prefixes and their symbols are not capitalized, except for the symbols T, G, and M (mega) (see 2.1.4).

3.5.2 *Plurals*—Unabbreviated SI units form their plurals in the usual manner. SI symbols are always written in singular form. For example,

50 newtons or 50 N, and
25 grams or 25 g.

3.5.3 *Punctuation*—Periods should not be used after SI unit symbols except at the end of a sentence.

3.5.4 *Number Grouping*—To facilitate the reading of numbers having four or more digits, the digits should be placed in groups of three separated by a space instead of commas counting both to the left and to the right of the decimal point. In the case of four digits the spacing is optional. This style also voids confusion caused by the European use of commas to express decimal points. For example, use

1 532 or 1532 instead of 1,532
132 541 816 instead of 132,541,816
983 769.816 78 instead of 983,769.81678

3.5.5 *Equations*—When U.S. customary units appear in equations, the SI equivalents should be omitted. Instead of inserting the SI equivalents in parentheses as in the case of text or small tables, the equations should be restated using SI quantities or a sentence, paragraph, or note added stating the factor to be used to convert the calculated result in U.S. units to the preferred SI units.

3.5.6 *Derived Units*—In derived unit abbreviations use the center dot to indicate multiplication and a slash to indicate division. Symbols to the left of the slash are in the numerator and those to the right in the denominator.

4. Rules for Conversion and Rounding

4.1 *General:*

4.1.1 Unit conversions should be handled with careful regard to the implied correspondence between the accuracy of the data and the given number of digits.

4.1.2 In all conversions, the number of significant digits retained should be such that accuracy is neither sacrificed nor exaggerated.

4.1.3 The most accurate equivalents are obtained by multiplying the specified quantity by the conversion factor exactly as given in Appendix A3 and then rounding in accordance with 4.2 to the appropriate number of significant digits (see 4.3). For example, to convert 11.4 ft to meters: $11.4 \times 0.3048 = 3.474\ 72$, which rounds to 3.47 m (see 4.3.6).

4.1.4 There is less assurance of accuracy when the equivalent is obtained by first rounding the conversion factor to the same number of significant digits as in the specified quantity, performing the multiplication, and then rounding the product in accordance with 4.3. This procedure may provide approximate values but it is not recommended for tolerances or limiting values. For example, again converting 11.4 ft to meters: $11.4 \times 0.305 = 3.4770$ which rounds to 3.48 m (see 4.3.6). This compares with the value of 3.47 m obtained by the more exact method of 4.1.3.

4.1.5 Unless greater accuracy is justifiable, the equivalents should be rounded in accordance with the applicable values in Table 1.

4.1.6 Converted values should be rounded to the minimum number of significant digits that will maintain the required accuracy, as discussed above. In certain cases slight deviation from this practice to make use of convenient or whole numbers may be feasible, in which case the word "approximate" must be used following the conversion. For example,

1 $^7/_8$ in.	= 47.625 mm	exact
	= 47.6 mm	normal rounding

= 48 mm (approx)	rounded to whole number
= 47.5 mm (approx)	rounded to preferred number

Other examples:

Determine the breaking load of a specimen 20 in. (approx 500 mm) long.
Take individual specimens about 1 yd (1 m) long.
Cut a speciman approximately 4 by 6 in. (100 by 150 mm).

4.1.6.1 A quantity stated as "not more than" is not "nominal." For example, a specimen *at least* 4 in. wide requires a width of at least 101.6 mm.

4.1.7 The practical aspects of measuring must be considered when using SI equivalents. If a scale divided into $^1/_{16}$ths of an inch is suitable for making the original measurements, a metric scale having divisions of 1 mm is obviously suitable for measuring the length and width in SI units, and the equivalents should not be reported closer than the nearest millimeter. Similarly, a gage or caliper graduated in divisions of 0.02 mm is comparable to one graduated in divisions of 0.001 in., and equivalents should be similarly indicated. Analogous situations exist in mass, force, and other measurements.

4.1.8 Where dimensional interchangeability is involved, the methods described in 4.4.2 should be employed. Selection of Method A or Method B will depend upon the functional interchangeability required and on the relationship of the limits in the original dimensioning system to the limits of mating or related parts.

4.1.9 Appendix A3 contains conversion factors that give exact (as defined in terms of the base units) or five-figure (or better) accuracy for implementing these rules.

4.2 *Rounding Values:*[8]

4.2.1 When a figure is to be rounded to fewer digits than the total number available, the procedure should be as follows:

4.2.1.1 When the first digit discarded is less than 5, the last digit retained should not be changed. For example, 3.463 25, if rounded to four digits, would be 3.463; if rounded to three digits, 3.46.

4.2.1.2 When the first digit discarded is greater than 5, or if it is a 5 followed by at least one digit other than 0, the last figure retained should be increased by one unit. For example 8.376 52, if rounded to four digits, would be 8.377; if rounded to three digits, 8.38.

4.2.1.3 When the first digit discarded is exactly 5, followed only by zeros, the last digit retained should be rounded upward if it is an odd number, but no adjustment made if it is an even number. For example, 4.365, when rounded to three digits, becomes 4.36. 4.355 would also round to the same value, 4.36, if rounded to three digits.

4.3 *Significant Digits*[9]

4.3.1 When converting integral values of units, consideration must be given to the implied or required precision of the integral value to be converted. For example, the value "4 in." may be intended to represent 4, 4.0, 4.00, 4.000, 4.0000 in., or even greater accuracy. Obviously, the converted value must be carried to a sufficient number of digits to maintain the accuracy implied or required in the original quantity.

4.3.2 Any digit that is necessary to define the specific value or quantity is said to be significant. When measured to the nearest meter, a distance may be recorded as 157 m; this number has three significant digits. If the measurement had been made to the nearest 0.1 m, the distance may have been 157.4 m; this number has four significant digits. In each of these cases the value of the right-hand digit was determined by measuring the value of an additional digit and then rounding to the desired degree of accuracy. In other words, 157.4 was rounded to 157; in the second case, the measurement in hundredths, 157.36 was rounded to 157.4.

4.3.3 Zeros may be used either to indicate a specific value, like any other digit, or to indicate the magnitude of a number. The 1960 population figure rounded to thousands was 179 323 000. The six left-hand digits of this number are significant; each of them *measures* a value. The three right-hand digits are zeros which merely indicate the *magnitude* of

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[8] Adapted from "American National Standard Practice for Inch-Millimeter Conversion for Industrial Use," ANSI B48.1-1933 (R1947), ISO R370 1964.

[9] See also ASTM Recommended Practice E 29, for Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values, *Annual Book of ASTM Standards*, Part 30.

E 380

the number rounded to the nearest thousand. This point may be further illustrated by the following list of estimates and measurements, each of which is of different magnitude but each of which has only one significant digit:

1000
100
10
0.01
0.001
0.0001

4.3.4 Occasionally data required for an investigation must be drawn from a variety of sources where they have been recorded with varying degrees of refinement. Specific rules must be observed when such data are to be added, subtracted, multiplied, or divided.

4.3.5 The rule for addition and subtraction is that the *answer* shall contain no significant digits farther to the right than occurs in the least accurate figure. Consider the addition of three numbers drawn from three sources, the first of which reported data in millions, the second in thousands, and the third in units:

```
163 000 000
217 885 000
 96 432 768
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477 317 768
```

The total indicates a precision that is not valid. The numbers should first be rounded to *one significant digit* farther to the right than that of the least accurate number, and the sum taken as follows:

```
163 000 000
217 900 000
 96 400 000
-----------
477 300 000
```

The answer is then rounded to 477 000 000 as called for by the rule. Note that if the second of the figures to be added had been 217 985 000, the rounding before addition would have produced 218 000 000, in which case the 0 following 218 would have been a significant digit.

4.3.6 The rule for multiplication and division is that the product or quotient shall contain no more significant digits than are contained in the number with the fewest significant digits used in the multiplication or division. The difference between this rule and the rule for addition and subtraction should be noted; the latter rule merely requires rounding of digits that lie to the right of the last significant digit in the least accurate number. The following illustration highlights this difference:

Multiplication:	$113.2 \times 1.43 = 161.876$, rounded to 162
Division:	$113.2 \div 1.43 = 79.16$, rounded to 79.2
Addition:	$113.2 + 1.43 = 114.63$, rounded to 114.6
Subtraction:	$113.2 - 1.43 = 111.77$, rounded to 111.8

The above product and quotient are limited to three significant digits since 1.43 contains only three significant digits. In contrast, the rounded answers in the addition and subtraction examples contain four significant digits.

4.3.7 Numbers used in the above illustrations have all been estimates or measurements. Numbers that are exact counts are treated as though they consist of an infinite number of significant digits. More simply stated, when a count is used in computation with a measurement the number of significant digits in the answer is the same as the number of significant digits in the measurement. If a count of 40 is multiplied by a measurement of 10.2, the product is 408. However, if 40 were an estimate accurate only to the nearest 10, and hence contained but one significant digit, the product would be 400.

4.4 *Dimensions and Tolerances:*[10]

4.4.1 *Dimensions Without Tolerances:*

4.4.1.1 If no tolerance is given and the dimension is not approximate, give the converted dimension in millimeters to one additional significant digit when the first digit in the SI value is smaller than the first digit in the U.S. customary value. For example, 5.4 in. = 137.16 mm, which rounds to 137 mm. When the first digit in the SI value is larger than the first digit in the U.S. customary value, round the converted dimension to the same number of significant digits as given in the U.S. customary value. For example, 2.3 in. = 58.42 mm, which rounds to 58 mm. In tool, gage, and similar work it is usually ad-

[10] Parts of this section are adapted from SAE Recommended Practice J916 (1968 SAE Handbook). Parts of SAE J916 were based on the earlier edition of the *ASTM Metric Practice Guide*.

visable to limit the millimeter equivalent to not more than three decimal places, as this represents as high a precision as is ordinarily required.

4.4.1.2 If no tolerance is given and the dimension is approximate, calculate the converted dimension in millimeters to one additional significant digit and round appropriately. If the rounded converted dimension is given to fewer significant digits than the original dimension, insert the word "approximately" before the converted dimension. For example, 77 in. = 1.9558 m, which rounds to approx 2 m.

4.4.1.3 If the dimensions are given in common fractions of an inch, give the converted dimensions in millimeters to the implied or required precision of the value to be converted.

4.4.1.4 As an alternative to 4.1.3 and 4.1.4, conversion tables and charts are frequently provided for the rapid determination of converted values of commonly used quantities by addition only. Table 2 is of this type, and provides values for converting inches to millimeters. In using this table, the inch value to be converted should be written to as many decimal places as accuracy requires. The value should then be split into groups of not more than two significant digits each. The inch equivalent of each group should be taken from Table 2 and tabulated as in the following example, proper regard being given to the position of the decimal point in each case. For example, to convert 2.4637 in. to millimeters,

2.0000 in.	=	50.800 00	mm exactly
0.4600 in.	=	11.684 00	mm exactly
0.0037 in.	=	0.093 98	mm exactly
2.4637 in.	=	62.577 98	mm exactly

or, correct to three decimal places:

2.4637 in. = 62.578 mm

In this example, to maintain accuracy during conversion without retaining an unnecessary number of digits, the rounded millimeter equivalent of each group is carried to one decimal place more than the inch value being converted. The sum of the group of equivalents is then rounded to one less decimal place than the original inch value.

4.4.1.5 Table 3 provides values for the conversion of decimal and fractional values of an inch to millimeters. Combinations of inch and fractional inch-millimeter equivalents may be tabulated to obtain the desired millimeter conversion. As in the example in 4.4.1.4, the millimeter value should be rounded to one less than the decimal equivalent of the inch fraction taken to the intended or implied accuracy.

4.4.2 *Toleranced Dimensions*—The use of the exact relation 1 in. = 25.4 mm generally produces converted values containing more decimal places than are required for the desired accuracy. It is, therefore, necessary to round these values suitably and at the same time maintain the degree of accuracy in the converted values compatible with that of the original values.

4.4.2.1 *General*—The number of decimal places given in Table 4 for rounding toleranced dimensions relates the degree of accuracy to the size of the tolerance specified. Two methods of using this table are given: Method A, which rounds to values nearest to each limit, and Method B, which rounds to values always inside the limits.

In Method A, rounding is effected to the nearest rounded value of the limit, so that, on the average, the converted tolerances remain statistically identical with the original tolerances. The limits converted by this method, where acceptable for interchangeability, serve as a basis for inspection.

In Method B, rounding is done systematically *toward the interior* of the tolerance zone so that the converted tolerances are never larger than the original tolerances. This method must be employed when the original limits have to be respected absolutely, in particular, when components made to converted limits are to be inspected by means of original gages.

Method A—The use of this method ensures that even in the most unfavorable cases neither of the two original limits will be exceeded (nor diminished) by more than 2 percent of the value of the tolerance. Proceed as follows:

(*a*) Calculate the maximum and minimum limits in inches.

(*b*) Convert the corresponding two values exactly into millimeters by means of the conversion factor 1 in. = 25.4 mm (see Table 2).

(*c*) Round the results obtained to the near-

E 380

est rounded value as indicated in Table 4, depending on the original tolerance in inches, that is, on the difference between the two limits in inches.

Method B—This method must be employed when the original limits may not be violated, as in the case of mating parts. In extreme cases, this method may increase the lower limit a maximum of 4 percent of the tolerance and decrease the upper limit a maximum of 4 percent of the tolerance.

(*a*) Proceed as in Method A, steps (*a*) and (*b*).

(*b*) Round each limit toward the interior of the tolerance, that is, to the next lower value for the upper limit and to the next higher value for the lower limit:[11] For example,

A dimension is expressed in inches as	1.950 ± 0.016
The limits are	1.934 to 1.966
Conversion of the two limits into millimeters gives	49.1236 to 49.9364
Method A—The tolerance equals 0.032 in. and thus lies between 0.01 and 0.1 in. (see Table 4). Rounding these values to the nearest 0.01 mm, the values in millimeters to be employed for these two limits are	49.12 to 49.94
Method B—Rounding towards the interior of the tolerance, millimeter values for these two limits are	49.13 to 49.93

This reduces the tolerance to 0.80 mm instead of 0.82 mm given by Method A.

4.4.2.2 *Special Methods for Nominal Size and Deviations*—In order to avoid accumulation of rounding errors, the two limits of size must be converted separately; thus, they must first be calculated if the dimension consists of a basic size and two tolerances. However (except when Method B is specified) as an alternative, the basic size may be converted to the nearest rounded value and each of the tolerances converted toward the interior of the tolerance. This method, which sometimes makes conversion easier, gives the same maximum guarantee of accuracy as Method A, but usually results in smaller converted tolerances.

4.4.2.3 *Special Methods for Limitation Imposed by Accuracy of Measurements*—If the increment of rounding given for the tolerances in Table 4 is too small for the available accuracy of measurement, limits that are acceptable for interchangeability must be determined separately for the dimensions. For example, where accuracy of measurement is limited to 0.001 mm, study shows that values converted from 1.0000 ± 0.0005 in. can be rounded to 25.413 and 25.387 mm instead of 25.4127 and 25.3873 mm with little disadvantage, since neither of the two original limits is exceeded by more than 1.2 percent of the tolerance.

4.4.2.4 *Positional Tolerance*—If the dimensioning consists solely of a positional tolerance around a point defined by a nontoleranced basic dimension, the basic dimension must be converted to the nearest rounded value and the positional variation (radius) separately converted by rounding downwards, these roundings depending on twice the original radial tolerance, that is, the diameter of the tolerance zone.

4.4.2.5 *Toleranced Dimension Applied to a Nontoleranced Position Dimension*—If the toleranced dimension is located in a plane, the position of which is given by nontoleranced basic or gage dimension, such as when dimensioning certain conical surfaces, proceed as follows:

(*a*) Round the reference gage arbitrarily, to the nearest convenient value.

(*b*) Calculate exactly, in the converted unit of measurement, new maximum and minimum limits of the specified tolerance zone, in the new plane defined by the new basic dimension.

(*c*) Round these limits in conformity with the rules given in 4.2. For example, a cone of taper 0.05 in./in. has a diameter of 1.000 ± 0.002 in. in a reference plane located by the nontoleranced dimension 0.9300 in. By virtue of the taper of the cone, the limits of the tolerance zone depend on the position of the reference plane. Consequently, if the dimension 0.9300 in. = 23.6220 mm is rounded to 23.600 mm, that is, a reduction of 0.022 mm, each of the two original limits, when converted exactly into millimeters, must be corrected by 0.022 × 0.05 = 0.0011 mm, in the appropriate sense, before being rounded.

[11] If the digits to be rounded are zeros, the retained digits remain unchanged.

E 380

4.4.2.6 *Consideration of Maximum and Minimum Material Condition*—The ability to assemble mating parts depends on a "go" condition at the maximum material limits of the parts. The minimum material limits which are determined by the respective tolerances are often not as critical from a functional standpoint. Accordingly, it may be desirable to employ a combination of Methods A and B in certain conversions by using Method B for the maximum material limits and Method A for the minimum material limits. Alternatively, it may be desirable to round automatically the converted minimum material limits outside the original limits to provide greater tolerances for manufacturing.

4.5 *Other Units:*

4.5.1 *Temperature*—The tolerances for converting from degrees Fahrenheit to kelvins or degrees Celsius are given in Table 5. All temperatures expressed in a whole number of degrees Fahrenheit should be converted to the nearest 0.1 kelvin (or degree Celsius) with the following exceptions:

4.5.1.1 Fahrenheit temperatures indicated to be approximate, a maximum, a minimum, or to have a tolerance of ±5 F or more should be converted to the nearest whole number in kelvins or degrees Celsius and rounded to the appropriate number of significant digits, for example,

$$100 \pm 5\ \text{F} = 38 \pm 3\ \text{C}$$
$$1000 \pm 50\ \text{F} = 540 \pm 30\ \text{C}$$

4.5.2 *Pressure or Stress*—Convert by one of the following factors and round in accordance with 4.2 and 4.3:

$$1\ \text{psi} = 6.894\ 757\ \text{kN/m}^2$$
$$1\ \text{ksi} = 6.894\ 757\ \text{MN/m}^2$$

4.5.2.1 Alternatively, psi or ksi may be converted to kN/m^2 or MN/m^2 by the use of Table 6. Converted values determined from the table should be rounded in accordance with 4.2 and 4.3.

4.5.2.2 Pressure or stress values having an uncertainty of more than 2 percent may be converted without rounding by the approximate factors:

$$1\ \text{psi} = 7\ \text{kN/m}^2$$
$$1\ \text{ksi} = 7\ \text{MN/m}^2$$

4.5.2.3 Pressure or stress values in kgf/mm^2 may be converted to MN/m^2 by the use of Table 7. Converted values determined from the table should be rounded in accordance with 4.2 and 4.3.

E 380

APPENDIXES

A1. Terminology

A1.1 To help ensure consistently reliable conversion and rounding practices, a clear understanding of the related nontechnical terms is a prerequisite. Accordingly, certain terms used in this Guide are defined as follows:

accuracy (as distinguished from **precision**)—the degree of conformity of a measured or calculated value to some recognized standard or specified value. This concept involves the systematic error of an operation, which is seldom negligible.

approximate—describes a value that is nearly but not exactly correct or accurate.

deviation—variations from a specified dimension or design requirement, usually defining upper and lower limits. (See also **tolerance**.)

digit—one of the ten Arabic numerals (0 to 9) by which all numbers are expressed.

dimension—a geometric element in a design, such as length, angle, etc., or the magnitude of such a quantity.

feature—an individual characteristic of a part, such as screw-thread, taper, slot, etc.

figure (numerical)—an arithmetic value expressed by one or more digits.

nominal—describes a value assigned for the purpose of convenient designation; existing in name only.

precision (as distinguished from **accuracy**)—the degree of mutual agreement between individual measurements, namely repeatability and reproducibility.

significant (as applied to a digit)—any digit that is necessary to define a value or quantity (see Footnote 9).

tolerance—the total range of variation (usually bilateral) permitted for a size, position, or other required quantity; the upper and lower limits between which a dimension must be held.

U.S. customary units—units based upon the yard and the pound commonly used in the United States of America and defined by the National Bureau of Standards (Ref 14). Some of these units have the same name as similar units in the United Kingdom (British, English, or U.K. units) but are not necessarily equal to them.

Three terms that may be encountered in the literature dealing with the modernized metric system are "metricize," "metrication," and "rationalize." These have been defined as follows:

metricize—to convert any other unit to its metric (SI) equivalent. This may be an exact, a rounded, or a rationalized equivalent. For example, a 2-in. test specimen becomes 50.8 mm by exact conversion; 51 mm by rounding in accordance with Section 4, Rules for Conversion and Rounding, and 50 mm when rationalized.

metrication—any act tending to increase the use of the metric system (SI).

rationalize—to round completely a converted value to a popular standard figure compatible with noncritical mating components, interchangeable parts, or other nominal sizes in a series.

A2. Development of the International System of Units

Le Système International d'Unités

A2.1 The decimal system of units was first conceived in the 16th century when there was a great confusion and jumble of units of weights and measures. It was not until 1790, however, that the French National Assembly requested the French Academy of Sciences to work out a system of units suitable for adoption by the entire world. This system, based on the meter as a unit of length and the gram as a unit of mass, was adopted as a practical measure to benefit industry and commerce. Physicists soon realized its advantages and it was adopted also in scientific and technical circles. The importance of the regulation of weights and measures was recognized in Article 1, Section 8, when the United States Constitution was written in 1787, but the metric system was not legalized in this country until 1866. In 1893, the international meter and kilogram became the fundamental standards of length and mass in the United States, both for metric and customary weights and measures.

A2.2 Meanwhile, international standardization began with an 1870 meeting of 15 nations in Paris that led to the May 20, 1875, International Metric Convention, and the establishment of a permanent International Bureau of Weights and Measures near Paris. A General Conference on Weights and Measures (CGPM) was also constituted to handle all international matters concerning the metric system. The CGPM nominally meets every sixth year in Paris and controls the International Bureau of Weights and Measures which preserves the metric standards, compares national standards with them, and conducts research to establish new standards. The National Bureau of Standards represents the United States in these activities.

A2.3 The original metric system provided a coherent set of units for the measurement of length, area, volume, capacity, and mass based on two fundamental units: the meter and the kilogram. Measurement of additional quantities required for science and commerce has necessitated development of additional fundamental and derived units. Numerous other systems based on these two metric units have been used. A unit of time was added to produce the centimeter-gram-second (cgs) system adopted in 1881 by the International Congress of Electricity. About 1900 practical measurements in metric units began to be based on the meter-kilogram-second (MKS) system. In 1935 Prof. Giovanni Giorgi recommended that the MKS system of mechanics be linked with the electromagnetic system of units by adoption of one of the units—ampere, coulomb, ohm, or volt—for the fourth basic unit. This recommendation was accepted and in 1950 the ampere, the unit of electrical current, was established as a basic unit to form the MKSA system.

A2.4 The 10th CGPM in 1954 adopted a rationalized and coherent system of units based on the four MKSA units, plus the degree Kelvin as the unit of temperature and the candela as a unit of luminous intensity. The 11th CGPM in 1960 formally gave it the full title, International System of Units, for which the abbreviation is "SI" in all languages. Thirty-six countries, including the United States, participated in this 1960 conference. The 12th CGPM in 1964 made some refinements, and the 13th CGPM in 1967 redefined the second, renamed the unit of temperature as the kelvin (K), and revised the definition of the candela.

A2.5 SI is a rationalized selection of units from the metric system which individually are not new. It includes a unit of force (the newton) which was introduced in place of the kilogram-force to indicate by its name that it is a unit of force and not of mass. SI is a coherent system with six base units for which names, symbols, and precise definitions have been established. Many derived units are defined in terms of the base units, symbols assigned to each, and, in some cases, given names, as for example, the newton (N).

A2.6 The great advantage of SI is that there is one and only one unit for each physical quantity—the meter for length (l), kilogram (instead of gram) for mass (m), second for time (t), etc. From these elemental units, units for all other mechanical quantities are derived. These derived units are defined by simple equations such as $v = dl/dt$ (velocity), $a = dv/dt$ (acceleration), $F = ma$ (force), $W = Fl$ (work or energy), $P = W/t$ (power). Some of these units have only generic names such as meter per second for velocity; others have special names such as newton (N) for force, joule (J) for work or energy, watt (W) for power. The SI units for force, energy, and power are the same regardless of whether the process is mechanical, electrical, chemical, or nuclear. A force of 1 newton applied for a distance of 1 meter can produce 1 joule of heat, which is identical with what 1 watt of electric power can produce in 1 second.

A2.7 Corresponding to the advantages of the SI system, which result from the use of a unique unit for each physical quantity, are the advantages which result from the use of a unique and well-defined set of symbols and abbreviations. Such symbols and abbreviations eliminate the confusion that can arise from current practices in different disciplines such as the use of *b* for both the *bar* (a unit of pressure) and *barn* (a unit of area).

A2.8 Another advantage of the SI is its retention of the decimal relation between multiples and submultiples of the base units for each physical quantity—not that there is anything inherently superior in a number system to the base 10 but that SI conforms to the system of Arabic numericals. Prefixes are established for designating multiple and submultiple units from "tera" (10^{12}) down to "atto" (10^{-18}) for convenience in writing and talking.

A2.9 Another major advantage of the SI system is its coherence. A system of units is coherent if the product or quotient of any two unit quantities in the system is a unit of the resulting quantity. For example, in any coherent system, unit area results when unit length is multiplied by unit length, unit velocity when unit length is divided by unit time, and unit force when unit mass is multiplied by unit acceleration. Thus, in a coherent system in which the foot is a unit of length, the square foot is the unit of area (but the acre is not). Similarly in a coherent system in which the foot, the pound, and the second are units of length, mass, and time, the unit of force is the poundal (and not the pound-weight or the pound-force).

A2.10 Whatever the system of units, whether it be coherent or noncoherent, magnitudes of some physical quantities must be arbitrarily selected and declared to have unit value. These magnitudes form a set of standards and are called base units. All other units are derived units related to the base units by definition. The six base SI units are each very accurately defined in terms of physical measurements that can be made in a laboratory, except the kilogram, which is a particular mass preserved by the International Bureau of Weights and Measures.

A2.11 Various other units are associated with SI but are not a part thereof. They are related to units of the system by powers of 10 and are employed in specialized branches of physics. Examples of such units are the bar, a unit of pressure, approximately equivalent to one atmosphere and equal exactly to 100 kilonewtons per square meter. It is employed extensively by meterologists. Another such unit is the gal (galileo) equal exactly to an acceleration of 0.01 meter per second^2. It is used in geodetic work. These, however, are not consistent units, that is to say, equations involving both these units and SI units cannot be written without a factor of proportionality even though the factor of proportionality is a simple multiple of 10.

A2.11.1 Originally (1795) the liter was intended to be identical with the cubic decimeter. The Third General Conference on Weights and Measures, meeting in 1901, decided to define the liter as the volume occupied by the mass of one kilogram of pure water at its maximum density under normal atmospheric pressure. Careful determinations subsequently established the liter so defined as being equivalent to 1.000028 dm^3. In 1964 the General Conference on Weights and Measures withdrew this definition of the liter, and declared that the word "liter" was a special name for the cubic decimeter. Thus its use is permitted in SI, but is discouraged, since it creates two units for the same quantity, and its use in precision measurements might conflict with measurements recorded under the old definition.

A2.12 Authorized translations of the original French definitions of the six base and two supplementary units of the International System are given in the following paragraphs:

A2.12.1 *Meter*—The meter is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the krypton-86 atom. (adopted at 11th CGPM 1960)

A2.12.2 *Kilogram*—The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram. (adopted at 1st and 3rd CGPM 1889 and 1901)

A2.12.3 *Second*—The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.[12] (adopted at 13th CGPM 1967)

A2.12.4 *Ampere*—The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible cross section, and placed one meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length. (adopted at 9th CGPM 1948)

A2.12.5 *Kelvin*—The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.[13] (adopted at 13th CGPM 1967)

A2.12.6 *Candela*—The candela is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square meter of a blackbody at the temperature of freezing platinum under a pressure of 101 325 newtons per square meter. (adopted at 13th CGPM 1967)

A2.12.7 *Radian*—The unit of measure of a plane angle with its vertex at the center of a circle and subtended by an arc equal in length to the radius. (adopted at 11th CGPM 1960)

A2.12.8 *Steradian*—The unit of measure of a solid angle with its vertex at the center of a sphere and enclosing an area of the spherical surface equal to that of a square with sides equal in length to the radius. (adopted at 11th CGPM 1960)

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[12] This definition supersedes the emphemeris second as the unit of time.

[13] The International Practical Kelvin Temperature Scale of 1968 and the International Practical Celsius Temperature Scale of 1968 are defined by a set of interpolation equations based on the following reference temperatures[a]:

	K	deg C
Hydrogen, solid-liquid-gas equilibrium	13.81	−259.34
Hydrogen, liquid-gas equilibrium at 33 330.6 N/m² (25/76 standard atmosphere)	17.042	−256.108
Hydrogen, liquid-gas equilibrium	20.28	−252.87
Neon, liquid-gas equilibrium	27.102	−246.048
Oxygen, solid-liquid-gas equilibrium	54.361	−218.789
Oxygen, liquid-gas equilibrium	90.188	−182.962
Water, solid-liquid-gas equilibrium	273.16	0.01
Water, liquid-gas equilibrium	373.15	100.00
Zinc, solid-liquid equilibrium	692.73	419.58
Silver, solid-liquid equilibrium	1235.08	961.93
Gold, solid-liquid equilibrium	1337.58	1064.43

[a] Except for the triple points and one equilibrium hydrogen point (17.042 K) the assigned values of temperature are for equilibrium states at a pressure

$$p_0 = 1 \text{ standard atmosphere } (101\ 325\ \mathrm{N/m^2}).$$

In this scale the degree Celsius and the kelvin are identical, and are related by an exact difference of 273.15 degrees. It is seldom necessary to recognize the differences between the thermodynamic and practical scales, but the General Conference of Weights and Measures in 1960 established the following quantity symbols for use if desired:

Thermodynamic temperature:	kelvins	T
	degrees Celsius	t
Practical temperature:	kelvins	T_{int}
	degrees Celsius	t_{int}

A2.13 *Definitions of Derived Units of the International System Having Special Names:*

Physical Quantity	Unit and Definition
A2.13.1 Electric capacitance	The *farad* is the capacitance of a capacitor between the plates of which there appears a difference of potential of one volt when it is charged by a quantity of electricity equal to one coulomb.
A2.13.2 Electric inductance	The *henry* is the inductance of a closed circuit in which an electromotive force of one volt is produced when the electric current in the circuit varies uniformly at a rate of one ampere per second.
A2.13.3 Electric potential difference (electromotive force)	The *volt* (unit of electric potential difference and electromotive force) is the difference of electric potential between two points of a conductor carrying a constant current of one ampere, when the power dissipated between these points is equal to one watt.
A2.13.4 Electric resistance	The *ohm* is the electric resistance between two points of a conductor when a constant difference of potential of one volt, applied between these two points, produces in this conductor a current of one ampere, this conductor not being the source of any electromotive force.
A2.13.5 Energy	The *joule* 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.
A2.13.6 Force	The *newton* is that force which, when applied to a body having a mass of one kilogram gives it an acceleration of one meter per second per second.

E 380

Physical Quantity	Unit and Definition
A2.13.7 Frequency	The *hertz* is a frequency of one cycle per second.
A2.13.8 Illumination	The *lux* is the luminous intensity given by a luminous flux of one lumen per square meter.
A2.13.9 Luminous flux	The *lumen* is the luminous flux emitted in a solid angle of one steradian by a point source having a uniform intensity of one candela.
A2.13.10 Magnetic flux	The *weber* is the magnetic flux which, linking a circuit of one turn, produces in it an electromotive force of one volt as it is reduced to zero at a uniform rate in one second.
A2.13.11 Magnetic flux density	The *tesla* is the magnetic flux density given by a magnetic flux of one weber per square meter.
A2.13.12 Power	The *watt* is the power which gives rise to the production of energy at the rate of one joule per second.
A2.13.13 Quantity of electricity	The *coulomb* is the quantity of electricity transported in one second by a current of one ampere.

A2.14 *Probable Acceptance of "Pascal" and "Siemens"*—The Advisory Committee on Units of the International Committee of Weights and Measures has recommended the pascal (Pa) as the name for the unit of pressure or stress instead of the newton per square meter; thus the unit for viscosity becomes the pascal-second. The Committee also recommended the name siemens (S) as the name for the unit of electrical conductance instead of the reciprocal ohm or the ampere per volt.

A3. Conversion Factors for Physical Quantities[14]

A3.1 *General*—The following tables of conversion factors are intended to serve two purposes:

A3.1.1 To express the definitions of miscellaneous units of measure as exact numerical multiples of coherent "metric" units. Relationships that are exact in terms of the base units are followed by an asterisk. Relationships that are not followed by an asterisk are either the results of physical measurements, or are only approximate.

A3.1.2 To provide multiplying factors for converting expressions of measurements given by numbers and miscellaneous units to corresponding new numbers and metric units.

A3.2 *Notation:*

A3.2.1 Conversion factors are presented for ready adaptation to computer readout and electronic data transmission. The factors are written as a number greater than one and less than ten with six or less decimal places. This number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example,

3.523 907 E−02 is $3.523\,907 \times 10^{-2}$

or 0.035 239 07.

Similarly,

3.386 389 E+03 is $3.386\,389 \times 10^{3}$

or 3 386.389.

A3.2.2 An asterisk (*) after the sixth decimal place indicates that the conversion factor is exact and that all subsequent digits are zero. All other conversion factors have been rounded to the figures given in accordance with 4.2.

A3.3 *Organization:*

A3.3.1 The conversion factors are listed in two ways—alphabetically and classified by physical quantity. The alphabetical list contains only those units that have specific names; compounded units derived from the specific units are given in the classified list. The classified list emphasizes the more frequently used units and contains both specific and compounded units.

A3.3.2 The conversion factors for other compounded units can easily be generated from numbers given in the alphabetical list by the well-known rules for manipulating units. These rules, being adequately discussed in many science and engineering textbooks, are not repeated here.

ALPHABETICAL LIST OF UNITS

(Symbols of SI units given in parentheses)

To convert from	to	Multiply by
abampere	ampere (A)	1.000 000*E+01
abcoulomb	coulomb (C)	1.000 000*E+01
abfarad	farad (F)	1.000 000*E+09
abhenry	henry (H)	1.000 000*E−09
abmho	mho[6]	1.000 000*E+09
abohm	ohm (Ω)	1.000 000*E−09
abvolt	volt (V)	1.000 000*E−08
acre	meter^2 (m^2)	4.046 856 E+03
ampere (international of 1948)	ampere (A)	9.998 35 E−01

[14] Based on E. A. Mechtly (Ref 19).

E 380

To convert from	to	Multiply by
angstrom	meter (m)	1.000 000*E−10
astronomical unit	meter (m)	1.495 98 E+11
atmosphere (normal)	newton/meter² (N/m²)	1.013 250*E+05
atmosphere (technical = 1 kgf/cm²)	newton/meter² (N/m²)	9.806 650*E+04
bar	newton/meter² (N/m²)	1.000 000*E+05
barn	meter² (m²)	1.000 000*E−28
barrel (for petroleum, 42 gal)	meter³ (m³)	1.589 873 E−01
British thermal unit (International Table)[15]	joule (J)	1.055 056 E+03
British thermal unit (mean)	joule (J)	1.055 87 E+03
British thermal unit (thermochemical)	joule (J)	1.054 350 E+03
British thermal unit (39 F)	joule (J)	1.059 67 E+03
British thermal unit (60 F)	joule (J)	1.054 68 E+03
bushel (U.S.)	meter³ (m³)	3.523 907 E−02
caliber	meter (m)	2.540 000*E−04
calorie (International Table)	joule (J)	4.186 800*E+00
calorie (mean)	joule (J)	4.190 02 E+00
calorie (thermochemical)	joule (J)	4.184 000*E+00
calorie (15 C)	joule (J)	4.185 80 E+00
calorie (20 C)	joule (J)	4.181 90 E+00
calorie (kilogram, International Table)	joule (J)	4.186 800*E+03
calorie (kilogram, mean)	joule (J)	4.190 02 E+03
calorie (kilogram, thermochemical)	joule (J)	4.184 000*E+03
carat (metric)	kilogram (kg)	2.000 000*E−04
centimeter of mercury (0 C)	newton/meter² (N/m²)	1.333 22 E+03
centimeter of water (4 C)	newton/meter² (N/m²)	9.806 38 E+01
centipoise	newton-second/meter² (N · s/m²)	1.000 000*E−03
circular mil	meter² (m²)	5.067 075 E−10
clo	kelvin-meter²/watt (K · m²/W)	2.003 712 E−01
coulomb (international of 1948)	coulomb (C)	9.998 35 E−01
cup	meter³ (m³)	2.365 882 E−04
curie	disintegration/second	3.700 000*E+10
day (mean solar)	second (s)	8.640 000 E+04
day (sidereal)	second (s)	8.616 409 E+04
degree (angle)	radian (rad)	1.745 329 E−02
degree Celsius	kelvin (K)	$t_K = t_C + 273.15$
degree centigrade	see 3.4.3	
degree Fahrenheit	degree Celsius	$t_C = (t_F - 32)/1.8$
degree Fahrenheit	kelvin (K)	$t_K = (t_F + 459.67)/1.8$
degree Rankine	kelvin (K)	$t_K = t_R/1.8$
decibar	newton/meter² (N/m²)	1.000 000*E+04
dyne	newton (N)	1.000 000*E−05
electron volt	joule (J)	1.602 10 E−19
EMU of capacitance	farad (F)	1.000 000*E+09
EMU of current	ampere (A)	1.000 000*E+01
EMU of electric potential	volt (V)	1.000 000*E−08
EMU of inductance	henry (H)	1.000 000*E−09
EMU of resistance	ohm (Ω)	1.000 000*E−09
ESU of capacitance	farad (F)	1.112 6 E−12
ESU of current	ampere (A)	3.335 6 E−10
ESU of electric potential	volt (V)	2.997 9 E+02
ESU of inductance	henry (H)	8.987 6 E+11
ESU of resistance	ohm (Ω)	8.987 6 E+11
erg	joule (J)	1.000 000*E−07
farad (international of 1948)	farad (F)	9.995 05 E−01
faraday (based on carbon-12)	coulomb (C)	9.648 70 E+04
faraday (chemical)	coulomb (C)	9.649 57 E+04
faraday (physical)	coulomb (C)	9.652 19 E+04
fathom	meter (m)	1.828 800*E+00
fermi (femtometer)	meter (m)	1.000 000*E−15
fluid ounce (U.S.)	meter³ (m³)	2.957 353 E−05
foot	meter (m)	3.048 000*E−01
foot (U.S. survey)	meter (m)	1200/3937*E+00
foot (U.S. survey)	meter (m)	3.048 006 E−01
foot of water (39.2 F)	newton/meter² (N/m²)	2.988 98 E+03
footcandle	lumen/meter² (lm/m²)	1.076 391 E+01

[15] This value was adopted in 1956. Some of the older International Tables use the value 1.05504 E+03.

E 380

To convert from	to	Multiply by
footlambert	candela/meter^2 (cd/m^2)	3.426 259 E+00
gal (galileo)	meter/second^2 (m/s^2)	1.000 000*E−02
gallon (Canadian liquid)	meter^3 (m^3)	4.546 122 E−03
gallon (U.K. liquid)	meter^3 (m^3)	4.546 087 E−03
gallon (U.S. dry)	meter^3 (m^3)	4.404 884 E−03
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 E−03
gamma	tesla (T)	1.000 000*E−09
gauss	tesla (T)	1.000 000*E−04
gilbert	ampere-turn	7.957 747 E−01
gill (U.K.)	meter^3 (m^3)	1.420 652 E−04
gill (U.S.)	meter^3 (m^3)	1.182 941 E−04
grad	degree (angular)	9.000 000*E−01
grad	radian (rad)	1.570 796 E−02
grain (1/7000 lbm avoirdupois)	kilogram (kg)	6.479 891*E−05
gram	kilogram (kg)	1.000 000*E−03
henry (international of 1948)	henry (H)	1.000 495 E+00
horsepower (550 ft · lbf/s)	watt (W)	7.456 999 E+02
horsepower (boiler)	watt (W)	9.809 50 E+03
horsepower (electric)	watt (W)	7.460 000*E+02
horsepower (metric)	watt (W)	7.354 99 E+02
horsepower (water)	watt (W)	7.460 43 E+02
horsepower (U.K.)	watt (W)	7.457 0 E+02
hour (mean solar)	second (s)	3.600 000 E+03
hour (sidereal)	second (s)	3.590 170 E+03
hundredweight (long)	kilogram (kg)	5.080 235 E+01
hundredweight (short)	kilogram (kg)	4.535 924 E+01
inch	meter (m)	2.540 000*E−02
inch of mercury (32 F)	newton/meter^2 (N/m^2)	3.386 389 E+03
inch of mercury (60 F)	newton/meter^2 (N/m^2)	3.376 85 E+03
inch of water (39.2 F)	newton/meter^2 (N/m^2)	2.490 82 E+02
inch of water (60 F)	newton/meter^2 (N/m^2)	2.488 4 E+02
joule (international of 1948)	joule (J)	1.000 165 E+00
kayser	1/meter (1/m)	1.000 000*E+02
kelvin	degree Celsius	$t_C = t_K - 273.15$
kilocalorie (International Table)	joule (J)	4.186 800*E+03
kilocalorie (mean)	joule (J)	4.190 02 E+03
kilocalorie (thermochemical)	joule (J)	4.184 000*E+03
kilogram-force (kgf)	newton (N)	9.806 650*E+00
kilogram-mass	kilogram (kg)	1.000 000*E+00
kilopond-force	newton (N)	9.806 650*E+00
kip	newton (N)	4.448 222 E+03
knot (international)	meter/second (m/s)	5.144 444 E−01
lambert	candela/meter^2 (cd/m^2)	$1/\pi$* E+04
lambert	candela/meter^2 (cd/m^2)	3.183 099 E+03
langley	joule/meter^2 (J/m^2)	4.184 000*E+04
light year	meter (m)	9.460 55 E+15
liter[16]	meter^3 (m^3)	1.000 000*E−03
lux	lumen/meter^2 (lm/m^2)	1.000 000*E+00
maxwell	weber (Wb)	1.000 000*E−08
micron	meter (m)	1.000 000*E−06
mil	meter (m)	2.540 000*E−05
mile (international nautical)	meter (m)	1.852 000*E+03
mile (U.K. nautical)	meter (m)	1.853 184*E+03
mile (U.S. nautical)	meter (m)	1.852 000*E+03
mile (U.S. statute)	meter (m)	1.609 344*E+03
millibar	newton/meter^2 (N/m^2)	1.000 000*E+02
millimeter of mercury (0 C)	newton/meter^2 (N/m^2)	1.333 224 E+02
minute (angle)	radian (rad)	2.908 882 E−04
minute (mean solar)	second (s)	6.000 000 E+01
minute (sidereal)	second (s)	5.983 617 E+01
moment of inertia (lbm · ft^2)	kilogram-meter^2 (kg · m^2)	4.214 012 E−02
moment of inertia (lbm · in^2)	kilogram-meter^2 (kg · m^2)	2.926 397 E−05
moment of section[17] (second moment of area) (foot^4)	meter^4 (m^4)	8.630 975 E−03

[16] In 1964 the General Conference on Weights and Measures adopted the name liter as a special name for the cubic decimeter. Prior to this decision the liter differed slightly (previous value, 1.000028 dm^3) and in expressions of precision volume measurement this fact must be kept in mind.

[17] This is sometimes called the moment of inertia of a plane section about a specified axis.

E 380

To convert from	to	Multiply by
moment of section[17] (second moment of area) (inch^4)	meter^4 (m^4)	4.162 314 E−07
month (mean calendar)	second (s)	2.628 000 E+06
oersted	ampere/meter (A/m)	7.957 747 E+01
ohm (international of 1948)	ohm (Ω)	1.000 495 E+00
ounce-force (avoirdupois)	newton (N)	2.780 139 E−01
ounce-mass (avoirdupois)	kilogram (kg)	2.834 952 E−02
ounce-mass (troy or apothecary)	kilogram (kg)	3.110 348 E−02
ounce (U.S. fluid)	meter^3 (m^3)	2.957 353 E−05
parsec	meter (m)	3.083 74 E+16
pascal	newton/meter^2 (N/m^2)	1.000 000*E+00
peck (U.S.)	meter^3 (m^3)	8.809 768 E−03
pennyweight	kilogram (kg)	1.555 174 E−03
perm (0 C)	kilogram/newton-second (kg/N · s)	5.721 35 E−11
perm (23 C)	kilogram/newton-second (kg/N · s)	5.745 25 E−11
perm-inch (0 C)	kilogram-meter/newton-second (kg · m/N · s)	1.453 22 E−12
perm-inch (23 C)	kilogram-meter/newton-second (kg · m/N · s)	1.459 29 E−12
phot	lumen/meter^2 (lm/m^2)	1.000 000*E+04
pica (printer's)	meter (m)	4.217 518 E−03
pint (U.S. dry)	meter^3 (m^3)	5.506 105 E−04
pint (U.S. liquid)	meter^3 (m^3)	4.731 765 E−04
point (printer's)	meter	3.514 598*E−04
poise (absolute viscosity)	newton-second/meter^2 ($N \cdot s/m^2$)	1.000 000*E−01
poundal	newton (N)	1.382 550 E−01
pound-force (lbf avoirdupois)[18]	newton (N)	4.448 222 E+00
pound-mass (lbm avoirdupois)[19]	kilogram (kg)	4.535 924 E−01
pound-mass (troy or apothecary)	kilogram (kg)	3.732 417 E−01
quart (U.S. dry)	meter^3 (m^3)	1.101 221 E−03
quart (U.S. liquid)	meter^3 (m^3)	9.463 529 E−04
rad (radiation dose absorbed)	joule/kilogram (J/kg)	1.000 000*E−02
rhe	meter^2/newton-second ($m^2/N \cdot s$)	1.000 000*E+01
rod	meter (m)	5.029 200*E+00
roentgen	coulomb/kilogram (C/kg)	2.579 760*E−04
second (angle)	radian (rad)	4.848 137 E−06
second (sidereal)	second (s)	9.972 696 E−01
section	meter^2 (m^2)	2.589 988 E+06
section modulus (foot^3)	meter^3 (m^3)	2.831 685 E−02
section modulus (inch^3)	meter^3 (m^3)	1.638 706 E−05
shake	second (s)	1.000 000*E−08
slug	kilogram (kg)	1.459 390 E+01
statampere	ampere (A)	3.335 640 E−10
statcoulomb	coulomb (C)	3.335 640 E−10
statfarad	farad (F)	1.112 650 E−12
stathenry	henry (H)	8.987 554 E+11
statmho	mho[6]	1.112 650 E−12
statohm	ohm (Ω)	8.987 554 E+11
statute mile (U.S.)	meter (m)	1.609 344*E+03
statvolt	volt (V)	2.997 925 E+02
stere	meter^3 (m^3)	1.000 000*E+00
stilb	candela/meter^2 (cd/m^2)	1.000 000*E+04
stoke (kinematic viscosity)	meter^2/second (m^2/s)	1.000 000*E−04
tablespoon	meter^3 (m^3)	1.478 676 E−05
teaspoon	meter^3 (m^3)	4.928 922 E−06
tex	kilogram/meter (kg/m)	1.000 000*E−06
ton (assay)	kilogram (kg)	2.916 667 E−02
ton (long, 2240 lbm)	kilogram (kg)	1.016 047 E+03
ton (metric)	kilogram (kg)	1.000 000*E+03
ton (nuclear equivalent of TNT)	joule (J)	4.20 E+09
ton (register)	meter^3 (m^3)	2.831 685 E+00
ton (short, 2000 lbm)	kilogram (kg)	9.071 847 E+02
tonne	kilogram (kg)	1.000 000*E+03

[18] The exact conversion factor is 4.448 221 615 260 5*E+00.
[19] The exact conversion factor is 4.535 923 7*E−01.

422-764 OL - 71 - 12

E 380

To convert from	to	Multiply by
torr (mm Hg, 0 C)	newton/meter² (N/m²)	1.333 22 E+02
township	meter² (m²)	9.323 957 E+07
unit pole	weber (Wb)	1.256 637 E−07
volt (international of 1948)	volt (absolute) (V)	1.000 330 E+00
watt (international of 1948)	watt (W)	1.000 165 E+00
yard	meter (m)	9.144 000*E−01
year (calendar)	second (s)	3.153 600 E+07
year (sidereal)	second (s)	3.155 815 E+07
year (tropical)	second (s)	3.155 693 E+07

CLASSIFIED LIST OF UNITS

Acceleration

foot/second²	meter/second² (m/s²)	3.048 000*E−01
free fall, standard	meter/second² (m/s²)	9.806 650*E+00
gal (galileo)	meter/second² (m/s²)	1.000 000*E−02
inch/second²	meter/second² (m/s²)	2.540 000*E−02

Area

acre	meter² (m²)	4.046 856 E+03
barn	meter² (m²)	1.000 000*E−28
circular mil	meter² (m²)	5.067 075 E−10
foot²	meter² (m²)	9.290 304*E−02
inch²	meter² (m²)	6.451 600*E−04
mile² (U.S. statute)	meter² (m²)	2.589 988 E+06
section	meter² (m²)	2.589 988 E+06
township	meter² (m²)	9.323 957 E+07
yard²	meter² (m²)	8.361 274 E−01

Bending Moment or Torque

dyne-centimeter	newton-meter (N · m)	1.000 000*E−07
kilogram-force-meter	newton-meter (N · m)	9.806 650*E+00
ounce-force-inch	newton-meter (N · m)	7.061 552 E−03
pound-force-inch	newton-meter (N · m)	1.129 848 E−01
pound-force-foot	newton-meter (N · m)	1.355 818 E+00

(Bending Moment or Torque)/Length

pound-force-foot/inch	newton-meter/meter (N · m/m)	5.337 866 E+01
pound-force-inch/inch	newton-meter/meter (N · m/m)	4.448 222 E+00

Capacity (See Volume)

Density (See Mass/Volume)

Electricity and Magnetism[20]

abampere	ampere (A)	1.000 000*E+01

[20] ESU means electrostatic cgs unit. EMU means electromagnetic cgs unit.

E 380

To convert from	to	Multiply by
abcoulomb	coulomb (C)	1.000 000*E+01
abfarad	farad (F)	1.000 000*E+09
abhenry	henry (H)	1.000 000*E−09
abmho	mho	1.000 000*E+09
abohm	ohm (Ω)	1.000 000*E−09
abvolt	volt (V)	1.000 000*E−08
ampere (international of 1948)	ampere (A)	9.998 35 E−01
ampere-hour	coulomb (C)	3.600 000*E+03
coulomb (international of 1948)	coulomb (C)	9.998 35 E−01
EMU of capacitance	farad (F)	1.000 000*E+09
EMU of current	ampere (A)	1.000 000*E+01
EMU of electric potential	volt (V)	1.000 000*E−08
EMU of inductance	henry (H)	1.000 000*E−09
EMU of resistance	ohm (Ω)	1.000 000*E−09
ESU of capacitance	farad (F)	1.112 6 E−12
ESU of current	ampere (A)	3.335 6 E−10
ESU of electric potential	volt (V)	2.997 9 E+02
ESU of inductance	henry (H)	8.987 6 E+11
ESU of resistance	ohm (Ω)	8.987 6 E+11
farad (international of 1948)	farad (F)	9.995 05 E−01
faraday (based on carbon-12)	coulomb (C)	9.648 70 E+04
faraday (chemical)	coulomb (C)	9.649 57 E+04
faraday (physical)	coulomb (C)	9.652 19 E+04
gamma	tesla (T)	1.000 000*E−09
gauss	tesla (T)	1.000 000*E−04
gilbert	ampere-turn	7.957 747 E−01
henry (international of 1948)	henry (H)	1.000 495 E+00
maxwell	weber (Wb)	1.000 000*E−08
oersted	ampere/meter (A/m)	7.957 747 E+01
ohm (international of 1948)	ohm (Ω)	1.000 495 E+00
ohm-centimeter	ohm-meter (Ω · m)	1.000 000*E−02
statampere	ampere (A)	3.335 640 E−10
statcoulomb	coulomb (C)	3.335 640 E−10
statfarad	farad (F)	1.112 650 E−12
stathenry	henry (H)	8.987 554 E+11
statmho	mho	1.112 650 E−12
statohm	ohm (Ω)	8.987 554 E+11
statvolt	volt (V)	2.997 925 E+02
unit pole	weber (Wb)	1.256 637 E−07
volt (international of 1948)	volt (V)	1.000 330 E+00

Energy (Includes Work)

To convert from	to	Multiply by
British thermal unit (International Table)[15]	joule (J)	1.055 056 E+03
British thermal unit (mean)	joule (J)	1.055 87 E+03
British thermal unit (thermochemical)	joule (J)	1.054 350 E+03
British thermal unit (39 F)	joule (J)	1.059 67 E+03
British thermal unit (60 F)	joule (J)	1.054 68 E+03
calorie (International Table)	joule (J)	4.186 800*E+00
calorie (mean)	joule (J)	4.190 02 E+00
calorie (thermochemical)	joule (J)	4.184 000*E+00
calorie (15 C)	joule (J)	4.185 80 E+00
calorie (20 C)	joule (J)	4.181 90 E+00
calorie (kg, International Table)	joule (J)	4.186 800*E+03
calorie (kg, mean)	joule (J)	4.190 02 E+03
calorie (kg, thermochemical)	joule (J)	4.184 000*E+03
electron volt	joule (J)	1.602 10 E−19
erg	joule (J)	1.000 000*E−07
foot-pound-force	joule (J)	1.355 818 E+00
foot-poundal	joule (J)	4.214 011 E−02
joule (International of 1948)	joule (J)	1.000 165 E+00
kilocalorie (International Table)	joule (J)	4.186 800*E+03
kilocalorie (mean)	joule (J)	4.190 02 E+03
kilocalorie (thermochemical)	joule (J)	4.184 000*E+03

E 380

To convert from	to	Multiply by
kilowatt-hour	joule (J)	3.600 000*E+06
kilowatt-hour (international of 1948)	joule (J)	3.600 59 E+06
ton (nuclear equivalent of TNT)	joule (J)	4.20 E+09
watt-hour	joule (J)	3.600 000*E+03
watt-second	joule (J)	1.000 000*E+00

ENERGY/AREA TIME

Btu (thermochemical)/foot²-second	watt/meter² (W/m²)	1.134 893 E+04
Btu (thermochemical)/foot²-minute	watt/meter² (W/m²)	1.891 489 E+02
Btu (thermochemical)/foot²-hour	watt/meter² (W/m²)	3.152 481 E+00
Btu (thermochemical)/inch²-second	watt/meter² (W/m²)	1.634 246 E+06
calorie (thermochemical)/centimeter²-minute	watt/meter² (W/m²)	6.973 333 E+02
erg/centimeter²-second	watt/meter² (W/m²)	1.000 000*E−03
watt/centimeter²	watt/meter² (W/m²)	1.000 000*E+04

FLOW (SEE MASS/TIME OR VOLUME/TIME)

FORCE

dyne	newton (N)	1.000 000*E−05
kilogram-force	newton(N)	9.806 650*E+00
kilopond-force	newton (N)	9.806 650*E+00
kip	newton (N)	4.448 222 E+03
ounce-force (avoirdupois)	newton (N)	2.780 139 E−01
pound-force (lbf avoirdupois)[18]	newton (N)	4.448 222 E+00
pound-force (lbf avoirdupois)[19]	kilogram-force[21]	4.535 924 E−01
poundal	newton (N)	1.382 550 E−01

FORCE/AREA (SEE PRESSURE)

FORCE/LENGTH

pound-force/inch	newton/meter (N/m)	1.751 268 E+02
pound-force/foot	newton/meter (N/m)	1.459 390 E+01

HEAT

Btu (thermochemical) · in./s · ft² · deg F (*k*, thermal conductivity)	watt/meter-kelvin (W/m · K)	5.188 732 E+02
Btu (Inthernational Table) · in./s · ft² · deg F (*k*, thermal conductivity)	watt/meter-kelvin (W/m · K)	5.192 204 E+02
Btu (thermochemical) · in./h · ft² · deg F (*k*, thermal conductivity)	watt/meter-kelvin (W/m · K)	1.441 314 E−01
Btu (International Table) · in./h · ft² · deg F (*k*, thermal conductivity)	watt/meter-kelvin (W/m · K)	1.442 279 E−01
Btu (International Table)/ft²	joule/meter² (J/m²)	1.135 653 E+04
Btu (thermochemical)/ft²	joule/meter² (J/m²)	1.134 893 E+04
Btu (International Table)/h · ft² · deg F (*C*, thermal conductance)	watt/meter²-kelvin (W/m² · K)	5.678 263 E+00
Btu (thermochemical)/h · ft² · deg F (*C*, thermal conductance)	watt/meter²-kelvin (W/m² · K)	5.674 466 E+00
Btu (International Table)/pound-mass	joule/kilogram (J/kg)	2.326 000*E+03
Btu (thermochemical)/pound-mass	joule/kilogram (J/kg)	2.324 444 E+03

[21] The metric unit of force, the newton, is approximately 1/10 kgf.

E 380

To convert from	to	Multiply by
Btu (International Table)/lbm · deg F (*c*, heat capacity)	joule/kilogram-kelvin (J/kg · K)	4.186 800*E+03
Btu (thermochemical)/lbm · deg F (*c*, heat capacity)	joule/kilogram-kelvin (J/kg · K)	4.184 000 E+03
Btu (International Table)/s · ft² · deg F	watt/meter²-kelvin (W/m² · K)	2.044 175 E+04
Btu (thermochemical)/s · ft² · deg F	watt/meter²-kelvin (W/m² · K)	2.042 808 E+04
cal (thermochemical)/cm²	joule/meter² (J/m²)	4.184 000*E+04
cal (thermochemical)/cm² · s	watt/meter² (W/m²)	4.184 000*E+04
cal (thermochemical)/cm · s · deg C	watt/meter-kelvin (W/m · K)	4.184 000*E+02
cal (International Table)/g	joule/kilogram (J/kg)	4.186 800*E+03
cal (International Table)/g · deg C	joule/kilogram-kelvin (J/kg · K)	4.186 800*E+03
cal (thermochemical)/g	joule/kilogram (J/kg)	4.184 000*E+03
cal (thermochemical)/g · deg C	joule/kilogram-kelvin (J/kg · K)	4.184 000*E+03
clo	kelvin-meter²/watt (K · m²/W)	2.003 712 E−01
deg F · h · ft²/Btu (thermochemical) (*R*, thermal resistance)	kelvin-meter²/watt (K · m²/W)	1.762 280 E−01
deg F · h · ft²/Btu (International Table) (*R*, thermal resistance)	kelvin-meter²/watt (K · m²/W)	1.761 102 E−01
ft²/h (thermal diffusivity)	meter²/second (m²/s)	2.580 640*E−05

Length

angstrom	meter (m)	1.000 000*E−10
astronomical unit	meter (m)	1.495 98 E+11
caliber	meter (m)	2.540 000*E−04
fathom	meter (m)	1.828 800*E+00
fermi (femtometer)	meter (m)	1.000 000*E−15
foot	meter (m)	3.048 000*E−01
foot (U.S. survey)	meter (m)	1200/3937*E+00
foot (U.S. survey)	meter (m)	3.048 006 E−01
inch	meter (m)	2.540 000*E−02
league (international nautical)	meter (m)	5.556 000*E+03
league (statute)	meter (m)	4.828 032*E+03
league (U.K. nautical)	meter (m)	5.559 552*E+03
light year	meter (m)	9.460 55 E+15
micron	meter (m)	1.000 000*E−06
mil	meter (m)	2.540 000*E−05
mile (international nautical)	meter (m)	1.852 000*E+03
mile (U.K. nautical)	meter (m)	1.853 184*E+03
mile (U.S. nautical)	meter (m)	1.852 000*E+03
mile (U.S. statute)	meter (m)	1.609 344*E+03
parsec	meter (m)	3.083 74 E+16
pica (printer's)	meter (m)	4.217 518 E−03
point (printer's)	meter (m)	3.514 598*E−04
rod	meter (m)	5.029 200*E+00
statute mile (U.S.)	meter (m)	1.609 344*E+03
yard	meter (m)	9.144 000*E−01

Light

footcandle	lumen/meter² (lm/m²)	1.076 391 E+01
footcandle	lux (lx)	1.076 391 E+01
footlambert	candela/meter² (cd/m²)	3.426 3 E+00
lux	lumen/meter² (lm/m²)	1.000 000*E+00

Mass

carat (metric)	kilogram (kg)	2.000 000*E−04
grain	kilogram (kg)	6.479 891*E−05
gram	kilogram (kg)	1.000 000*E−03
hundredweight (long)	kilogram (kg)	5.080 235 E+01

E 380

To convert from	to	Multiply by
hundredweight (short)	kilogram (kg)	4.535 924 E+01
kilogram-force-second^2/meter (mass)	kilogram (kg)	9.806 650*E+00
kilogram-mass	kilogram (kg)	1.000 000*E+00
ounce-mass (avoirdupois)	kilogram (kg)	2.834 952 E−02
ounce-mass (troy or apothecary)	kilogram (kg)	3.110 348 E−02
pennyweight	kilogram (kg)	1.555 174 E−03
pound-mass (lbm avoirdupois)[19]	kilogram (kg)	4.535 924 E−01
pound-mass (troy or apothecary)	kilogram (kg)	3.732 417 E−01
slug	kilogram (kg)	1.459 390 E+01
ton (assay)	kilogram (kg)	2.916 667 E−02
ton (long, 2240 lbm)	kilogram (kg)	1.016 047 E+03
ton (metric)	kilogram (kg)	1.000 000*E+03
ton (short, 2000 lbm)	kilogram (kg)	9.071 847 E+02
tonne	kilogram (kg)	1.000 000*E+03

Mass/Area

To convert from	to	Multiply by
ounce-mass/yard^2	kilogram/meter^2 (kg/m^2)	3.390 575 E−02
pound-mass/foot^2	kilogram/meter^2 (kg/m^2)	4.882 428 E+00

Mass/Capacity (See Mass/Volume)

Mass/Time (Includes Flow)

To convert from	to	Multiply by
perm (0 C)	kilogram/newton-second (kg/N · s)	5.721 35 E−11
perm (23 C)	kilogram/newton-second (kg/N · s)	5.745 25 E−11
perm-inch (0 C)	kilogram-meter/newton-second (kg · m/N · s)	1.453 22 E−12
perm-inch (23 C)	kilogram-meter/newton-second (kg · m/N · s)	1.459 29 E−12
pound-mass/second	kilogram/second (kg/s)	4.535 924 E−01
pound-mass/minute	kilogram/second (kg/s)	7.559 873 E−03
ton (short, mass)/hour	kilogram/second (kg/s)	2.519 958 E−01

Mass/Volume (Includes Density and Mass Capacity)

To convert from	to	Multiply by
grain (lbm avoirdupois/7000)/gallon (U.S. liquid)	kilogram-meter^3 (kg/m^3)	1.711 806 E−02
gram/centimeter^3	kilogram/meter^3 (kg/m^3)	1.000 000*E+03
ounce (avoirdupois)/gallon (U.K. liquid)	kilogram/meter^3 (kg/m^3)	6.236 027 E+00
ounce (avoirdupois)/gallon (U.S. liquid)	kilogram/meter^3 (kg/m^3)	7.489 152 E+00
ounce (avoirdupois) (mass)/inch^3	kilogram/meter^3 (kg/m^3	1.729 994 E+03
pound-mass/foot^3	kilogram/meter^3 (kg/m^3)	1.601 846 E+01
pound-mass/inch^3	kilogram/meter^3 (kg/m^3)	2.767 990 E+04
pound-mass/gallon (U.K. liquid)	kilogram/meter^3 (kg/m^3)	9.977 644 E+01
pound-mass/gallon (U.S. liquid)	kilogram/meter^3 (kg/m^3)	1.198 264 E+02
slug/foot^3	kilogram/meter^3 (kg/m^3)	5.153 788 E+02
ton (long, mass)/yard^3	kilogram/meter^3 (kg/m^3)	1.328 939 E+03

Power

To convert from	to	Multiply by
Btu (International Table)/hour	watt (W)	2.930 711 E−01
Btu (thermochemical)/second	watt (W)	1.054 350 E+03
Btu (thermochemical)/minute	watt (W)	1.757 250 E+01
Btu (thermochemical)/hour	watt (W)	2.928 751 E−01
calorie (thermochemical)/second	watt (W)	4.184 000*E+00

E 380

To convert from	to	Multiply by
calorie (thermochemical)/minute	watt (W)	6.973 333 E−02
erg/second	watt (W)	1.000 000*E−07
foot-pound-force/hour	watt (W)	3.766 161 E−04
foot-pound-force/minute	watt (W)	2.259 697 E−02
foot-pound-force/second	watt (W)	1.355 818 E+00
horsepower (550 ft · lbf/s)	watt (W)	7.456 999 E+02
horsepower (boiler)	watt (W)	9.809 50 E+03
horsepower (electric)	watt (W)	7.460 000*E+02
horsepower (metric)	watt (W)	7.354 99 E+02
horsepower (water)	watt (W)	7.460 43 E+02
horsepower (U.K.)	watt (W)	7.457 0 E+02
kilocalorie (thermochemical)/minute	watt (W)	6.973 333 E+01
kilocalorie (thermochemical)/second	watt (W)	4.184 000*E+03
watt (international of 1948)	watt (W)	1.000 165 E+00

Pressure or Stress (Force/Area)

atmosphere (normal = 760 torr)	newton/meter^2 (N/m^2)	1.013 250*E+05
atmosphere (technical = 1 kgf/cm^2)	newton/meter^2 (N/m^2)	9.806 650*E+04
bar	newton/meter^2 (N/m^2)	1.000 000*E+05
centimeter of mercury (0 C)	newton/meter^2 (N/m^2)	1.333 22 E+03
centimeter of water (4 C)	newton/meter^2 (N/m^2)	9.806 38 E+01
decibar	newton/meter^2 (N/m^2)	1.000 000*E+04
dyne/centimeter^2	newton/meter^2 (N/m^2)	1.000 000*E−01
foot of water (39.2 F)	newton/meter^2 (N/m^2)	2.988 98 E+03
gram-force/centimeter^2	newton/meter^2 (N/m^2)	9.806 650*E+01
inch of mercury (32 F)	newton/meter^2 (N/m^2)	3.386 389 E+03
inch of mercury (60 F)	newton/meter^2 (N/m^2)	3.376 85 E+03
inch of water (39.2 F)	newton/meter^2 (N/m^2)	2.490 82 E+02
inch of water (60 F)	newton/meter^2 (N/m^2)	2.488 4 E+02
kilogram-force/centimeter^2	newton/meter^2 (N/m^2)	9.806 650*E+04
kilogram-force/meter^2	newton/meter^2 (N/m^2)	9.806 650*E+00
kilogram-force/millimeter^2	newton/meter^2 (N/m^2)	9.806 650*E+06
kip/inch^2	newton/meter^2 (N/m^2)	6.894 757 E+06
millibar	newton/meter^2 (N/m^2)	1.000 000*E+02
millimeter of mercury (0 C)	newton/meter^2 (N/m^2)	1.333 224 E+02
pascal	newton/meter^2 (N/m^2)	1.000 000*E+00
poundal/foot^2	newton/meter^2 (N/m^2)	1.488 164 E+00
pound-force/foot^2	newton/meter^2 (N/m^2)	4.788 026 E+01
pound-force/inch^2 (psi)	newton/meter^2 (N/m^2)	6.894 757 E+03
pound-force/inch^2 (psi)	kilogram-force/mm^2 [22]	7.030 696 E−04
psi	newton/meter^2 (N/m^2)	6.894 757 E+03
torr (mm Hg, 0 C)	newton/meter^2 (N/m^2)	1.333 22 E+02

Speed (See Velocity)

Stress (See Pressure)

Temperature

degree Celsius	kelvin (K)	$t_K = t_C + 273.15$
degree Fahrenheit	kelvin (K)	$t_K = (t_F + 459.67)/1.8$
degree Rankine	kelvin (K)	$t_K = t_R/1.8$
degree Fahrenheit	degree Celsius	$t_C = (t_F - 32)/1.8$
kelvin	degree Celsius	$t_C = t_K - 273.15$

[22] The metric unit of pressure or stress is the newton per square meter (N/m^2). 1 kgf/mm^2 is approximately 10^7 N/m^2 or 10 MN/m^2.

E 380

Time

To convert from	to	Multiply by
day (mean solar)	second (s)	8.640 000 E+04
day (sidereal)	second (s)	8.616 409 E+04
hour (mean solar)	second (s)	3.600 000 E+03
hour (sidereal)	second (s)	3.590 170 E+03
minute (mean solar)	second (s)	6.000 000 E+01
minute (sidereal)	second (s)	5.983 617 E+01
month (mean calendar)	second (s)	2.628 000 E+06
second (sidereal)	second (s)	9.972 696 E−01
year (calendar)	second (s)	3.153 600 E+07
year (sidereal)	second (s)	3.155 815 E+07
year (tropical)	second (s)	3.155 693 E+07

Torque (See Bending Moment)

Velocity (Includes Speed)

To convert from	to	Multiply by
foot/hour	meter/second (m/s)	8.466 667 E−05
foot/minute	meter/second (m/s)	5.080 000*E−03
foot/second	meter/second (m/s)	3.048 000*E−01
inch/second	meter/second (m/s)	2.540 000*E−02
kilometer/hour	meter/second (m/s)	2.777 778 E−01
knot (international)	meter/second (m/s)	5.144 444 E−01
mile/hour (U.S. statute)	meter/second (m/s)	4.470 400*E−01
mile/minute (U.S. statute)	meter/second (m/s)	2.682 240*E+01
mile/second (U.S. statute)	meter/second (m/s)	1.609 344*E+03
mile/hour (U.S. statute)	kilometer/hour[21]	1.609 344*E+00

Viscosity

To convert from	to	Multiply by
centipoise	newton-second/meter^2 ($N \cdot s/m^2$)	1.000 000*E−03
centistoke	meter^2/second (m^2/s)	1.000 000*E−06
foot^2/second	meter^2/second (m^2/s)	9.290 304*E−02
poise	newton-second/meter^2 ($N \cdot s/m^2$)	1.000 000*E−01
poundal-second/foot^2	newton-second/meter^2 ($N \cdot s/m^2$)	1.488 164 E+00
pound-mass/foot-second	newton-second/meter^2 ($N \cdot s/m^2$)	1.488 164 E+00
pound-force-second/foot^2	newton-second/meter^2 ($N \cdot s/m^2$)	4.788 026 E+01
rhe	meter^2/newton-second ($m^2/N \cdot s$)	1.000 000*E+01
slug/foot-second	newton-second/meter^2 ($N \cdot s/m^2$)	4.788 026 E+01
stoke	meter^2/second (m^2/s)	1.000 000*E−04

Volume (Includes Capacity)

To convert from	to	Multiply by
acre-foot	meter^3 (m^3)	1.233 482 E+03
barrel (oil, 42 gal)	meter^3 (m^3)	1.589 873 E−01
board foot	meter^3 (m^3)	2.359 737 E−03
bushel (U.S.)	meter^3 (m^3)	3.523 907 E−02
cup	meter^3 (m^3)	2.365 882 E−04
fluid ounce (U.S.)	meter^3 (m^3)	2.957 353 E−05
foot^3	meter^3 (m^3)	2.831 685 E−02
gallon (Canadian liquid)	meter^3 (m^3)	4.546 122 E−03
gallon (U.K. liquid)	meter^3 (m^3)	4.546 087 E−03
gallon (U.S. dry)	meter^3 (m^3)	4.404 884 E−03

[21] Although speedometers may read km/h, the correct SI unit is m/s.

E 380

To convert from	to	Multiply by
gallon (U.S. liquid)	meter^3 (m^3)	3.785 412 E−03
gill (U.K.)	meter^3 (m^3)	1.420 652 E−04
gill (U.S.)	meter^3 (m^3)	1.182 941 E−04
inch^3 [24]	meter^3 (m^3)	1.638 706 E−05
liter[16]	meter^3 (m^3)	1.000 000*E−03
ounce (U.K. fluid)	meter^3 (m^3)	2.841 305 E−05
ounce (U.S. fluid)	meter^3 (m^3)	2.957 353 E−05
peck (U.S.)	meter^3 (m^3)	8.809 768 E−03
pint (U.S. dry)	meter^3 (m^3)	5.506 105 E−04
pint (U.S. liquid)	meter^3 (m^3)	4.731 765 E−04
quart (U.S. dry)	meter^3 (m^3)	1.101 221 E−03
quart (U.S. liquid)	meter^3 (m^3)	9.463 529 E−04
stere	meter^3 (m^3)	1.000 000*E+00
tablespoon	meter^3 (m^3)	1.478 676 E−05
teaspoon	meter^3 (m^3)	4.928 922 E−06
ton (register)	meter^3 (m^3)	2.831 685 E+00
yard^3	meter^3 (m^3)	7.645 549 E−01

Volume/Time (Includes Flow)

foot^3/minute	meter^3/second (m^3/s)	4.719 474 E−04
foot^3/second	meter^3/second (m^3/s)	2.831 685 E−02
inch^3/minute	meter^3/second (m^3/s)	2.731 177 E−07
yard^3/minute	meter^3/second (m^3/s)	1.274 258 E−02
gallon (U.S. liquid)/day	meter^3/second (m^3/s)	4.381 264 E−08
gallon (U.S. liquid/minute	meter^3/second (m^3/s)	6.309 020 E−05

Work (See Energy)

References

American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103:

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(2) Method D 2161, Conversion of Kinematic Viscosity to Saybolt Universal Viscosity or to Saybolt Furol Viscosity
(3) Petroleum Measurement Tables D 1250
(4) Rec. Practice D 1914, Conversion Units and Factors Relating to Atmospheric Analysis
(5) Rec. Practice E 29, for Indicating Which Places of Figures Are to Be Considered Significant in Specified Limiting Values

American National Standards Institute, Inc., 1430 Broadway, New York, N. Y. 10018:

(6) American National Standard Z10.1-1941, Abbreviations for Scientific and Engineering Terms
(7) American National Standard B48.1-1933 (R1947), Inch-Millimeter Conversion for Industrial Use, Practice for (ISO R370-1964)

International Organization for Standardization, Geneva, Switzerland (available from American National Standards Institute):

(8) ISO/R31/Part I—1956, Basic Quantities and Units of the SI
(9) ISO/R31/Part II—1958, Quantities and Units of Periodic and Related Phenomena
(10) ISO/R31/Part III—1960, Quantities and Units of Mechanics
(11) ISO/R31/Part IV—1960, Quantities and Units of Heat
(12) ISO/R31/Part V—1965, Quantities and Units of Electricity and Magnetism
(13) ISO/R1000—1969, Rules for the Use of Units of the International System of Units and a Selection of the Decimal Multiples and Sub-Multiples of the SI Units

[24] The exact conversion factor is 1.638 706 4*E−05.

E 380

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Miscellaneous:

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(20) Palmer, J. F., "The International System of Units Handbook," Brown Engineering Co., Inc., Huntsville, Ala.
(21) McNish, A. G., "The International System of Units," *Materials Research & Standards*, Am. Soc. Testing Mats., Vol 5, No. 10, October 1965
(22) "Conversion Factors and Tables," British Standard 350, Part 1, 1959.
(23) "Conversion Factors and Tables," British Standard 350, Part 2, 1962.
(24) "Changing to the Metric System, Conversion Factors, Symbols, Definitions," Nat. Physical Lab., Her Majesty's Stationery Office, London, England, 1965
(25) *Metric Standards for Engineering*, British Standard Handbook No. 18 (1966)

Index of Terms

(by Section Number)

E 380

TABLE 1 Rounding of Minimum and Maximum Limits

Note—The table can be extended on the same basis in either direction as the need arises. Use of the table will result in maximum differences of 1 percent between the actual and rounded values.

Numerical Range		Round to Nearest
from	but less than	
0.005	0.025	0.0001
0.025	0.05	0.0005
0.05	0.25	0.001
0.25	0.5	0.005
0.5	2.5	0.01
2.5	5	0.05
5	25	0.1
25	50	0.5
50	250	1
250	500	5
500	2 500	10
2 500	5 000	50
5 000	25 000	100
25 000	50 000	500
50 000	250 000	1 000

TABLE 2 Inch-Millimeter Equivalents

Note—All values in this table are exact, based on the relation 1 in. = 25.4 mm. By manipulation of the decimal point any decimal value or multiple of an inch may be converted to its exact equivalent in millimeters.

in.	0	1	2	3	4	5	6	7	8	9
					mm					
0		25.4	50.8	76.2	101.6	127.0	152.4	177.8	203.2	228.6
10	254.0	279.4	304.8	330.2	355.6	381.0	406.4	431.8	457.2	482.6
20	508.0	533.4	558.8	584.2	609.6	635.0	660.4	685.8	711.2	736.6
30	762.0	787.4	812.8	838.2	863.6	889.0	914.4	939.8	965.2	990.6
40	1016.0	1041.4	1066.8	1092.2	1117.6	1143.0	1168.4	1193.8	1219.2	1244.6
50	1270.0	1295.4	1320.8	1346.2	1371.6	1397.0	1422.4	1447.8	1473.2	1498.6
60	1524.0	1549.4	1574.8	1600.2	1625.6	1651.0	1676.4	1701.8	1727.2	1752.6
70	1778.0	1803.4	1828.8	1854.2	1879.6	1905.0	1930.4	1955.8	1981.2	2006.6
80	2032.0	2057.4	2082.8	2108.2	2133.6	2159.0	2184.4	2209.8	2235.2	2260.6
90	2286.0	2311.4	2336.8	2362.2	2387.6	2413.0	2438.4	2463.8	2489.2	2514.6
100	2540.0									

E 380

TABLE 3 Inch-Millimeter Equivalents of Decimal and Common Fractions
From 1/64 to 1 in.

Inch	½'s	¼'s	8ths	16ths	32nds	64ths	Millimeters	Decimals of an Inch[a]
						1	0.397	0.051 625
					1	2	0.794	0.031 25
						3	1.191	0.046 875
				1	2	4	1.588	0.062 5
						5	1.984	0.078 125
					3	6	2.381	0.093 75
						7	2.778	0.109 375
			1	2	4	8	3.175[a]	0.125 0
						9	3.572	0.140 625
					5	10	3.969	0.156 25
						11	4 366	0.171 875
				3	6	12	4.762	0.187 5
						13	5.159	0.203 125
					7	14	5.556	0.218 75
						15	5.953	0.234 375
		1	2	4	8	16	6.350[a]	0.250 0
						17	6.747	0.265 625
					9	18	7.144	0.281 25
						19	7.541	0.296 875
				5	10	20	7.938	0.312 5
						21	8.334	0.328 125
					11	22	8.731	0.343 75
						23	9 128	0.359 375
			3	6	12	24	9.525[a]	0.375 0
						25	9.922	0.390 625
					13	26	10.319	0.406 25
						27	10.716	0.421 875
				7	14	28	11.112	0.437 5
						29	11.509	0.453 125
					15	30	11.906	0.468 75
						31	12.303	0.484 375
1	2	4	8	16	32	12.700[a]	0.500 0
						33	13.097	0.515 625
					17	34	13.494	0.531 25
						35	13.891	0.546 875
				9	18	36	14.288	0.562 5
						37	14.684	0.578 125
					19	38	15.081	0.593 75
						39	15.478	0.609 375
			5	10	20	40	15.875[a]	0.625 0
						41	16.272	0.640 625
					21	42	16.669	0.656 25
						43	17.066	0.671 875
				11	22	44	17.462	0.687 5
						45	17.859	0.703 125
					23	46	18.256	0.718 75
						47	18.653	0.734 375
		3	6	12	24	48	19.050[a]	0.750 0
						49	19.447	0.765 625
					25	50	19.844	0.781 25
						51	20.241	0.796 875
				13	26	52	20.638	0.812 5

E 380

TABLE 3—*Continued*

Inch	½'s	¼'s	8ths	16ths	32nds	64ths	Millimeters	Decimals of an Inch[a]
						53	21.034	0.828 125
					27	54	21.431	0.843 75
						55	21.828	0.859 375
			7	14	28	56	22.225[a]	0.875 0
						57	22.622	0.890 625
					29	58	23.019	0.906 25
						59	23.416	0.921 875
				15	30	60	23.812	0.937 5
						61	24.209	0.953 125
					31	62	24.606	0.968 75
						63	25.003	0.984 375
1	2	4	8	16	32	64	25.400[a]	1.000 0

[a] Exact.

TABLE 4 Rounding Tolerances
Inches to Millimeters

Original Tolerance, in.		Fineness of Rounding, mm
at least	less than	
0.000 01	0.000 1	0.000 01
0.000 1	0.001	0.000 1
0.001	0.01	0.001
0.01	0.1	0.01
0.1	1	0.1

TABLE 5 Conversion of Temperature Tolerance Requirements

Tolerance, deg F	±1	±2	±5	±10	±15	±20	±25
Tolerance, K or deg C...	±0.5	±1.1	±3	±5.5	±8	±11	±14

TABLE 6 Pressure and Stress Equivalents—Pounds-Force per Square Inch and Thousand Pounds-Force per Square Inch to Meganewtons per Square Meter

NOTE 1—This table may be used to obtain SI equivalents of values expressed in psi or ksi. SI values are usually expressed in kN/m² when original value is in psi and in MN/m² when original value is in ksi.

NOTE 2—This table may be extended to values below 1 or above 100 psi (ksi) by manipulation of the decimal point and addition as illustrated in 4.4.1.4.

Conversion Relationships: 1 in. = 0.0254 m (exactly)
1 lbf = 4.448 221 615 260 5 N (exactly)

psi ksi	0	1	2	3	4	5	6	7	8	9
						kN/m² MN/m²				
0	0.0000	6.8948	13.7895	20.6843	27.5790	34.4738	41.3685	48.2633	55.1581	62.0528
10	68.9476	75.8423	82.7371	89.6318	96.5266	103.4214	110.3161	117.2109	124.1056	131.0004
20	137.8951	144.7899	151.6847	158.5794	165.4742	172.3689	179.2637	186.1584	193.0532	199.9480
30	206.8427	213.7375	220.6322	227.5270	234.4217	241.3165	248.2113	255.1060	262.0008	268.8955
40	275.7902	282.6850	289.5798	296.4746	303.3693	310.2641	317.1588	324.0536	330.9483	337.8431
50	344.7379	351.6326	358.5274	365.4221	372.3169	379.2116	386.1064	393.0012	399.8959	406.7907
60	413.6854	420.5802	427.4749	434.3697	441.2645	448.1592	455.0540	461.9487	468.8435	475.7382
70	482.6330	489.5278	496.4225	503.3173	510.2120	517.1068	524.0015	530.8963	537.7911	544.6858
80	551.5806	558.4753	565.3701	572.2648	579.1596	586.0544	592.9491	599.8439	606.7386	613.6334
90	620.5281	627.4229	634.3177	641.2124	648.1072	655.0019	661.8967	668.7914	675.6862	682.5810
100	689.4757									

TABLE 7 Pressure and Stress Equivalents—Metric Engineering to SI Units

NOTE 1—This table may be used for obtaining SI equivalents of quantities expressed in kgf/cm^2 by multiplying the given values by 10^{-2}, that is, by moving the decimal point two places to the left.

NOTE 2—This table may be extended to values below 1 or above 100 kgf/cm^2 by manipulation of the decimal point and addition as illustrated in 4.4.1.4.

Conversion Relationships: 1 mm = 0.001 m (exactly)
1 kgf = 9.80665 N (exactly)

kgf/mm^2	0	1	2	3	4	5	6	7	8	9
					MN/m^2					
0		9.8066	19.6133	29.4200	39.2266	49.0332	58.8399	68.6466	78.4532	88.2598
10	98.0665	107.8731	117.6798	127.4864	137.2931	147.0998	156.9064	166.7130	176.5197	186.3264
20	196.1330	205.9396	215.7463	225.5530	235.3596	245.1662	254.9729	264.7796	274.5862	284.3928
30	294.1995	304.0062	313.8128	323.6194	333.4261	343.2328	353.0394	362.8460	372.6527	382.4594
40	392.2660	402.0726	411.8793	421.6860	431.4926	441.2992	451.1059	460.9126	470.7192	480.5258
50	490.3325	500.1392	509.9458	519.7524	529.5591	539.3658	549.1724	558.9790	568.7857	578.5924
60	588.3990	598.2056	608.0123	617.8190	627.6256	637.4322	647.2389	657.0456	666.8522	676.6588
70	686.4655	696.2722	706.0788	715.8854	725.6921	735.4988	745.3054	755.1120	764.9187	774.7254
80	784.5320	794.3386	804.1453	813.9520	823.7586	833.5652	843.3719	853.1786	862.9852	872.7918
90	882.5985	892.4052	902.2118	912.0184	921.8251	931.6318	941.4384	951.2450	961.0517	970.8584
100	980.6650									

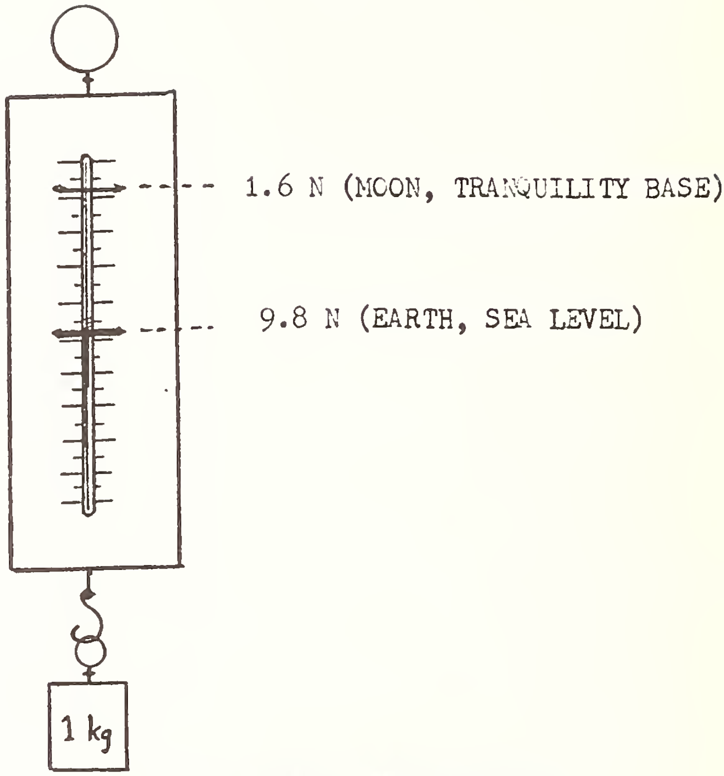

FIG. 1 Illustration of Difference Between Mass (Unit = Kilogram) and Force (Unit = Newton).

COMPATIBILITY OF SCREW THREADS

Equations are developed for determining the compatibility of comparable standards; i.e., standards sufficiently identical in thread profile such that compatibility can be achieved by scaling size.

A. General plan.

1. In this study, threads are considered to be compatible if mating parts, such as a nut and a bolt

   a. Fit together without interference over a sufficient length of threaded segment as to be considered adequate. This length, called "length of engagement" is usually considered adequate for general use if it equals 1 1/2 diameters.[1]

   b. Fit together with sufficient overlap of material of internal and external thread as to insure strength of coupling and with sufficient binding or friction as to resist loosening due to vibration, etc.

2. Given the nominal profile of the thread, which can be defined by dimensionless quantities, the considerations above lead to the establishment of minimum and maximum values for the dimensions of various thread elements such as

   a. Major diameter (that diameter measured at the crests of the external thread and the roots of the internal thread).

   b. Minor diameter (that diameter measured at the roots of the external thread and at the crest of the internal thread).

   c. The pitch diameter (see A.4 below).

3. Thus, in evaluating the compatibility of external with internal thread one has knowledge of the dimensions of the maximum profile of the thread beyond which material cannot exist if interference is to be avoided and also minimum profile which must be filled with material if the threaded coupling is to serve its function. It is the practice of thread standards to give as "basic values" those dimensions of thread elements that define the maximum profile and to specify as tolerance and allowance, departures from basic values that define minimum profile. Although the sum of tolerance and allowance defines the minimum profile (of importance to the study) allowance is usually specified separately to insure a minimum clearance for some classes of threads to facilitate ease of assembly or to provide for plated finishes or other coatings. In this survey for compatibility the sum of the tolerance and allowance values will be considered significant. In other words, one thread will be considered equivalent to another thread if basic values of the elements of one thread fall between the maximum and minimum profile of the other.

[1] Handbook H28 (1969) pt. 1, sec. 2, par. 7, p. 2.21.

422-764 OL - 71 - 13

4. In comparing threads of the same shape, but of different dimensions, the similarity of pitch diameter is most critical and implicitly provides limitation on the differences in pitch that can be tolerated between two dissimilar threads.

a. In general, standards specify significantly smaller magnitude of tolerance on pitch diameter than they do for major or minor diameters. Dissimilar threads that can be adjusted to fit utilizing pitch diameter tolerances can also be adjusted to fit at root and crest utilizing major and minor diameter tolerances.

b. There are two aspects of pitch diameter—a geometrical aspect and a functional aspect. The geometrical pitch diameter (called "pitch diameter" or "simple pitch diameter") is the diameter of that imaginary cylinder whose surface would pass through a straight thread in such a manner as to make the widths of the thread ridges and the thread groove equal.[2]

The functional pitch diameter (called the "virtual pitch diameter") is the pitch diameter of the enveloping thread of perfect pitch, lead and flank angles and with specified length of engagement. It is derived by adding to the pitch diameter in case of an external thread or subtracting from the pitch diameter of an internal thread, the cumulative effects of deviations from perfect profile, including variations in lead and flank angle over the specified length of engagement.[3] The cumulative effect due to deviation from perfect pitch is[4]

$$\Delta D = (\pm \delta P) \text{ Cot } \alpha$$

where $\alpha = \dfrac{\text{THREAD APEX ANGLE}}{2}$

$$(\pm \delta P) = \frac{L_e}{P_a} |P_a - P_b|$$

L_e = length of engagement (positive locking will occur).

P_a = the perfect pitch

$|P_a - P_b|$ = the absolute value of deviation from perfect pitch.

ΔD = deviation added to the pitch diameter in the case of external threads and subtracted from the pitch diameter in case of internal threads.

5. As tolerances on screw thread elements are meant to provide maximum and minimum dimensions for screw thread profile, tolerances on pitch diameter have the following relation to pitch diameter and to vertical pitch diameter.

a. The maximum-material pitch diameter limits are a limitation on the virtual pitch diameter.[5]

b. The minimum-material pitch diameter limits are a limitation on the pitch diameter.[5]

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[2] Handbook H28 (1969) pt. 1, sec. 1, par. 6.21, p. 1.05.

[3] Handbook H28 (1969) pt. 1, sec. 1, par. 6.24, p. 1.05.

[4] Handbook H28 (1969) pt. 1, sec. 2, par. 8.2, p. 2.22.

[5] Handbook H28 (1969) pt. 1, sec. 2, par. 8, p. 2.21.

6. As pitch diameter tolerances are, in general, most critical and as the effective pitch diameter (virtual) is a function of the geometrical pitch diameter, the difference in pitch between mating parts and the length of engagement, the general plan for assessment of the compatibility of threads of different standards is to utilize these degrees of freedom to identify pitches and pitch diameters that would be interchangeable with U.S. and International Metric Standard Threads.

a. A fundamental requirement is that threads of different standards have compatible shape; that is, that compatibility can be achieved by modification of dimension rather than modification of shape.

b. Threads of U.S. and ISO Standards that have compatible shape all provide for a thread apex angle of 60 degrees. Therefore, the equation of A.4.b reduces to $\Delta D = (\pm \delta P)\ 1.732051$.

B. Defining a screw thread that is interchangeable in pitch diameter with a U.S. Thread and an ISO Metric Thread.

1. The pitch and pitch diameter of the external thread must be chosen such that the virtual pitch diameter equals the basic pitch diameter of the internal thread as specified in either the U.S. Standard or the ISO Metric Standard.

$$D_e = D_1 - 1.732051\, L_{e1}|1 - P_e/P_1| = D_2 - 1.732051\, L_{e2}|1 - P_e/P_2| \qquad (1)$$

D_e = the basic pitch diameter of the proposed external thread
P_e = the pitch of the proposed external thread
D_1 = the basic pitch diameter of the U.S. internal thread[6]
P_1 = the pitch of the U.S. internal thread[6]
D_2 = the basic pitch diameter of the ISO internal thread[7]
P_2 = the pitch of the ISO internal thread[7]
L_{e1} = the maximum length of engagement when coupled with a U.S. internal thread. As locking will occur at this length, it must equal or exceed length of engagement required of US threads for normal usage; i.e., approximately 1.5 D_1.
L_{e2} = the maximum length of engagement when coupled with a ISO internal thread. As locking will occur at this length, it must equal or exceed length of engagement required of ISO threads for normal usage; i.e., approximately 1.5 D_2.

2. The pitch and pitch diameter of the internal thread must be chosen such that the virtual pitch diameter equals the basic pitch diameter of the external thread as specified in either the U.S. Standard or the ISO Metric Standard.

$$D_n = D_1 1.732051 L_{e1}[1 - P_n/P_1] = D_2 1.732051 L_{e1}[1 - P_n/P_2] \qquad (2)$$

D_n = The basic pitch diameter of the proposed internal thread
P_n = The pitch of the proposed internal thread

[6] This value is the same for U.S. external and internal threads.
[7] This value is the same for ISO external and internal threads.

3. From equations 1 and 2, expressions for P_2 and P_n are derived. P_e and P_n are limited to values between P_1 and P_2.

$$P_e = \left[(L_{e1} + L_{e2}) \pm \frac{(D_1 - D_2)}{1.732051} \right] \frac{P_1 P_2}{L_{e1} P_1 + L_{e1} P_2} \tag{3}$$

Use (+) when $P_1 < P_2$; $P_1 \leqq P_e \leqq P_2$
Use (−) when $P_1 > P_2$; $P_2 \leqq P_e \leqq P_1$.

$$P_n = \left[(L_{e1} + L_{e2}) \mp \frac{(D_1 - D_2)}{1.732051} \right] \frac{P_1 P_2}{L_{e1} P_1 + L_{e1} P_2} \tag{4}$$

Use (−) when $P_1 < P_2$; $P_1 \leqq P_n \leqq P_2$
Use (+) when $P_1 > P_2$; $P_2 \leqq P_n \leqq P_1$.

4. In equations 3 and 4, note that P_e and P_n are symmetrically distributed about a value established by the quantity

$$(L_{e1} + L_{e2}) \frac{P_1 P_2}{L_{e2} P_1 + L_{e1} P_2}$$

Therefore, if derived values of P_e and P_n are not to be unduly biased in favor of P_1 and P_2, the maximum length of engagements, L_{e1} and L_{e2}, should be selected such that

$$(L_{e1} + L_{e2}) \frac{P_1 P_2}{L_{e1} P_1 + L_{e1} P_2} = \frac{P_1 + P_2}{2}$$

$$\text{or } L_{e2}/L_{e1} = P_2/P_1.$$

5. Minimum limits to values for L_{e1} and L_{e2}

a. If values of P_e and P_n are limited to fall between P_1 and P_2, then

$$\frac{|D_1 - D_2|}{1.732051} \cdot \frac{P_1 P_2}{L_{e2} P_1 + L_{e1} P_2} \leqq \frac{|P_1 - P_2|}{2}$$

b. Combining this requirement with the required ratio of L_{e1} and L_{e2} established above

$$L_{e1} \geqq \frac{P_1}{1.732051} \cdot \frac{\Delta D}{\Delta P} \tag{5}$$

$$L_{e2} \geqq \frac{P_2}{1.732051} \cdot \frac{\Delta D}{\Delta P} \tag{6}$$

$$\text{where } \Delta D = |D_1 - D_2|$$

$$\Delta P = |P_1 - P_2|$$

c. If these minimum values for length of engagement are sufficiently large as to fulfill requirements of U.S. and ISO Standards, there is advantage in utilizing them in determining the pitch and pitch diameter of the proposed thread.

1. P_e will equal P_1 or P_2 and P_N will equal P_2 or P_1
2. D_e will equal D_1 or D_2 and D_N will equal D_2 or D_1
3. A manufacturer would need to modify only the external thread or the internal thread, not both, in order to achieve a thread compatible with both the U.S. and ISO Metric Standard.

6. It should be noted that the proposed thread will in general have different basic values for the pitch and the pitch diameter of external and internal thread. Therefore, in coupling together, even perfect threads (made to the proposed dimensions) would have limited rather than infinite length of engagement L_e where

$$L_e = \frac{D_n - D_e}{1.732051|1 - P_e/P_n|}. \tag{7}$$

C. Limitations on D_e and D_n

1. Equations (1) and (2) (sec. B) assure that the basic pitch diameters of the proposed thread do not exceed maximum material values as specified in either the U.S. or ISO Metric Standard.

2. Equations (5) and (6) (sec. B) establish minimum values for length of engagement L_{e1} and L_{e2}.

3. Therefore, except for the case noted in section B.5.c, the basic pitch diameters of the proposed thread will not meet maximum material conditions as specified in either the U.S. or ISO Metric Standard. The greater the values of L_{e1} and L_{e2}, the closer the basic pitch diameters will move to minimum material conditions as specified in the U.S. or ISO Metric Standard. This implies the existence of maximum limits for L_{e1} and L_{e2}.

4. To circumvent disagreements as to whether the proposed threads will couple with threads of existing U.S. and ISO Standards with sufficient precision as to provide functional adequacy, differences in pitch diameters of the proposed thread and present standard threads are limited to values approximately equal to or less than the tolerances for pitch diameter specified in existing standards.

5. Whereas tolerances established for maximum material limits are rigorously applied to avoid interference in coupling external with internal thread, it appears that standard practice provides more leniency in application of tolerances that establish minimum material limits.[8] Therefore, in the development of equations in this section some lack of rigor will be allowed so as to serve the purposes of an overall survey for potential compatibility of threads.

6. If D_e and D_n are to meet the requirements for minimum material conditions, then

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[8] Handbook H28 (1969) pt. 1, sec. 2, par. 8, p. 2.21.

$$D_e \geqq D_1 - A$$
$$D_e \geqq D_2 - B$$
$$D_n \leqq D_1 + C$$
$$D_n \leqq D_2 + D$$

where

A = External thread tolerance plus allowance for pitch diameter as specified in the U.S. Standard.

B = External thread tolerance plus allowance for pitch diameter as specified in the ISO Metric Standard.

C = Internal thread tolerance for pitch diameter as specified in the U.S. Standard.

D = Internal thread tolerance for pitch diameter as specified in the ISO Metric Standard.

a. A necessary condition[9] for the quantity $(D_n - D_e)$ is

$$D_n - D_e \leqq A + C \qquad \text{For } A + C < B\ D$$
$$D_n - D_e \leqq B + D \qquad \text{For } A + C > B\ D.$$

b. Substituting for D_n and D_e using eqs 1 and 2 and utilizing the relation $L_{e1}P_1 = L_{e2}P_2$ (see section B4)

$$L_{e1} \leqq \frac{P_1}{1.732051} \cdot \frac{X}{\Delta P} \tag{8}$$

$$L_{e1} \leqq \frac{P_2}{1.732051} \cdot \frac{X}{\Delta P} \tag{9}$$

where $\Delta P = |P_1 - P_2|$
and $X = (A + C)$ or $(B + D)$ whichever is smaller.

7. Limiting condition for the absolute magnitude of $D_1 - D_2$ Equating eq 8 with eq 5 or eq 9 with eq 6, provides a maximum limit for ΔD

$$\Delta D = |D_1 - D_2| \leqq X \tag{10}$$

8. Limiting condition for the absolute magnitude of $P_1 - P_2$

a. Equations (8) and (9) indicate that the maximum limit for ΔP, depends upon the ratio of P/L.

b. The value, L, is the length of engagement at which positive locking will occur. Thus, L must be at least equal to the length of engagement specified by U.S. and international standards. This implies limits on the value of ΔP.

c. The ratio between pitch and required length of engagement will vary among standards but for threads having general application it usually

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[9] This condition is not sufficient in itself because it ignores differences between D_1 and D_2.

follows some function of the major diameter of the thread.[10] Therefore, for the purposes of this survey, eqs (8) and (9) are added to yield

$$P = |P_1 - P_2| \leqq \frac{X}{2 \cdot 1.732051}\left[\frac{P_1}{L_{e1}} + \frac{P_2}{L_{e2}}\right].$$

D. Utilization of the equations in surveying the compatibility of thread series having compatible profile but dissimilar dimensions.

1. The ratio of pitch to required length of engagement is estimated for each thread series. Generally this ratio will roughly follow a linear function of diameter.

2. The values of pitch diameter tolerances (the sum of external and internal tolerance and allowance) are estimated for each thread series. This value usually increases with diameter.

3. These estimates are used to derive a limiting value for pitch difference using eq (11). The pitches of the two thread series are then compared relative to this limit. As threads series specifying hundreds of threads generally utilize a relatively small number of pitch values, large thread series can be quickly surveyed for potential compatibility.

4. For those threads of each series having sufficiently similar pitch values, the pitch diameters are compared relative to limiting values established using eq (10).

5. For those threads of each series that pass the test for pitch and pitch diameter similarity, calculations are made using eqs (3, 4, 1, 2). These calculations provide basic values for pitch diameters and pitches of external and internal threads that are interchangeable with the threads of the two series being considered. In selecting values for the length of engagement used in these equations, the minimum values required are determined using eqs (5) and (6). If these lengths are greater than that required for the thread series under consideration, these values are used as this minimizes the need for modification. If these minimum values are smaller than those required to meet length of engagements required by the standards, the standard length of engagement is used in the equations, modified only to the extent of maintaining the relation $L_{e2}\ P_2 = L_{e1}\ P_1$. However, lengths of engagement may not exceed values defined by eqs (8) and (9).

E. Advantages and disadvantages of the proposed thread.

1. The proposed thread will be interchangeable with both the U.S. Standard and the ISO Metric Standard and will in itself function as a system.

   a. A screw thread manufacturer can convert to the proposed system at his discretion, knowing that the conversion will be interchangeable with his past production.
   b. It will be advantageous for the manufacturer to convert in the sense that the proposed system will be compatible with both U.S. and ISO Metric Standard threads.

[10] ISO Recommendation 965/1, sec. 12.2, p. 19.

2. As the general approach is to utilize a portion of the present tolerances to derive basic values for a new system that is compatible with both U.S. and ISO Metric Standards, it follows that deterioration of functional performance (at least theoretically) can only be avoided if present tolerances are reduced in the proposed system. Even with such reduced tolerances functional performance cannot be as optimum as is sometimes achieved by threads of the present standards.

First Progress Report, January 5, 1971

APPENDIX V

A Study to Develop an Optimum Metric Fastener System

ENGINEERING REPORT:

This report is included with permission of the Industrial Fasteners Institute.

INDUSTRIAL FASTENERS INSTITUTE

Industrial Fasteners Institute
1505 East Ohio Building
1717 E. 9th Street
Cleveland, Ohio 44114 USA

FOREWORD

The Industrial Fasteners Institute is an association of leading American and Canadian manufacturers of bolts, nuts, screws, rivets, and all types of special industrial fasteners. IFI member companies combine their technical knowledge to advance the technology and application engineering of fasteners through planned programs of research and education. The Institute and its member companies work closely with leading national and international technical organizations in developing fastener standards and other technical practices.

On May 20, 1970, the IFI Governing Board met to establish a policy position relative to metric. Part of that policy states:

> "Industrial Fasteners Institute recognizes that important segments of American Industry may elect to convert to metric. In such event, the IFI position is that a new system of standard fasteners designed for optimum performance capability should be developed and stated in metric units.
>
> The new system would be a complete "fresh start" approach not necessarily related to any existing system. The purpose would be to achieve optimum performance capability in the use of all materials used in the fastening function and to attain maximum simplification in the number and styles of standard fasteners."

The Board then instructed its two principal technical committees - Standards and Technical Practices Committee and the Engineering Committee on Small Screws - to initiate a priority program of study and research. First discussions were held at a joint meeting in mid-June, and a carefully selected Task Group on Fastener Design and Simplification was appointed. (Annex F) Since that time, the Task Group has met several times, and has completed a massive program of work as outlined in this report. The results of this effort led to the development of a recommended series of sizes, thread pitches, and a basic thread form for a series of metric module fasteners.

The technical content of this report was reviewed at a joint meeting of the two technical committees on December 16, 1970, and the recommendations presented herein received their endorsement.

A STUDY TO DEVELOP AN OPTIMUM METRIC FASTENER SYSTEM

INTRODUCTION

Most large USA corporations are internationally based with significant financial and manufacturing commitments located in other countries of the world. While all of these corporations still use customary inch/pound units as the principal engineering and production base for their domestic operations, the world markets they serve have obligated design of many products in conformance with engineering standards and units of measurement other than those commonly used in USA. Worldwide interchangeability of assemblies and their component parts has been sacrificed to accommodate those systems of standards and systems of measuring units common to the country of manufacturing origin or prime consuming market.

During recent years many corporations have been studying means for reducing or eliminating the cost of supporting two or more systems of engineering practices. Some are already planning a unification of their corporate engineering standards into a single system to be used by all their facilities, both domestic and foreign.

In August 1968, the 90th Congress of USA passed Public Law 90-472. This act instructs the Secretary of Commerce to conduct a comprehensive program of investigation to determine the impact on the United States of the increasing worldwide usage of the metric system of measurement. It further instructs the Secretary to return to Congress within a three year period to outline the findings of the study and present recommendations on what actions USA should take.

The metric study, which has now been under way for over two years, has sharply focused management attention upon the potential values inherent in the development of engineering standards which would be truly international in recognition and acceptance, and attendant with such a system, a single measuring practice. Realistically, although the great burden and expense of change would fall on USA, the only system of measuring units with any chance of worldwide acceptance is the International System of Units.

The International Organization for Standardization (ISO) is a federation of national standardization bodies representing about 60 countries of the world. The first two technical activities authorized by ISO, shortly after it was formed in 1946, concerned screw threads and threaded fasteners. ISO/TC1 on screw threads and ISO/TC2 on threaded fasteners each have held numerous meetings, progress has been excellent, many projects have been completed, and several ISO Recommendations published. However, TC1, and particularly TC2, have years of work ahead before documents will be available permitting the selection and manufacture of threaded fasteners completely from ISO standards.

The fastener manufacturing industry supplies to all other industries standard and special bolts, screws, nuts and other threaded parts used in joining the component parts of engineered assemblies. Observing the growing interest in metric by many important USA corporations, it has become increasingly evident to the USA fastener manufacturing industry that within the near future it will be asked to produce and market a system of metric fasteners. The industry is willing to meet its responsibilities.

However, before any metric module fasteners can be manufactured, engineering documentation must be made available. It does not now exist. Because of the incompleteness of ISO documents, and because no other single system of national standards has international acceptance, it is apparent that new documents must be prepared. Such documents will probably be a mixture of copying from existing ISO standards, adapting from current domestic practices, and creation of new material as necessary to properly specify all requirements.

A question of prime importance concerns the level of technical sophistication of ISO documents for metric fasteners and the national standards of metric countries compared to USA based standards (ANSI, ASTM, SAE, IFI, etc.) for inch series products. Do the metric based fastener standards now in current use equate favorably in performance capability, mechanical properties, and quality assurance to those with which American industry is now accustomed? Would present legal statutes and regulations controlling the manufacture and sale of several consumer products permit levels of performance capability lower than those now available?

A realistic evaluation of current metric documentation leads to the conclusion that the inadequacy of their technical requirements will necessitate development of an entirely new system of engineering standards for metric module fasteners.

If it is accepted that new documentation must be prepared, it logically follows that when preparing such documents, every opportunity should be taken to improve the performance capabilities of fasteners through redesign. It also seems logical that the number of sizes, grades, types, styles, and series be limited to the fewest possible number consistent with providing an adequate system of fasteners to properly accommodate the engineering requirements of the majority of industrial applications.

THE PROJECT

In May 1970, Industrial Fasteners Institute authorized the project - A Study to Design an Optimum Metric Fastener System. Its object is -

> To develop a system of threaded fasteners, to be stated in metric units of measurement, to incorporate into the design of each fastener technical refinements contributing to improvement in performance capability, and to simplify to the absolute degree possible the number of items recognized as standard in the system.

OBJECTIVES

There are four objectives -

- technical improvement
- simplification
- cost reduction
- realism

In the development of a system of threaded fasteners, the performance capability of each item, as it will be used in its service application, should equal or surpass that which is now offered by any similar fastener standard within any existing system. Consequently, a prime objective is introduction of technical improvement to attain superior performance capability.

Addition of unnecessary parts to a system is equally expensive to the user as it is to the producer. An over-proliferation of standard parts is confusing to designers and greatly complicates the problems of those responsible for procurement. There are tremendous opportunities for simplification of standard fasteners in terms of numbers of sizes, grades, types, styles, and series. An objective of the program is to explore and exploit these opportunities fully.

While important cost reductions may logically be expected from improved design of fasteners through optimum use of materials and improved mechanical and performance properties, the savings realized through simplification can be considerable. By exercising strict discipline throughout the development of a new system, immediate cost savings will be experienced when the system is first introduced, and will compound indefinitely.

For any system of threaded fasteners to be acceptable domestically, it must be attractive internationally. The advantages offered by a new system to any corporation interested in planning unification of its engineering standards must be compelling enough to encourage it to absorb modest change in its foreign based operations while simultaneously making the much more extensive and costly conversion domestically. Consequently, the system must be realistic in terms of existing standards and practices of other industrialized countries. A major objective is to maximize the advantages offered to USA corporations in their domestic operations, while minimizing the inconvenience caused to their foreign based operations.

CONDUCT OF PROJECT

The total program logically divides into four separate phases -

I - Determination of a series of basic diameters, thread pitches, and a thread form.

II - Dimensional design of various families of mechanical fasteners built around the sizes accepted in Phase I.

III - Determination of mechanical properties and performance capabilities of products designed in Phase II.

IV - A study of related parts such as rivets, washers, pins, etc., and application data such as grip ranges, hole sizes, clearances, drive systems, etc.

This report covers Phase I. It outlines the work done, the data developed, and the conclusions reached. The completion of Phase I is as far as the program can progress until fastener users and producers have had full opportunity to evaluate the merits of the Phase I recommendations. They are also invited to consider the long range objectives of the total program, and determine if there is sufficient value to their own personal and corporate interests, both domestically and internationally, to warrant support and active participation in the conduct of Phases II, III, and IV.

A STUDY TO DEVELOP AN OPTIMUM METRIC FASTENER SYSTEM

SECTION A - SCOPE

The scope of Phase I is -

- to evaluate the current metric and inch diameter/pitch series and thread form for standard threaded fasteners, to learn their merits, deficiencies, and possibilities for technical improvement.
- to develop through analytical research and experience an optimum diameter/pitch series, to be stated in metric units, which would offer designers using threaded fasteners an adequate selection of sizes to properly accommodate commercial and industrial applications.
- in the development of the series, to critically examine thread form and introduce technical refinements contributing to improved performance capability of threaded fasteners.

SUMMARY OF RECOMMENDATIONS

The recommendation of this study is that a new metric diameter/pitch series for threaded fasteners be introduced. Its principal features would be -

1. That there be only one thread pitch series.

2. That there be 25 sizes in the series through the size range of 1 mm to 100 mm.

422-764 OL - 71 - 14

3. That the 25 diameter/pitch combinations in the series be -

1 x .25	3.15 x .65	10 x 1.5	30 x 3.5	64 x 6
1.25 x .3	4 x .8	12.5 x 1.75	36 x 4	72 x 6
1.6 x .35	5 x .9	16 x 2	42 x 4.5	80 x 6
2 x .45	6.3 x 1	20 x 2.5	48 x 5	90 x 6
2.5 x .55	8 x 1.25	25 x 3	56 x 5.5	100 x 6

4. That the diameter/pitch combinations for sizes larger than 100 mm be the "first choice" series for ISO general purpose metric screw threads, ISO R261.

5. That the thread form for the series be the basic ISO thread form, ISO R68, with two modifications,

   a) the root of the external thread be radiused within the limits of 0.150 P and 0.180 P, where P equals thread pitch.

   b) the addendum of the internal thread be reduced to 0.1875 H, where H equals the height of the fundamental thread triangle.

SECTION B - EVALUATION OF CURRENT THREAD SERIES STANDARDS

The evaluation of the current ISO metric and inch coarse and fine thread series is separated into two parts - an analytical study and an appreciation of the lessons learned through years of use experience.

Analytical Evaluation

Annex E-1 gives the metric diameter/pitch combinations recognized as standard in ISO Recommendation R261. In the size range of 1 thru 100 mm, 25 sizes are listed as first choice, 19 as second choice, and 22 as third choice for a total of 66 sizes. Not all sizes are used for threaded fasteners, and consequently, a more meaningful guide to which sizes are considered standard for metric fasteners is a study of published ISO Recommendations and national standards of metric countries. Typical is R272 (Annex C) which outlines the size series standard for metric hexagon bolts, screws and nuts. Other documents for machine screws and socket screws follow a similar pattern. Rarely do they differentiate between sizes as being first, second or third choice.

For the comparative purposes of this study, the metric size series selected was made up of those sizes, in the range of 1 thru 100 mm, for which there are actual fastener standards in ISO Recommendations.

The preponderant majority of all fasteners are produced with either coarse or fine threads. The uniform pitch thread series are infrequently used for standard products, and consequently, the study was limited to just the two thread series, coarse and fine (UNC and UNF in inch series, coarse and preferred fine in metric series).

Fig 1 details the metric series of sizes and thread pitches studied in this program. There are 43 coarse thread sizes, 12 are smaller than 6 mm (0.236 in.), 8 are between 6 and 18 mm (0.709 in.), and 23 are larger than 18 mm. In the fine thread series there are 14 sizes, 6 between 8 and 18 mm, and 8 larger than 18 mm. In the size range of 1 thru 100 mm, there is a total of 43 sizes and 57 standard diameter/pitch combinations for metric threaded fasteners.

Computer analyses of these ISO metric coarse and fine thread series are given in Annexes B-1 and B-3, respectively.

Annex E-3 gives the inch series diameter/pitch combinations recognized as standard in ISO Recommendation R263. The smallest size is No. 0 (0.060 in./1.524 mm), however, to be directly comparable to the size range of the metric series, the two fine thread diameter/pitch combinations No. 00 - 96 (0.047 in./1.194 mm) and No. 000 - 120 (0.034 in./0.864 mm) have been included. In the size range of No. 000 thru 4 in. (101.6 mm) there are 33 primary sizes and 22 secondary sizes for a total of 55. However, similarly to the establishment of the metric series of sizes to be studied, only those inch series sizes, coarse and fine threads, applicable to standard fasteners were included.

Fig. 1 details the inch series of sizes for coarse and fine thread series. There are 33 coarse thread sizes, 9 smaller than 6 mm, 7 between 6 and 18 mm, and 17 larger than 18 mm. In the fine thread series there are 26 sizes, 12 smaller than 6 mm, 7 between 6 and 18 mm, and 7 larger than 18 mm. In the size range of No. 000 thru 4 in. there is a total of 36 sizes and 59 standard diameter/pitch combinations for threaded fasteners.

Computer analyses of these ISO inch coarse and fine thread series are given in Annexes B-2 and B-3, respectively.

Observations

A study of the graphical presentations of metric and inch diameter/pitch combinations in Figs. 1 thru 5 and the data given in Annex B leads to certain observations.

a) There are too many sizes and too many diameter/pitch combinations in both the metric and inch series. (Fig. 1)

b) The metric coarse series has too many large diameter sizes, the inch series has too many small size diameter/pitch combinations. (Metric fine thread series does not extend below 8 mm.)

c) Ratios of load carrying capacities between adjacent sizes (RF = stress area of a size divided by the stress area of the next smaller size in the series) are extremely erratic for all four series. (Fig. 3)

d) The ratios of areas (RA = stress area (SA) x 100% divided by the area of basic diameter) follow similar patterns, ascending as size increases. (Fig. 4). RA for metric coarse is generally higher than for equivalent sizes in the inch coarse series, and appreciably higher for small sizes, in fact, it is surprisingly close to inch fine. (RA is a measure of the coarseness or fineness of thread pitch; for a given diameter, the higher the RA the finer the pitch.)

e) Stress concentration factors (SCF) follow a similar pattern for all series. (Fig. 5). (NOTE: when computing SCF, the root radius of the thread was assumed to be 0.144 times the thread pitch which is the maximum root radius permissible for ISO inch and metric threads. In actual production of threaded fasteners, root radius would normally be somewhat less which would then increase SCF.) For all series SCF generally increases as size increases.

Fine threads have substantially higher stress concentration factors than coarse threads for equivalent basic diameters. This indicates that, all else being equal, products with coarse threads should exhibit a better fatigue behavior than those with fine threads. SCF values for metric and inch coarse threads are nearly identical.

Experience

The thread series introduced by Whitworth in the mid 19th century serves as the basis for the present ISO inch coarse thread series. The relatively coarse pitches selected at that time were probably chosen as much for being those which lent themselves to the production techniques of the day as for any other single reason. As manufacturing skills improved and it became economically feasible to produce threads to greater degrees of accuracy, finer pitch thread series were introduced and gained considerable popularity. Proponents pointed to strength improvement and argued that finer threads have greater resistance against loosening in service.

The debate on the respective advantages and disadvantages of coarse and fine threads has continued ever since. It has been an interesting exchange because no overwhelming support has been generated for either series - a reasonably good indication that merits and deficiencies are shared equally.

In recent years there has been a gradual gravitation toward increased use of coarse threads. The motivation is probably more closely aligned with simplification programs than for purely technical reasons. This pattern of preference applies to both inch and metric threads.

In the USA demand for fine thread small screws, (sizes smaller than 1/4 in.) except for the No. 10 size, is practically non-existant. Fine thread sizes larger than 1 in. are rarely used in commercial applications. Similarly, in Europe the great preponderance of fastener production is coarse thread. Many of the national standards of metric countries now actively discourage selection of metric fine thread fasteners.

Although coarse threads are more popular, there is questionable technical validity for a thread series to have thread pitches as coarse as ISO inch. It would seem reasonable that a series with thread pitches falling between the present inch coarse and fine would be a technical improvement over both.

These observations led to the recommendation that there be only one thread series.

SECTION C - DESIGN OF DIAMETER/PITCH SERIES

The most important service function of a fastener is to transmit load. In this program first efforts were directed toward a study of static load carrying capacities with a study of fatigue behavior following initial selection of the most promising diameter/pitch series.

The six basic inter-dependent factors in the design of a series are -

- D - basic diameter or size
- P - thread pitch
- TF - basic thread form
- SA - stress area of threaded section
- RA - ratio of areas = $\frac{SA}{.7854\ D^2} \times 100\%$
- RF - ratio of load carrying capacities between adjacent sizes in the series = $\frac{SA_{(I+1)}}{SA_I}$,

  where I is the number of the size in the series.

D - Basic Diameter

Two important criteria are total number of sizes and the distribution of these sizes within the series. It has already been pointed out that present metric and inch series have too many sizes in the size range of 1 thru 100 mm. R261 recognizes 25 "first choice" metric sizes; in the comparable size range of inch series fasteners there are 27 sizes which have a popularity of use far exceeding the remaining sizes. It seems reasonable that an optimum size series should not exceed 27 sizes, and should preferably be less.

Within the series the number of sizes should be properly distributed between those for small screws, generally smaller than 6 mm, those in the range of 6 thru 18 mm where the great preponderance of automotive, farm equipment, machinery, and heavy appliance needs fall, and sizes larger than 18 mm as used in construction of buildings and bridges, heavy earth moving equipment, ship building, railroads, etc. The experience of present fastener usage indicates a reasonable distribution in a 24 to 27 size series would be to include not more than 8 sizes smaller than 6 mm and not less than 11 sizes larger than 18 mm.

P - Thread Pitch

Fig. 2 presents graphs of the current ISO metric and inch coarse and fine diameter/pitch series.

In an optimum series, thread pitch, particularly since there would ideally be only one thread series, should be no coarser nor finer than existing ISO metric and inch coarse and fine thread series.

TF - Thread Form

It would be extremely difficult, if not impossible, to interest fastener users and manufacturers in any thread form drastically different from the standard 60 deg thread of ISO R68.

The long history of successful experience in using fasteners with 60 deg threads is too extensive to permit serious consideration of a major change without overwhelming masses of research data, production of parts, and well documented reports of their performance when actually used in a full gamut of service conditions.

While thread designs different from the basic 60 deg form are being investigated at this time, evidence in support of a total change is insufficient. Consequently, when designing the diameter/pitch series, threads were assumed to be the basic 60 deg form of ISO R68.

SA - Stress Area

Stress areas in this study were all computed using the standard formula -

$$SA = 0.7854\ (D - .9743\ P)^2$$

It is worth noting that as root radius increases, minor diameter also increases and stress area becomes larger. One of the final recommendations of this study is a thread form modification to increase root radius (Section D). It might be useful to reconsider stress area formulation in Phase II because any increase in stress area gives recognition to greater load carrying capacities.

RA - Ratio of Areas

Ratio of areas is a useful parameter in the design of a diameter/pitch series. It is an indicator of the coarseness or fineness of thread pitch, is a measure of thread efficiency (how much of the load carrying cross sectional area remains after threading), and gives an indication of ease or difficulty of thread assemblability.

Fig. 4 is a plot of RA values for ISO metric and inch coarse and fine threads as given in Annex B. An interesting observation is that RA values for metric coarse sizes 7 mm and smaller are surprisingly close to inch fine. Also, it is noted that RA values for metric coarse sizes 8 mm and larger generally fall between those for inch coarse and fine.

A first obvious approach is to design a series having a constant RA for all sizes. A reasonable value might be the mean of the RA values of the existing series, say 75%. With an RA equal to 75%, the thread pitch of the 100 mm size would be 13.8 mm (1.8 tpi), and for the 1 mm size would be .14 mm (183 tpi). Both are quite impractical. The strength capacity of large sizes in the series would be appreciably reduced, a waste of material; assembly problems when using small sizes would be compounded, not to mention the great difficulty in commercially producing screws with excessively small thread pitches. Consequently, the practicalities of ease of assembly and efficient use of material dictate a graduated progression of RA values increasing as size increases.

In the first trial runs to determine the most promising diameter/pitch series, it was decided to maintain the same set of RA values for each series. These values were arbitrarily chosen as grading from 65% for the smallest size through 88% for the largest - roughly paralleling those of the present series. It was understood that when the most promising series were determined, refinements and adjustments to RA values would be introduced.

RF - Ratio of Load Carrying Capacities

RF values for ISO metric and inch coarse and fine threads are plotted on Fig. 3 from data given in Annex B.

The range for metric coarse is a high of 1.63 (the strength ratio between 2 and 1.6 mm sizes) to a low of 1.11 (100 mm over 95 mm). In metric fine the range varies between 1.56 and 1.14. For inch coarse the highest RF value is 1.65 (5/16 in. over 1/4 in.), and the lowest 1.14 (No. 6 over No. 5). In inch fine the range is 2.03 to 1.20.

From a designer's standpoint, what is a reasonable increment in load carrying ability between sizes? Should it be maintained as a constant percentage increase, or should size effect be considered? In terms of real metal, to gain a strength increase of 25 percent over the 10 mm size would require a diameter of only 11 mm; a strength increase of 25 percent over the 100 mm size would need a diameter of 109.6 mm.

It seems wasteful to include sizes in a series that offer strength increases of less than 20 to 25 percent over the next smaller size. In the metric coarse series 23 of 42 RF values are below 1.25. In the inch coarse series 13 of 32 RF values are less than 1.25.

If a constant strength increase of 75 percent between sizes was assumed, the next larger size in the series to the 1 mm size would be 1.3 mm, to the 10 mm size would be 13 mm, and to the 100 mm size would be 130 mm. In terms of metal, the increase is reasonable for small sizes but becomes impractical as size increases.

A rational approach in the design of a diameter/pitch series would be to graduate RF values from relatively high values for small sizes, and decrease RF as size increases. A minimum RF of about 1.25 is practical.

Design of Series

There are two basic approaches which were researched. The first was to assume a series of sizes, and then knowing RA (a series of set values was assumed), compute SA, RF and P. The second was to assume an RF load progression series, and then knowing RA, compute SA, P and D.

In a "broad brush" exploratory study, seventeen different series were put through the computer. Five were "diameter" series, twelve were "load" series. (Annex A lists the principal computer programs of the study.)

Most of these trial series were rejected for further study as they grossly violated one or more of the predetermined parameters. Some series had too many sizes, two had too few, and others had a disproportionate distribution of sizes within the three generalized size ranges. The three series meeting the parameters best were -

1. A "diameter" series in which the sizes were based on a combination of the R10/R20 preferred number series. This series yielded 25 sizes distributed 8, 5, and 12 in the three size ranges.

2. A "load" series in which RF was graduated as a linear function from 1.75 to 1.25. This yielded a 24 size series, distributed 7, 6 and 11.

3. A "load" series in which RF was varied in a geometric progression from 2.00 to 1.20. This yielded 25 sizes, distributed 6, 5 and 14.

These three series were then investigated more thoroughly and minor adjustments, primarily RA values, introduced.

It is well known that fine thread small screws have assemblability problems, both in terms of ease and time. Largely for this reason USA demand for fine thread small screws is practically non-existent. Reports from users of small size metric screws indicate a similar experience - metric thread pitches are too fine and cause assembly difficulties. As experience in using inch series coarse thread small screws has been quite good, it seems only reasonable that thread pitches approaching those of inch coarse threads should be acceptable in a new series. A small sacrifice in load carrying capacity is a fair price to pay for ease of assemblability. Consequently, an adjustment to RA values for sizes smaller than 8 mm was made, reducing them from the original "first trial" assumption to graduate evenly from 57% for the 1 mm size through 71% for the 8 mm size.

The results of these additional studies pointed out fairly well the diameter/pitch series which fitted best within the predetermined parameters.

The Ingredient of Reality

One conclusion of all the analytical research completed during the course of this study is that it is virtually impossible to design the ideal series, one in which all parameters are satisfied most favorably. The optimization of one criterion forces sacrifice by one or more of the others. Consequently, the final series must be a compromise, an attempt to gain the most while giving up the least.

It is at this stage where the ingredient of reality must be introduced. If the recommended diameter/pitch series was based on the best compromise of all technical data, every size and thread pitch would be foreign to present standards. Regardless of technical purity, the realities of present day international involvements would seriously jeopardize acceptance, and more importantly actual use of such a series.

Consequently, when determining the final series to be recommended in this Phase I, the ISO standard metric coarse thread diameter/pitch combinations exerted a strong influence.

In the recommended series, only those new sizes and different thread pitches which are completely supportable by the technical data generated in this study are included. The remaining sizes and thread pitches in the series are continued unchanged from the present ISO metric coarse thread series.

The Recommended Metric Diameter/Pitch Series

The "final" series resulting from all the studies is -

1 x .25	6.3 x 1	42 x 4.5
1.25 x .3	8 x 1.25	48 x 5
1.6 x .35	10 x 1.5	56 x 5.5
2 x .45	12.5 x 1.75	64 x 6
2.5 x .55	16 x 2	72 x 6
3.15 x .65	20 x 2.5	80 x 6
4 x .8	25 x 3	90 x 6
5 x .9	30 x 3.5	100 x 6
	36 x 4	

Certain observations are in order.

a) There are 25 sizes in the series, 8 are smaller than 6 mm, 5 are between 6 and 18 mm, and 12 are larger than 18 mm.

b) The sizes 1 thru 25 mm are in exact conformance with the R10 preferred number series. The sizes 30 thru 100 mm are "first choice" sizes of ISO R261. Of the 15 sizes in the range 1 thru 25 mm, 10 sizes are "first choice" sizes of R261, 5 are new sizes.

c) Thread pitches conform with metric coarse thread pitches given in R261 for all sizes except 2, 2.5, 4, and 5 mm and the five new sizes.

d) Fig. 1A shows the 25 sizes in the series and their relationship to the present metric size series. It should be noted that each of the new sizes 1.25, 3.15, 6.3, 12.5 mm serves to replace two sizes in the current series and the new 25 mm size replaces three.

e) Fig. 2A shows the diameter/pitch graph of the new series. It falls within the extremes of those for the current standards.

f) RF values for the new series are plotted on Fig. 3A. It is immediately apparent that the RF curve of the recommended series is a considerable improvement over the very erratic plots of the current ISO metric and inch thread series. RF values vary from a high of 1.73 to a low of 1.25. Generally, through the 16 mm size RF is approximately 1.65 and for sizes 20 thru 100 mm RF decreases with reasonable uniformity to 1.25.

Ideally the RF curve should be smooth but this would be impossible unless diameters and/or thread pitches were adjusted. Such adjustments would introduce impractical values. As an example, the 16 mm size appears inconsistent with adjacent values. If thread pitch was increased from the recommended 2 mm (12.7 tpi) to 2.25 mm (11.3 tpi) RF values for sizes 16 mm with respect to 12.5 mm and 20 mm with respect to 16 mm (now 1.69 and 1.56) would change to 1.64 and 1.62 respectively. The RF curve would smooth out a little but at a sacrifice in the load carrying capacity of the 16 mm size because its thread would now be coarser and its stress area smaller. The other apparent highs and lows of the RF curve can be similarily rationalized.

As pointed out the new sizes "bridge" between existing standard sizes and each makes it possible to eliminate one or more sizes that otherwise would be required. For example, the new 12.5 mm size bridges the 10 and 16 mm sizes. RF values for sizes 12.5 mm with respect to 10 mm and 16 mm with respect to 12.5 mm are 1.60

and 1.69 respectively. If the 12 mm size which is now standard in the metric series was retained and the 14 mm size eliminated, RF values for sizes 12 mm with respect to 10 mm and 16 mm with respect to 12 mm would be 1.45 and 1.82 respectively. An 82 percent increase in the load carrying capacity between adjacent sizes at this important size range of 10 thru 16 mm (0.394 thru 0.630 in.) is excessive and would necessitate another intermediate size.

g) RA values for the new series are plotted on Fig. 4A. The curve shows a considerable smoothing out of RA values as compared to the existing metric and inch thread series. It also shows the effect of the thread pitch adjustments in the sizes 2 thru 5 mm. When studying this curve it is worth recalling that as RA increases, thread pitch becomes finer and stress area increases, however ease of assembly decreases and manufacturing practicality may be adversely affected. The recommended series yields RA values that for all sizes in the series represent reasonable compromises between these considerations.

h) It was this series that was investigated for its fatigue behavior properties. (Section D). The conclusions of that study are that the recommended thread pitches are valid.

422-764 OL - 71 - 15

SECTION D - FATIGUE BEHAVIOR

The majority of assemblies joined by mechanical fasteners are subjected in some degree to dynamic loading during their service life. Relatively few remain static and totally insulated from some form of fluctuating stress, vibration, stress reversal, or impact. However, only a small percentage of joints necessitate design where the fatigue resistant properties of the fastener become the primary design consideration.

Joints in which the rigidity of the joined material is less than that of the fastener material; joints subjected to stress reversal and loads which induce flexural stresses in the fastener; and joints connected with fasteners having low ductility properties are some of those in which the dynamic load transmitting capability of the fastener is a matter of design importance.

In the design of an optimum metric series an objective should be to improve the fatigue resistant properties of threaded fasteners in every possible and practical way.

In Phase I of this study, potential improvement was limited to thread design. While important, it should be noted that fatigue property gains of considerably greater magnitude can be obtained when designing actual fasteners in Phase II and, secondarily through the processing techniques employed during their manufacture.

The stress concentration factor of the thread, together with a knowledge of the endurance limit and notch sensitivity properties of the fastener material is needed to guide a designer in the proper selection of fasteners for a joint subjected to known internal and externally applied forces. Any reduction in the stress concentration factor of the thread enhances the fatigue resistant properties of the product.

The mathematical determination of stress concentration factors (SCF) is extremely complicated. The method used in this program is outlined in Annex D.

Using this method SCF values for ISO metric and inch coarse and fine threads were computed and are given in Annex B and are shown graphically in Fig. 5. It must be pointed out that in these computations a root radius to thread pitch ratio (RRPP) of .144 was used for all four series. This is the maximum root radius possible with the ISO basic thread form. In actual production root radius would normally be less, and consequently, SCF would be higher. Therefore, the SCF values given in Annex B and shown on Fig. 5 are the optimum that could be expected for the present ISO thread series.

Thread pitch, thread depth, minor diameter and root radius are the dimensional elements influencing SCF. Minor diameter and thread depth are functions of pitch, consequently, variations in either or both pitch and root radius will cause variations in SCF.

When first studying SCF it was thought it would be advantageous to design a thread series with a constant SCF value for all sizes. Unfortunately, this approach was proven completely impractical. If RRPP is maintained constant at .180 (equivalent to max root radius of UNJ thread form) to attain a uniform SCF of 3.00 for all sizes in the 1 thru 100 mm series, the pitch of the 1 mm size would be .12 mm (212 tpi) and for the 100 mm size would be 10.5 mm (2.4 tpi).

Similarly, if the presently specified pitches for metric coarse are retained and root radius varied, to attain a constant SCF of 3.00, RRPP for the 1 mm size would be .12

and for the 100 mm size would be .22. While seeming to be within reasonable limits, it should be pointed out that with this approach, small sizes in the series would be unnecessarily penalized by having root radii smaller than are practical even though larger sizes may be advantaged. Also, RRPP values exceeding .180 risk strength depreciations between mating threads because of reduced thread engagement.

The great majority of fatigue applications occur in joints using fasteners in the size range of 5 thru 30 mm (0.197 thru 1.181 in.). A second effort was made to learn the possibility of designing a thread series with constant SCF values for the sizes in this range, and varying SCF values as necessary for larger and smaller sizes.

Annex D-5 presents two tables detailing thread pitches for different SCF values and for RRPP values of .150 and .180. The striking observation is the great difficulty there would be to attain a uniform SCF just for these few sizes without major adjustments in thread pitches, either making the pitch coarser as size increases, or finer as size decreases. Another point is the considerable effect on thread pitch and/or SCF by changing RRPP from .150 to .180.

The stress concentration studies led to the following conclusions -

a) it would be impractical to maintain constant SCF values for all diameter/pitch combinations in a series, or for a range of sizes within the series.

b) RRPP should be held as a constant ratio for all sizes.

c) the only practical means for improving SCF values through dimensioning is by increasing root radii.

Thread Form

The basic thread form as given in ISO R68 is standard for both metric and inch series threads. Fig. 6 illustrates this thread form with the one modification of showing the root as radiused. Root radius limits of .108 to .144 of thread pitch (UNR) are now standard for most USA commercially produced fasteners. While root radius limits are not specified for ISO metric threads, it is a reasonable assumption that the large majority of metric fasteners produced today have radiused roots falling within the UNR limits.

Many years ago a modified thread form designated as UNJ was introduced, and has since become the standard for aerospace fasteners. It has also been used successfully with some commercial fasteners designed for use in selected industrial applications.

UNJ threads have more generous root radii than UNR. Because of the large root (.180 P at max material limit), the minor diameters of internal threads had to be increased slightly to offset the theoretical possibility of mating thread interference during assembly. Despite the increase in minor diameters of internal threads, thus reducing thread engagements (overlap of internal with external threads when assembled), the load carrying capacities of UNJ bolt-nut assemblies are still in conformance with all specified strength requirements.

Extensive research has proven that fasteners with UNJ threads have improved fatigue resistant properties. The UNJ thread form, now standard in USA, is being considered by ISO/TC1 for adoption as an international standard.

A thread form of the R68 basic form, but modified to incorporate the proven advantages of UNJ, is entirely practical. It is a recommendation of this study that such a thread form be adopted for the new metric series. This form is illustrated in Fig. 6. The two modifications in geometry are an increase in root radius of external threads to be within the limits of .150 to .180 P, and a reduction of the addendum of the internal thread.

SECTION E - SUMMARY OF THE PHASE I RECOMMENDATIONS

The recommendation of this study is that a new metric diameter/pitch series for threaded fasteners be introduced. The principal features would be -

1. That there be only one thread pitch series.

2. That there be 25 sizes in the series through the size range of 1 mm to 100 mm.

3. That the 25 diameter/pitch combinations (Annex B-4) in the series be -

1 x .25	3.15 x .65	10 x 1.5	30 x 3.5	64 x 6
1.25 x .3	4 x .8	12.5 x 1.75	36 x 4	72 x 6
1.6 x .35	5 x .9	16 x 2	42 x 4.5	80 x 6
2 x .45	6.3 x 1	20 x 2.5	48 x 5	90 x 6
2.5 x .55	8 x 1.25	25 x 3	56 x 5.5	100 x 6

4. That the diameter/pitch combinations for sizes larger than 100 mm be the "first choice" series for ISO general purpose metric screw threads, ISO R261 (Annex E-2).

5. That the thread form for the series be the basic ISO thread form (ISO R68) with two modifications,

   a) the root of the external thread be radiused within the limits of 0.150 P and 0.180 P, where P equals thread pitch (Fig. 6).

   b) the addendum of the internal thread be reduced to 0.1875 H, where H equals the height of the fundamental thread triangle (Fig. 6).

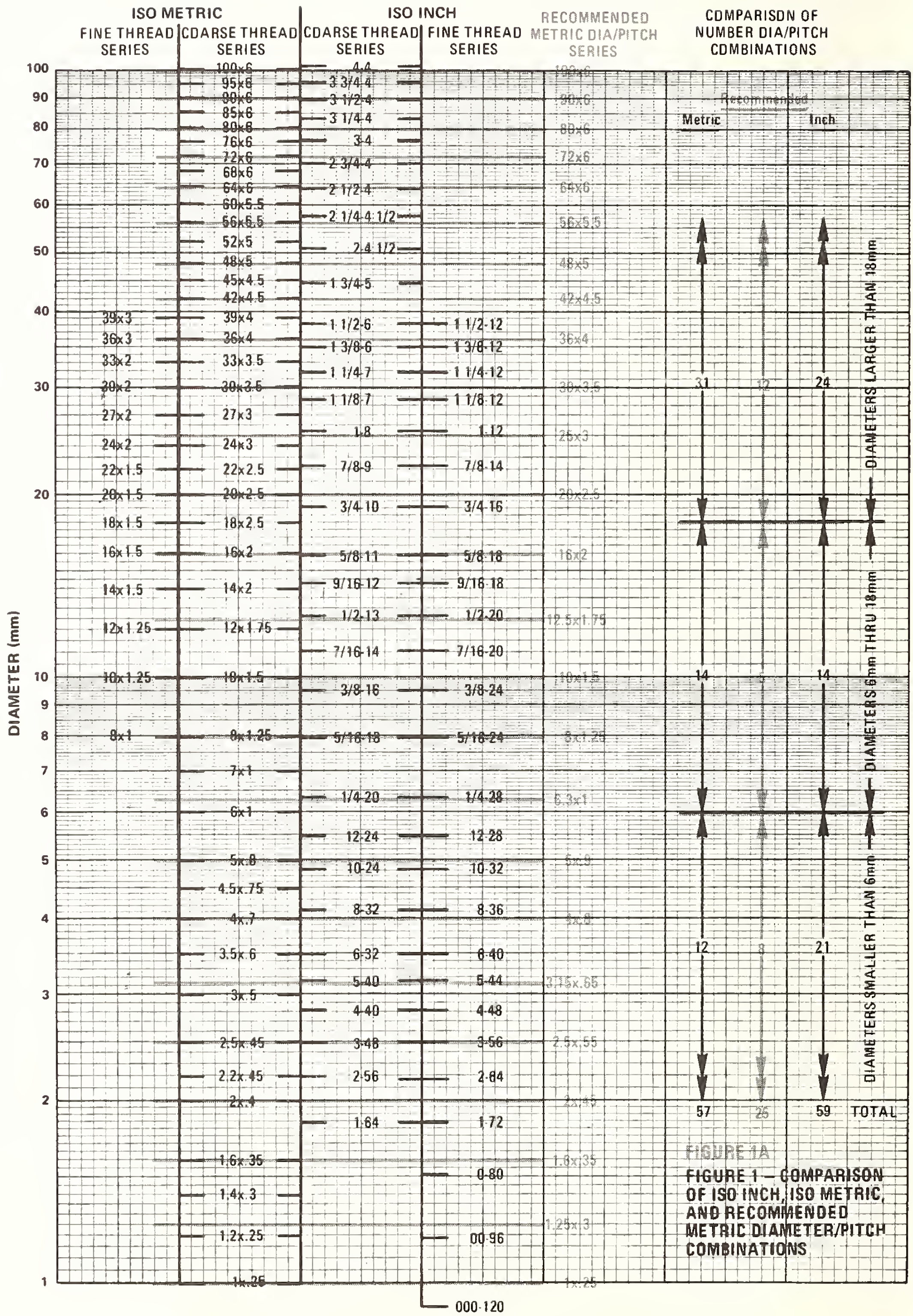


FIGURE 1A

FIGURE 1 — COMPARISON OF ISO INCH, ISO METRIC, AND RECOMMENDED METRIC DIAMETER/PITCH COMBINATIONS

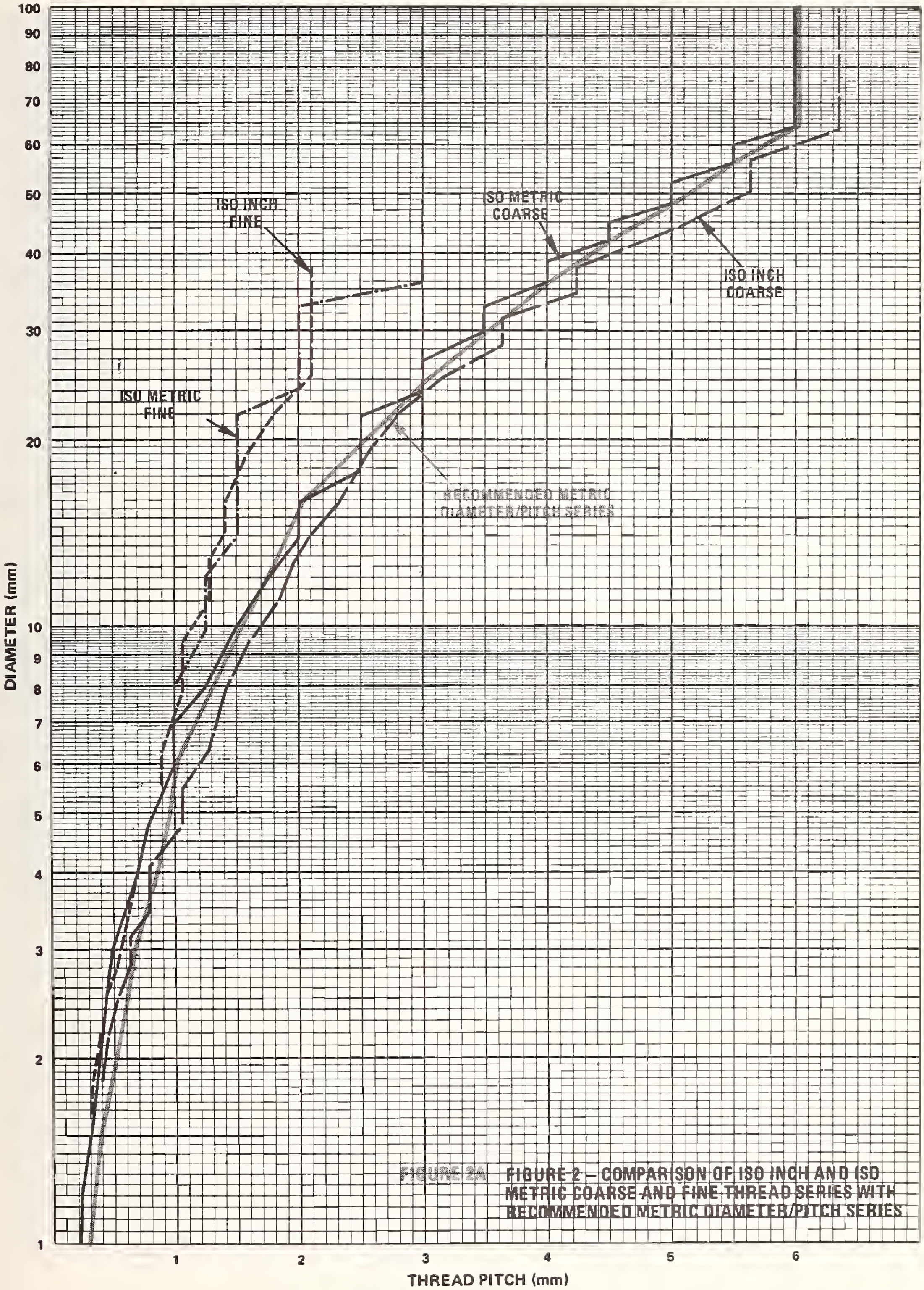


FIGURE 2 – COMPARISON OF ISO INCH AND ISO METRIC COARSE AND FINE THREAD SERIES WITH RECOMMENDED METRIC DIAMETER/PITCH SERIES

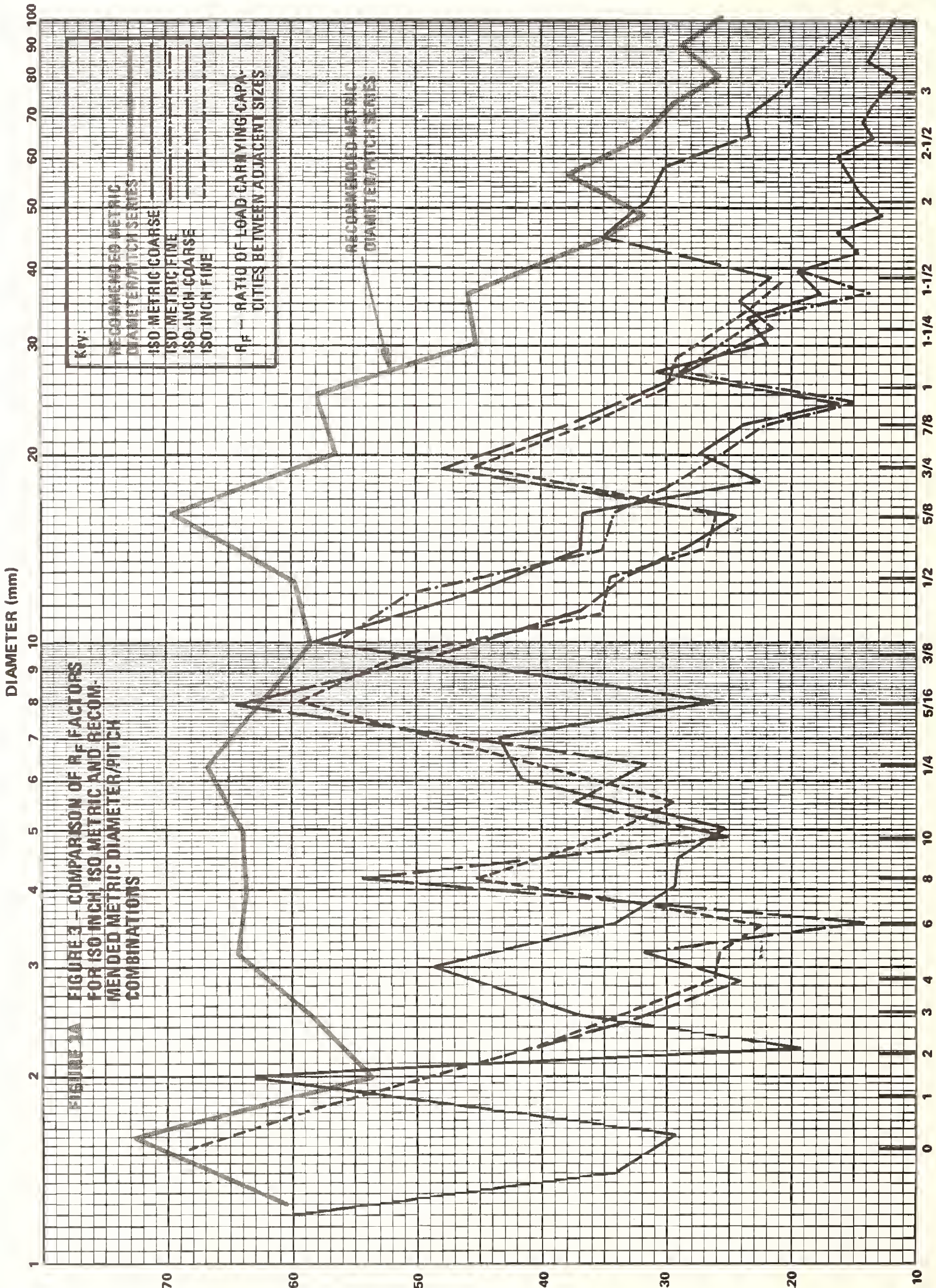


FIGURE 3A FIGURE 3 – COMPARISON OF R_F FACTORS FOR ISO INCH, ISO METRIC AND RECOMMENDED METRIC DIAMETER/PITCH COMBINATIONS

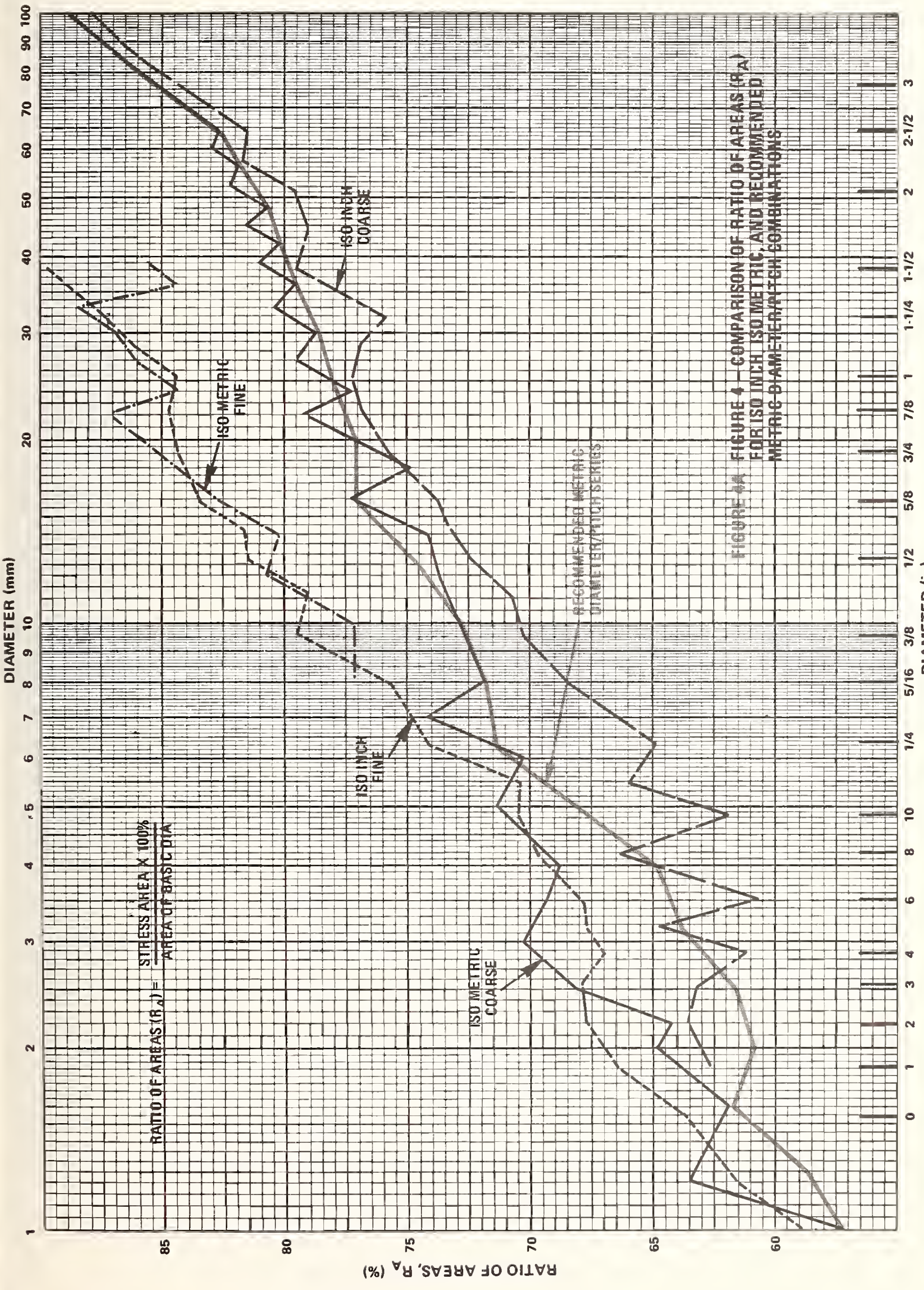


FIGURE 4 — COMPARISON OF RATIO OF AREAS (R_A) FOR ISO INCH, ISO METRIC, AND RECOMMENDED METRIC DIAMETER/PITCH COMBINATIONS

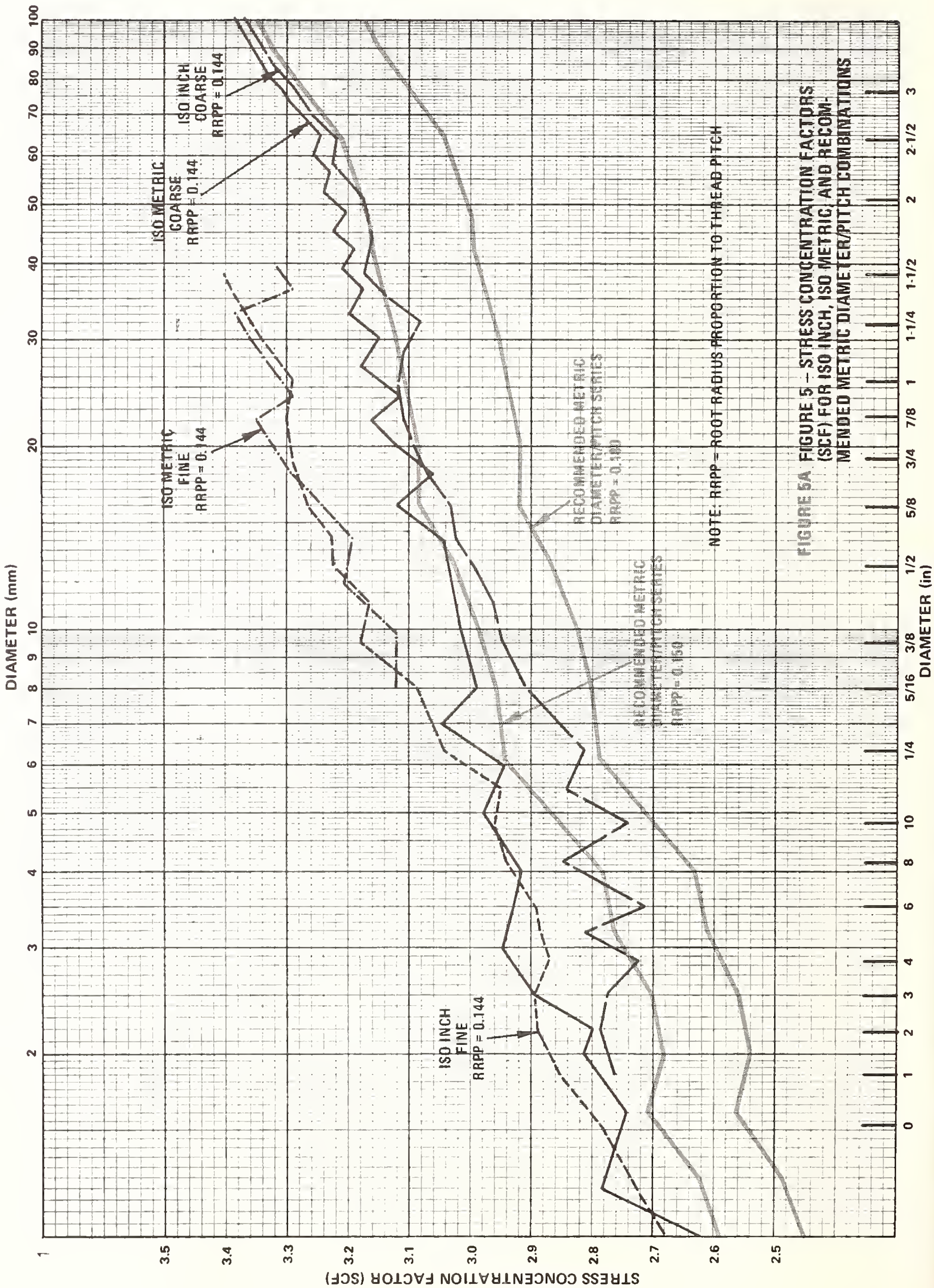
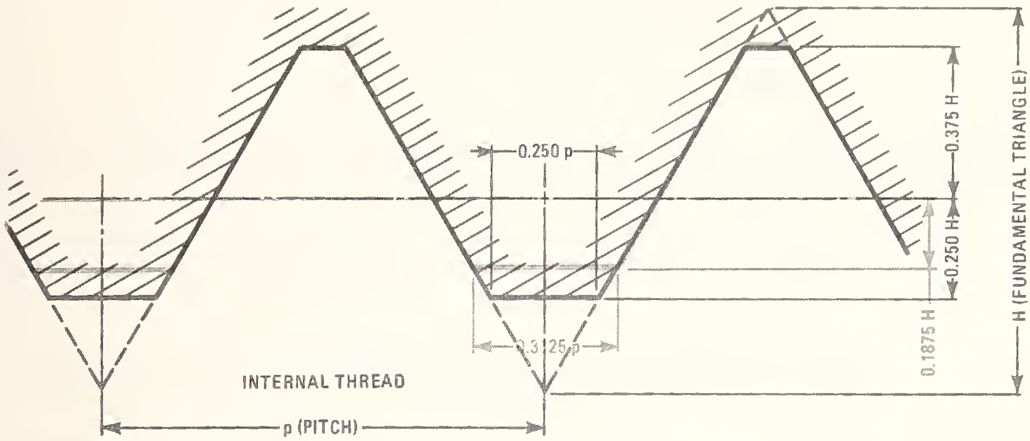
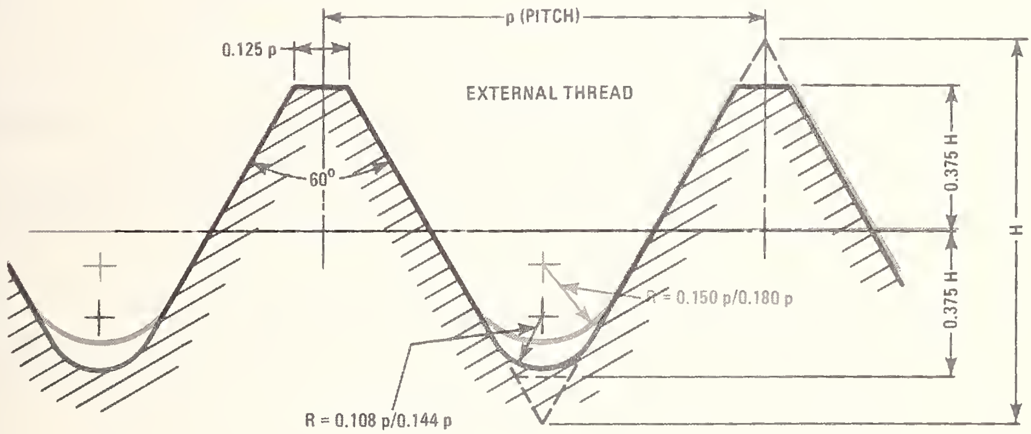


FIGURE 5A FIGURE 5 — STRESS CONCENTRATION FACTORS (SCF) FOR ISO INCH, ISO METRIC, AND RECOMMENDED METRIC DIAMETER/PITCH COMBINATIONS



THREAD FORM – RECOMMENDED METRIC SERIES



THREAD FORM – ISO METRIC AND ISO INCH SERIES

FIGURE 6 – THREAD FORM COMPARISON, ISO INCH, ISO METRIC AND RECOMMENDED METRIC DIAMETER/PITCH SERIES.

ANNEX A - COMPUTER PROGRAMS

During the study, several computer programs were designed for computing by direct or iterative approach. The majority yielded data within two main sets of parameters -

a) Distribution of load transmitting capability (RF) - linear, parabolic, geometric progression, preferred numbers, etc.

b) Relationships between stress concentration factors (SCF), ratio of areas (RA), thread pitches, and root radii proportions (RRPP).

Over 140 separate computer runs were made. The principal ones were -

1 - to determine RF for a diameter series with sizes increasing by $\sqrt[4]{2}$ (18.9%), for sizes 1 thru 100 mm, and with RA graduated from 65 thru 88%.

2 - same as 1 but with sizes increasing by $\sqrt{3}$ (14%).

3 - Same as 1 but with sizes selected from a combination of the R10 and R20 preferred number series.

4 - to determine a 26 size dia/pitch series, with RA graduated from 65 to 88%, and with constant RF of $\sqrt{2}$ (1.4142).

5 - same as 4 but with constant RF of 1.3333.

6 - same as 4 but with a linear distribution of RF from 2.0000 to 1.2500.

7 - same as 4 but with a linear distribution of RF from 1.7500 to 1.2500.

8 - same as 4 but with a linear distribution of RF from 1.5000 to 1.2500.

9 - same as 7 but with 27 sizes in the series.

10 - same as 7 but with 25 sizes in the series.

11 - to determine a 25 size dia/pitch series, with RA graduated from 65 to 88%, and with a geometric progression of RF from 1.7500 to 1.2500.

12 - same as 11 but with geometric progression of RF from 2.0000 to 1.2000.

3A - same as 3 but with RA graduated from 62 to 90%.

10A - same as 10 but with RA graduated from 62 to 90%.

12A - same as 12 but with RA graduated from 62 to 90%.

100 - to determine RRPP and root radius of thread of Series 3 with constant SCF of 3.0.

101 - to determine SCF of Series 3 with RRPP of .180.

102 - to determine thread pitch and RA of Series 3 with RRPP of .180 and constant SCF of 2.85.

103 - same as 102 but with constant SCF of 3.15.

104 - same as 102 but with constant SCF of 3.25.

200 - to determine SCF of Series 10 with RRPP of .180.

301 - to determine RA, RF, SCF of ISO inch coarse thread series, sizes No. 1 thru 4 in., with RRPP of .14434. (Annex B-2)

302 - same as 301 but for ISO inch fine thread series, sizes No. 000 thru 1-1/2 in. (Annex B-3)

303-1 - same as 301 but for ISO metric coarse thread series, sizes 1 thru 100 mm. (Annex B-1)

304-1 - same as 301 but for ISO metric fine thread series, sizes 8 thru 39 mm. (Annex B-3)

305 - to determine RA, RF, and SCF of "first selection" of recommended metric dia/pitch series with RRPP of .150.

306 - same as 305 but with RRPP of .180.

307 - to determine RF, SCF and thread pitches of "first selection" of recommended metric dia/pitch series with RA uniformly graduated from 57 to 71% thru size range of 1 to 8 mm, and with RRPP of .150.

308 - same as 307 but with RRPP of .180.

401 - to determine RA, RF, SCF of "final" recommended metric dia/pitch series with RRPP of .150.

402 - same as 401 but with RRPP of .180. (Annex B-4)

NOTE: - the computer print outs for 301, 302, 303-1, 304-1, and 402 are given in Annex B.

ISO METRIC COARSE THREAD SERIES

I	D	DIN	P	TIN	PD	DMI	SA	RA	RF	SCRA	SCF	TH	RRPP	H1	RR	T
1	1.000	0.0394	0.250	101.6	0.838	0.693	0.449	57.2	0.0	21.81	2.623	83.3326	0.144	0.135	0.036	0.153
2	1.200	0.0472	0.250	101.6	1.038	0.893	0.718	63.5	1.599	22.80	2.786	83.3326	0.144	0.135	0.036	0.153
3	1.400	0.0551	0.300	84.7	1.205	1.032	0.964	62.6	1.341	22.66	2.763	83.3326	0.144	0.162	0.043	0.184
4	1.600	0.0630	0.350	72.6	1.373	1.171	1.245	61.9	1.292	22.56	2.745	83.3326	0.144	0.189	0.051	0.215
5	2.000	0.0787	0.400	63.5	1.740	1.509	2.037	64.8	1.636	22.99	2.819	83.3326	0.144	0.217	0.058	0.245
6	2.200	0.0866	0.450	56.4	1.908	1.648	2.437	64.1	1.197	22.89	2.801	83.3326	0.144	0.244	0.065	0.276
7	2.500	0.0984	0.450	56.4	2.208	1.948	3.338	68.0	1.370	23.45	2.900	83.3326	0.144	0.244	0.065	0.276
8	3.000	0.1181	0.500	50.8	2.675	2.387	4.959	70.2	1.486	23.75	2.954	83.3326	0.144	0.271	0.072	0.307
9	3.500	0.1378	0.600	42.3	3.110	2.764	6.676	69.4	1.346	23.65	2.934	83.3326	0.144	0.325	0.087	0.368
10	4.000	0.1575	0.700	36.3	3.545	3.141	8.646	68.8	1.295	23.57	2.920	83.3326	0.144	0.379	0.101	0.429
11	4.500	0.1772	0.750	33.9	4.013	3.580	11.158	70.2	1.291	23.75	2.954	83.3326	0.144	0.406	0.108	0.460
12	5.000	0.1969	0.800	31.7	4.480	4.019	13.990	71.3	1.254	23.90	2.981	83.3326	0.144	0.433	0.115	0.491
13	6.000	0.2362	1.000	25.4	5.350	4.773	19.837	70.2	1.418	23.75	2.954	83.3326	0.144	0.541	0.144	0.613
14	7.000	0.2756	1.000	25.4	6.350	5.773	28.517	74.1	1.438	24.29	3.051	83.3326	0.144	0.541	0.144	0.613
15	8.000	0.3150	1.250	20.3	7.188	6.466	36.126	71.9	1.267	23.99	2.996	83.3326	0.144	0.677	0.180	0.767
16	10.000	0.3937	1.500	16.9	9.026	8.160	57.261	72.9	1.585	24.13	3.022	83.3325	0.144	0.812	0.217	0.920
17	12.000	0.4724	1.750	14.5	10.863	9.853	83.242	73.6	1.454	24.22	3.039	83.3326	0.144	0.947	0.253	1.074
18	14.000	0.5512	2.000	12.7	12.701	11.546	114.068	74.1	1.370	24.29	3.051	83.3326	0.144	1.083	0.289	1.227
19	16.000	0.6299	2.000	12.7	14.701	13.546	155.070	77.1	1.359	24.68	3.125	83.3326	0.144	1.083	0.289	1.227
20	18.000	0.7087	2.500	10.2	16.376	14.933	190.259	74.8	1.227	24.38	3.067	83.3325	0.144	1.353	0.361	1.534
21	20.000	0.7874	2.500	10.2	18.376	16.933	242.297	77.1	1.274	24.68	3.125	83.3325	0.144	1.353	0.361	1.534
22	22.000	0.8661	2.500	10.2	20.376	18.933	300.618	79.1	1.241	24.94	3.171	83.3325	0.144	1.353	0.361	1.534
23	24.000	0.9449	3.000	8.5	22.051	20.319	348.908	77.1	1.161	24.68	3.125	83.3326	0.144	1.624	0.433	1.840
24	27.000	1.0630	3.000	8.5	25.051	23.319	455.300	79.5	1.305	24.99	3.182	83.3326	0.144	1.624	0.433	1.840
25	30.000	1.1811	3.500	7.3	27.727	25.706	555.296	78.6	1.220	24.87	3.159	83.3326	0.144	1.894	0.505	2.147
26	33.000	1.2992	3.500	7.3	30.727	28.706	687.667	80.4	1.238	25.11	3.203	83.3326	0.144	1.894	0.505	2.147
27	36.000	1.4173	4.000	6.3	33.402	31.093	809.423	79.5	1.177	24.99	3.182	83.3326	0.144	2.165	0.577	2.454
28	39.000	1.5354	4.000	6.3	36.402	34.093	967.772	81.0	1.196	25.18	3.217	83.3326	0.144	2.165	0.577	2.454
29	42.000	1.6535	4.500	5.6	39.077	36.479	1111.289	80.2	1.148	25.08	3.198	83.3326	0.144	2.436	0.650	2.760
30	45.000	1.7717	4.500	5.6	42.077	39.479	1295.617	81.5	1.166	25.24	3.227	83.3326	0.144	2.436	0.650	2.760
31	48.000	1.8898	5.000	5.1	44.752	41.866	1460.893	80.7	1.128	25.15	3.210	83.3326	0.144	2.706	0.722	3.067
32	52.000	2.0472	5.000	5.1	48.752	45.866	1744.444	82.1	1.194	25.33	3.243	83.3326	0.144	2.706	0.722	3.067
33	56.000	2.2047	5.500	4.6	52.428	49.252	2014.189	81.8	1.155	25.28	3.235	83.3326	0.144	2.977	0.794	3.374
34	60.000	2.3622	5.500	4.6	56.428	53.252	2344.945	82.9	1.164	25.43	3.262	83.3326	0.144	2.977	0.794	3.374
35	64.000	2.5197	6.000	4.2	60.103	56.639	2656.146	82.6	1.133	25.38	3.253	83.3326	0.144	3.248	0.866	3.681
36	68.000	2.6772	6.000	4.2	64.103	60.639	3034.106	83.5	1.142	25.50	3.276	83.3326	0.144	3.248	0.866	3.681
37	72.000	2.8346	6.000	4.2	68.103	64.639	3437.197	84.4	1.133	25.62	3.296	83.3326	0.144	3.248	0.866	3.681
38	76.000	2.9921	6.000	4.2	72.103	68.639	3865.423	85.2	1.125	25.71	3.314	83.3326	0.144	3.248	0.866	3.681
39	80.000	3.1496	6.000	4.2	76.103	72.639	4318.781	85.9	1.117	25.80	3.330	83.3326	0.144	3.248	0.866	3.681
40	85.000	3.3465	6.000	4.2	81.103	77.639	4920.816	86.7	1.139	25.90	3.348	83.3326	0.144	3.248	0.866	3.681
41	90.000	3.5433	6.000	4.2	86.103	82.639	5562.129	87.4	1.130	25.99	3.363	83.3326	0.144	3.248	0.866	3.681
42	95.000	3.7402	6.000	4.2	91.103	87.639	6242.711	88.1	1.122	26.08	3.378	83.3326	0.144	3.248	0.866	3.681
43	100.000	3.9370	6.000	4.2	96.103	92.639	6962.559	88.7	1.115	26.15	3.390	83.3326	0.144	3.248	0.866	3.681

For legend of symbols see page B-4.

ISO INCH COARSE THREAD SERIES

I	DIN	D	P	TIN	PD	DMI	SAIN	RA	RF	SCRA	SCF	TH	RRPP	HI	RR	T
1	0.0730	1.854	0.397	64.0	1.596	1.367	0.00262	62.6	0.0	22.67	2.763	83.3326	0.144	0.215	0.057	0.243
2	0.0860	2.184	0.454	56.0	1.890	1.628	0.00370	63.6	1.410	22.82	2.789	83.3326	0.144	0.246	0.065	0.278
3	0.0990	2.515	0.529	48.0	2.171	1.865	0.00486	63.2	1.316	22.75	2.778	83.3326	0.144	0.286	0.076	0.325
4	0.1120	2.845	0.635	40.0	2.432	2.066	0.00603	61.2	1.240	22.45	2.727	83.3326	0.144	0.344	0.092	0.390
5	0.1250	3.175	0.635	40.0	2.763	2.396	0.00796	64.8	1.319	22.99	2.819	83.3326	0.144	0.344	0.092	0.390
6	0.1380	3.505	0.794	32.0	2.990	2.531	0.00909	60.7	1.142	22.38	2.715	83.3326	0.144	0.430	0.115	0.487
7	0.1640	4.166	0.794	32.0	3.650	3.192	0.01401	66.3	1.542	23.21	2.857	83.3326	0.144	0.430	0.115	0.487
8	0.1900	4.826	1.058	24.0	4.139	3.528	0.01753	61.8	1.251	22.54	2.743	83.3326	0.144	0.573	0.153	0.649
9	0.2160	5.486	1.058	24.0	4.799	4.188	0.02416	65.9	1.378	23.16	2.848	83.3326	0.144	0.573	0.153	0.649
10	0.2500	6.350	1.270	20.0	5.525	4.792	0.03182	64.8	1.317	22.99	2.819	83.3326	0.144	0.687	0.183	0.779
11	0.3125	7.937	1.411	18.0	7.021	6.206	0.05243	68.4	1.648	23.50	2.909	83.3325	0.144	0.764	0.204	0.866
12	0.3750	9.525	1.587	16.0	8.494	7.577	0.07749	70.2	1.478	23.75	2.954	83.3326	0.144	0.859	0.229	0.974
13	0.4375	11.112	1.814	14.0	9.934	8.887	0.10631	70.7	1.372	23.83	2.968	83.3326	0.144	0.982	0.262	1.113
14	0.5000	12.700	1.954	13.0	11.431	10.303	0.14190	72.3	1.335	24.04	3.006	83.3325	0.144	1.058	0.282	1.199
15	0.5625	14.287	2.117	12.0	12.913	11.691	0.18194	73.2	1.282	24.17	3.029	83.3325	0.144	1.146	0.306	1.298
16	0.6250	15.875	2.309	11.0	14.375	13.042	0.22600	73.7	1.242	24.23	3.040	83.3326	0.144	1.250	0.333	1.416
17	0.7500	19.050	2.540	10.0	17.400	15.934	0.33446	75.7	1.480	24.50	3.090	83.3326	0.144	1.375	0.367	1.558
18	0.8750	22.225	2.822	9.0	20.392	18.762	0.46173	76.8	1.381	24.64	3.116	83.3326	0.144	1.528	0.407	1.731
19	1.0000	25.400	3.175	8.0	23.338	21.505	0.60574	77.1	1.312	24.68	3.125	83.3326	0.144	1.719	0.458	1.948
20	1.1250	28.575	3.629	7.0	26.218	24.123	0.76327	76.8	1.260	24.64	3.116	83.3326	0.144	1.964	0.524	2.226
21	1.2500	31.750	4.233	6.0	29.000	26.556	0.92905	75.7	1.217	24.50	3.090	83.3326	0.144	2.291	0.611	2.597
22	1.3750	34.925	4.233	6.0	32.175	29.731	1.15488	77.8	1.243	24.77	3.140	83.3326	0.144	2.291	0.611	2.597
23	1.5000	38.100	4.233	6.0	35.350	32.906	1.40525	79.5	1.217	24.99	3.182	83.3326	0.144	2.291	0.611	2.597
24	1.7500	44.450	5.080	5.0	41.151	38.217	1.89945	79.0	1.352	24.92	3.169	83.3326	0.144	2.750	0.733	3.116
25	2.0000	50.800	5.644	4.5	47.134	43.875	2.49822	79.5	1.315	24.99	3.182	83.3326	0.144	3.055	0.815	3.462
26	2.2500	57.150	5.644	4.5	53.484	50.225	3.24768	81.7	1.300	25.27	3.233	83.3326	0.144	3.055	0.815	3.462
27	2.5000	63.500	6.350	4.0	59.376	55.709	3.99882	81.5	1.231	25.24	3.227	83.3326	0.144	3.437	0.917	3.895
28	2.7500	69.850	6.350	4.0	65.726	62.059	4.93400	83.1	1.234	25.44	3.265	83.3326	0.144	3.437	0.917	3.895
29	3.0000	76.200	6.350	4.0	72.076	68.409	5.96735	84.4	1.209	25.62	3.296	83.3326	0.144	3.437	0.917	3.895
30	3.2500	82.550	6.350	4.0	78.426	74.759	7.09888	85.6	1.190	25.76	3.322	83.3326	0.144	3.437	0.917	3.895
31	3.5000	88.900	6.350	4.0	84.776	81.109	8.32859	86.6	1.173	25.89	3.344	83.3326	0.144	3.437	0.917	3.895
32	3.7500	95.250	6.350	4.0	91.126	87.459	9.65647	87.4	1.159	25.99	3.363	83.3326	0.144	3.437	0.917	3.895
33	4.0000	101.600	6.350	4.0	97.476	93.809	11.08253	88.2	1.148	26.09	3.380	83.3326	0.144	3.437	0.917	3.895

For legend of symbols see page B-4.

422-764 OL - 71 - 16

ISO METRIC FINE THREAD SERIES

I	O	DIN	P	TIN	PD	DMI	SA	RA	RF	SCRA	SCF	TH	RRPP	HI	RR	T
1	8.000	0.3150	1.000	25.4	7.350	6.773	38.768	77.1	0.0	24.68	3.125	83.3326	0.144	0.541	0.144	0.613
2	10.000	0.3937	1.250	20.3	9.188	8.466	60.574	77.1	1.563	24.68	3.125	83.3326	0.144	0.677	0.180	0.767
3	12.000	0.4724	1.250	20.3	11.188	10.466	91.306	80.7	1.507	25.15	3.210	83.3326	0.144	0.677	0.180	0.767
4	14.000	0.5512	1.500	16.9	13.026	12.160	123.477	80.2	1.352	25.08	3.198	83.3325	0.144	0.812	0.217	0.920
5	16.000	0.6299	1.500	16.9	15.026	14.160	166.009	82.6	1.344	25.38	3.253	83.3325	0.144	0.812	0.217	0.920
6	18.000	0.7087	1.500	16.9	17.026	16.160	214.825	84.4	1.294	25.62	3.296	83.3325	0.144	0.812	0.217	0.920
7	20.000	0.7874	1.500	16.9	19.026	18.160	269.924	85.9	1.256	25.80	3.330	83.3325	0.144	0.812	0.217	0.920
8	22.000	0.8661	1.500	16.9	21.026	20.160	331.306	87.2	1.227	25.96	3.357	83.3325	0.144	0.812	0.217	0.920
9	24.000	0.9449	2.000	12.7	22.701	21.546	381.910	84.4	1.153	25.62	3.296	83.3326	0.144	1.083	0.289	1.227
10	27.000	1.0630	2.000	12.7	25.701	24.546	492.894	86.1	1.291	25.83	3.333	83.3326	0.144	1.083	0.289	1.227
11	30.000	1.1811	2.000	12.7	28.701	27.546	618.014	87.4	1.254	25.99	3.363	83.3326	0.144	1.083	0.289	1.227
12	33.000	1.2992	2.000	12.7	31.701	30.546	757.272	88.5	1.225	26.13	3.388	83.3326	0.144	1.083	0.289	1.227
13	36.000	1.4173	3.000	8.5	34.051	32.319	859.299	84.4	1.135	25.62	3.296	83.3326	0.144	1.624	0.433	1.840
14	39.000	1.5354	3.000	8.5	37.051	35.319	1022.240	85.6	1.190	25.76	3.322	83.3326	0.144	1.624	0.433	1.840

ISO INCH FINE THREAD SERIES

For legend of symbols see page B-4.

I	DIN	D	P	TIN	PD	DMI	SAIN	RA	RF	SCRA	SCF	TH	RRPP	HI	RR	T
1	0.0340	0.864	0.212	120.0	0.726	0.604	0.00053	57.9	0.0	21.93	2.642	83.3326	0.144	0.115	0.031	0.130
2	0.0470	1.194	0.265	96.0	1.022	0.869	0.00107	61.5	2.027	22.49	2.734	83.3326	0.144	0.143	0.038	0.162
3	0.0600	1.524	0.317	80.0	1.318	1.134	0.00180	63.5	1.684	22.80	2.786	83.3326	0.144	0.172	0.046	0.195
4	0.0730	1.854	0.353	72.0	1.625	1.421	0.00278	66.4	1.546	23.22	2.858	83.3326	0.144	0.191	0.051	0.216
5	0.0860	2.184	0.397	64.0	1.927	1.697	0.00393	67.7	1.416	23.41	2.893	83.3326	0.144	0.215	0.057	0.243
6	0.0990	2.515	0.454	56.0	2.220	1.958	0.00523	67.9	1.329	23.44	2.898	83.3326	0.144	0.246	0.065	0.278
7	0.1120	2.845	0.529	48.0	2.501	2.196	0.00660	67.0	1.263	23.31	2.875	83.3326	0.144	0.286	0.076	0.325
8	0.1250	3.175	0.577	44.0	2.800	2.467	0.00831	67.7	1.258	23.41	2.892	83.3326	0.144	0.312	0.083	0.354
9	0.1380	3.505	0.635	40.0	3.093	2.726	0.01014	67.8	1.221	23.43	2.895	83.3326	0.144	0.344	0.092	0.390
10	0.1640	4.166	0.706	36.0	3.707	3.300	0.01473	69.7	1.452	23.69	2.943	83.3326	0.144	0.382	0.102	0.433
11	0.1900	4.826	0.794	32.0	4.310	3.852	0.01999	70.5	1.358	23.80	2.963	83.3326	0.144	0.430	0.115	0.487
12	0.2160	5.486	0.907	28.0	4.897	4.373	0.02579	70.4	1.290	23.78	2.959	83.3326	0.144	0.491	0.131	0.556
13	0.2500	6.350	0.907	28.0	5.761	5.237	0.03637	74.1	1.410	24.29	3.051	83.3326	0.144	0.491	0.131	0.556
14	0.3125	7.937	1.058	24.0	7.250	6.639	0.05807	75.7	1.596	24.50	3.090	83.3326	0.144	0.573	0.153	0.649
15	0.3750	9.525	1.058	24.0	8.838	8.227	0.08783	79.5	1.513	24.99	3.182	83.3326	0.144	0.573	0.153	0.649
16	0.4375	11.112	1.270	20.0	10.288	9.554	0.11872	79.0	1.352	24.92	3.169	83.3326	0.144	0.687	0.183	0.779
17	0.5000	12.700	1.270	20.0	11.875	11.142	0.15995	81.5	1.347	25.24	3.227	83.3326	0.144	0.687	0.183	0.779
18	0.5625	14.287	1.411	18.0	13.371	12.556	0.20298	81.7	1.269	25.27	3.233	83.3325	0.144	0.764	0.204	0.866
19	0.6250	15.875	1.411	18.0	14.958	14.144	0.25596	83.4	1.261	25.49	3.273	83.3325	0.144	0.764	0.204	0.866
20	0.7500	19.050	1.587	16.0	18.019	17.102	0.37296	84.4	1.457	25.62	3.296	83.3326	0.144	0.859	0.229	0.974
21	0.8750	22.225	1.814	14.0	21.047	19.999	0.50947	84.7	1.366	25.65	3.303	83.3326	0.144	0.982	0.262	1.113
22	1.0000	25.400	2.117	12.0	24.025	22.803	0.66304	84.4	1.301	25.62	3.296	83.3325	0.144	1.146	0.306	1.298
23	1.1250	28.575	2.117	12.0	27.200	25.978	0.85572	86.1	1.291	25.83	3.333	83.3325	0.144	1.146	0.306	1.298
24	1.2500	31.750	2.117	12.0	30.375	29.153	1.07294	87.4	1.254	25.99	3.363	83.3325	0.144	1.146	0.306	1.298
25	1.3750	34.925	2.117	12.0	33.550	32.328	1.31471	88.5	1.225	26.13	3.388	83.3325	0.144	1.146	0.306	1.298
26	1.5000	38.100	2.117	12.0	36.725	35.503	1.58102	89.5	1.203	26.25	3.408	83.3325	0.144	1.146	0.306	1.298

RECOMMENDED METRIC DIAMETER/PITCH SERIES

I	D	DIN	P	TIN	PD	DMI	SA	RA	RF	SCRA	SCF	TH	RRPP	H1	RR	T
1	1.000	0.0394	0.250	101.6	0.838	0.711	0.449	57.2	0.0	23.27	2.459	75.0049	0.180	0.122	0.045	0.144
2	1.250	0.0492	0.300	84.7	1.055	0.904	0.720	58.7	1.603	23.54	2.494	75.0049	0.180	0.146	0.054	0.173
3	1.600	0.0630	0.350	72.6	1.373	1.196	1.245	61.9	1.728	24.09	2.570	75.0049	0.180	0.171	0.063	0.202
4	2.000	0.0787	0.450	56.4	1.708	1.480	1.915	61.0	1.538	23.93	2.547	75.0049	0.180	0.219	0.081	0.260
5	2.500	0.0984	0.550	46.2	2.143	1.865	3.030	61.7	1.582	24.06	2.566	75.0049	0.180	0.268	0.099	0.318
6	3.150	0.1240	0.650	39.1	2.728	2.399	4.975	63.8	1.642	24.41	2.615	75.0049	0.180	0.317	0.117	0.375
7	4.000	0.1575	0.800	31.7	3.480	3.076	8.146	64.8	1.638	24.57	2.639	75.0049	0.180	0.390	0.144	0.462
8	5.000	0.1969	0.900	28.2	4.415	3.961	13.352	68.0	1.639	25.06	2.713	75.0049	0.180	0.438	0.162	0.520
9	6.300	0.2480	1.000	25.4	5.650	5.145	22.276	71.5	1.668	25.58	2.794	75.0049	0.180	0.487	0.180	0.577
10	8.000	0.3150	1.250	20.3	7.188	6.557	36.126	71.9	1.622	25.64	2.803	75.0048	0.180	0.609	0.225	0.722
11	10.000	0.3937	1.500	16.9	9.026	8.268	57.261	72.9	1.585	25.79	2.827	75.0048	0.180	0.731	0.271	0.866
12	12.500	0.4921	1.750	14.5	11.363	10.479	91.524	74.6	1.598	26.03	2.865	75.0048	0.180	0.853	0.316	1.010
13	16.000	0.6299	2.000	12.7	14.701	13.691	155.070	77.1	1.694	26.39	2.923	75.0049	0.180	0.974	0.361	1.155
14	20.000	0.7874	2.500	10.2	18.376	17.113	242.297	77.1	1.562	26.39	2.923	75.0048	0.180	1.218	0.451	1.443
15	25.000	0.9843	3.000	8.5	23.051	21.536	382.801	78.0	1.580	26.51	2.942	75.0048	0.180	1.462	0.541	1.732
16	30.000	1.1811	3.500	7.3	27.727	25.958	555.296	78.6	1.451	26.58	2.955	75.0049	0.180	1.705	0.631	2.021
17	36.000	1.4173	4.000	6.3	33.402	31.381	809.423	79.5	1.458	26.72	2.976	75.0049	0.180	1.949	0.722	2.309
18	42.000	1.6535	4.500	5.6	39.077	36.804	1111.289	80.2	1.373	26.81	2.992	75.0049	0.180	2.192	0.812	2.598
19	48.000	1.8898	5.000	5.1	44.752	42.226	1460.873	80.7	1.315	26.88	3.003	75.0049	0.180	2.436	0.902	2.887
20	56.000	2.2047	5.500	4.6	52.428	49.649	2014.189	81.8	1.379	27.02	3.026	75.0049	0.180	2.679	0.992	3.176
21	64.000	2.5197	6.000	4.2	60.103	57.072	2656.146	82.6	1.319	27.13	3.043	75.0049	0.180	2.923	1.082	3.464
22	72.000	2.8346	6.000	4.2	68.103	65.072	3437.197	84.4	1.294	27.38	3.083	75.0049	0.180	2.923	1.082	3.464
23	80.000	3.1496	6.000	4.2	76.103	73.072	4318.781	85.9	1.256	27.58	3.115	75.0049	0.180	2.923	1.082	3.464
24	90.000	3.5433	6.000	4.2	86.103	83.072	5562.129	87.4	1.288	27.78	3.147	75.0049	0.180	2.923	1.082	3.464
25	100.000	3.9370	6.000	4.2	96.103	93.072	6962.559	88.7	1.252	27.95	3.172	75.0049	0.180	2.923	1.082	3.464

LEGEND

I - size number in the series

D - basic diameter, mm

DIN - basic diameter, inches

P - thread pitch, mm

TIN - threads per inch

PD - pitch diameter, mm

DMI - minor diameter, mm

SA - stress area, mm^2

SAIN - stress area, $in.^2$

RA - ratio of areas, %, $\frac{SA}{\pi D^2}$

RF - ratio of load carrying capacities between adjacent sizes, %, $\left[\frac{SA_{(I+1)}}{SA_I}\right]$

SCRA - RA/SCF

SCF - stress concentration factor for axial loading

TH - depth of thread engagement, %

RRPP - root radius in proportion to thread pitch

H1 - depth of thread, mm

RR - root radius, mm

T - total depth of thread, mm

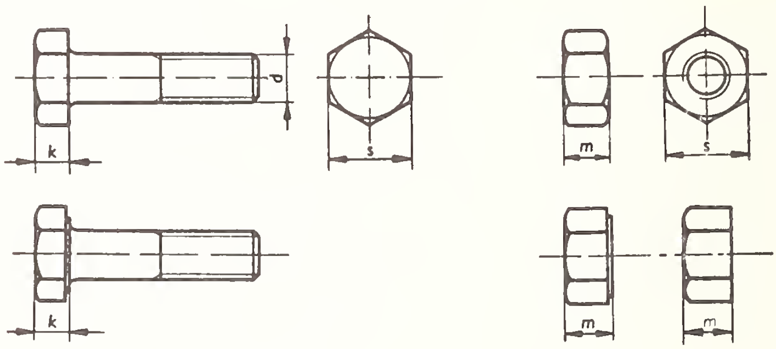
ISO / R 272 - 1968 (E)

ISO Recommendation R 272 February 1968

HEXAGON BOLTS AND NUTS

WIDTHS ACROSS FLATS, HEIGHTS OF HEADS, THICKNESSES OF NUTS

METRIC SERIES



Dimensions in millimetres

Thread diameter	Width* across flats		Height of head	Thickness of nut
d	normal	small	k	m
1.6	3.2	—	1.1	1.3
2	4	—	1.4	1.6
2.5	5	—	1.7	2
3	5.5	—	2	2.4
4	7	—	2.8	3.2
5	8	—	3.5	4
6	10	—	4	5
7	11	—	5	5.5
8	13	12	5.5	6.5
10	17	14	7	8
12	19	17	8	10
14	22	19	9	11
16	24	22	10	13
18	27	24	12	15
20	30	27	13	16
22	32	30	14	18
24	36	32	15	19
27	41	36	17	22
30	46	41	19	24
33	50	46	21	26
36	55	50	23	29
39	60	55	25	31

Thread diameter	Width across flats	Height of head	Thickness of nut
d	s	k	m
42	65	26	34
45	70	28	36
48	75	30	38
52	80	33	42
56	85	35	45
60	90	38	48
64	95	40	51
68	100	43	54
72	105	45	58
76	110	48	61
80	115	50	64
85	120	54	68
90	130	57	72
95	135	60	76
100	145	63	80
105	150	66	84
110	155	69	88
115	165	72	92
120	170	76	96
125	180	79	100
130	185	82	104
140	200	88	112
150	210	95	120

* Where larger metric hexagons are required, the next larger width across flats for any given diameter, as shown in the normal metric series, should be chosen, leaving the other dimensions unchanged.

ANNEX D - METHOD FOR DETERMINING STRESS CONCENTRATION FACTOR

For fatigue evaluation in axial mode of threaded fasteners, both the static and alternating stress components must be determined. The static stress component can be considered as being primarily dependent on the stress area. The alternating stress component will be dependent on the stress area and the effective stress concentration factor.

Stress concentrations occur in thread roots due to two simultaneous types of loadings:

1. Axial bolt loading (Core load)

2. Local thread projection loading (Thread load)

The actual magnitudes of core and thread loading are influenced by many factors in the mating threads, and therefore, cannot be determined with great accuracy.

Stress concentration factors (SCF) due to core loading were determined by using the methods given by Neuber (1) and Heywood (2).

According to Neuber, the stress concentration factor in a single circumferential "U" notch in a round specimen is a function of a/ρ and t/ρ where a is the shank radius of the notch at the root, ρ is the radius of curvature of the root, and t is the depth of the notch. Using the stress concentration factors for shallow notches and deep notches, a stress concentration factor for a notch of arbitrary depth can be given as

$$\alpha_k = 1 + \frac{(\alpha_{fk} - 1)\cdot(\alpha_{tk} - 1)}{\sqrt{(\alpha_{fk} - 1)^2 + (\alpha_{tk} - 1)^2}} \qquad [1]$$

where

α_k = stress concentration factor for a notch of arbitrary depth

α_{fk} = stress concentration factor for a shallow notch

α_{tk} = stress concentration factor for a deep notch

The obtained stress concentration factors then can be corrected for:

a) Load relieving effects of multiple notches by using a load relieving factor γ which is given as a function of (b/t) where b is the pitch between the notches. (Ref. 1, p. 206 eq. (24) and Fig. 93)

422-764 OL - 71 - 17

b) Flank angle effects (Ref. 2, eq. 6-12)

$$\alpha = 1 + (\alpha_K - 1) \cdot \left(1 - \left(\frac{\beta}{180}\right)^{\left(1 + 2.4\sqrt{g/t}\right)}\right) \qquad [2]$$

where

β = flank angle

α = corrected stress concentration value

These methods and modifications will be used in determining the stress concentration factor for a threaded section due to axial load alone based on the maximum axial stress criterion.

New symbols for parameters to be used in further calculations are:

DMI - minor diameter

P = pitch

T = depth of thread

RR = root radius

ν = Poisson's Ratio

With these symbols the constituent parts of equation (1) can be rewritten as

$$\alpha_{fK} = 1 + 2\sqrt{\gamma T/RR} \qquad [3]$$

(Ref. 1, p 207, eq. 27)

$$\alpha_{tK} = \frac{1}{N}\left[(DR) \cdot \sqrt{(DR) + 1} + (.5 + \nu) \cdot DR + (1 + \nu) \cdot \sqrt{(DR) + 1} + 1\right] \qquad [4]$$

(Ref. 1, p 132, eq. 59, 6]

where

$$N = (DR) + 2\nu\sqrt{(DR) + 1} + 2$$

and

$$DR = \sqrt{DMI/2RR}$$

The calculated α_{fK} and α_{tK} factors then can be entered into equations (1) and (2) for obtaining the stress concentration factor (SCF) for a threaded section with a 30 deg flank angle due to axial load alone and will take the form of

$$SCF = 1 + (\alpha_K - 1)\cdot(1 - .3333)^{\left(1 + 2.4/\sqrt{T/RR}\right)} \qquad [5]$$

The three major geometric ratios involved in calculations of SCF are:

$$(DMI/2RR), \quad (T/RR) \quad \text{and} \quad (P/T) \qquad [6]$$

All of these parameters in the case of threaded fasteners can be related to pitch. Consequently, with the specified root radius to pitch proportion (RRPP) and the depth of thread engagement, the rest of the parameters in the ratios of eq. (6) will also be predetermined.

In any series of fasteners where it would be required to have a constant stress concentration factor (SCF), the above three ratios must be constant or nearly constant. By maintaining a uniform RRPP for the entire series, a series with a constant SCF can be derived at the expense of disproportioned pitches.

Additional stress effects in engagement can be considered by introducing the overall stress concentration factor (SCFO) for dynamic rating of the screw-nut system. This factor can be given as

$$SCFO = SCF\left[1 + 1/(1 + C\cdot SR)\ SR\right] \qquad [7]$$

(Ref. 2)

where:

$C = \left((60 - \theta)/44\right)^2$ = a thread constant

θ = inclination of flank to radial plane, degrees
C = .465 for 60 deg thread form (30 deg flank angle)

$SR = S_a/S_p$ = stress ratio

S_a = maximum root stress due to axial load alone. SCF is based on S_a

S_p = maximum root stress due to the local projection (cantilever loading on thread flank) load alone. This stress is a function of several parameters. By maintaining the predetermined pitch and root radius dimensions or proportions and thread angles, the length of helix of thread in engagement becomes the controlling parameter in changing the S_p and SR quantities.

The stress concentration factor due to axial load alone (SCF) in equation (7) can be treated as the predominant indicator of the dynamic performance of a threaded fastener. The notch sensitivity of involved materials and the stress ratio (SR) are the remaining factors needed to determine the dynamic rating of a fastener.

By maintaining a constant stress ratio (SR) the overall stress concentration factor (SCFO) will remain constant. With the specified pitch and root radius dimensions and thread flank angles, the helix length of thread in contact with the nut (height of the nut) becomes theoretically the controlling parameter in changing the S_p and SR quantities. At the present phase of the task, the SCFO factors were not computed. In addition, considerations of notch sensitivities of involved materials would be required for a true dynamic rating of a fastener.

If the true dynamic rating of a fastener is not required or cannot be practically achieved, then the stress concentration factor (SCF) in conjunction with the static rating would become one of the better indicators of dynamical performance.

REFERENCES

1. H. Neuber, "Theory of Notch Stresses: Principles for Exact Calculations of Strength with References to Structural Form and Material", Translated from a publication of Springer-Verlag, Berlin, Goettingen, Heidelberg 1958, (AEC-tr-4547).

2. R. B. Heywood, "Designing by Photoelasticity", Chapman & Hall Ltd., London 1952.

TABLE 1 - STRESS CONCENTRATION FACTOR (SCF) TO THREAD PITCH RELATIONSHIP FOR DIAMETERS 5 THRU 30 mm WITH RRPP = .150

BASIC DIA mm \ SCF	2.75	2.80	2.85	2.90	2.95	3.00	THREAD PITCH RECOMMENDED METRIC SERIES
	THREAD PITCH, mm (COMPUTED)						
5	1.043	.983	.917	.855	.797	.735	.9
6.3	1.317	1.241	1.159	1.081	1.000	.922	1
8	1.677	1.566	1.476	1.363	1.273	1.176	1.25
10	2.095	1.956	1.844	1.722	1.591	1.456	1.5
12.5	2.616	2.443	2.303	2.150	1.986	1.835	1.75
16	3.332	3.140	2.960	2.734	2.553	2.337	2
20	4.193	3.916	3.691	3.409	3.184	2.914	2.5
25	5.209	4.910	4.628	4.275	3.992	3.653	3
30	6.253	5.894	5.504	5.140	4.748	4.434	3.5

NOTE: - RRPP = root radius in proportion to thread pitch.

TABLE 2 - STRESS CONCENTRATION FACTOR (SCF) TO THREAD PITCH RELATIONSHIP FOR DIAMETERS 5 THRU 30 mm WITH RRPP = .180

BASIC DIA mm \ SCF	2.75	2.80	2.85	2.90	2.95	3.00	THREAD PITCH RECOMMENDED METRIC SERIES
	THREAD PITCH, mm (COMPUTED)						
5	.847	.781	.721	.651	.589	.522	.9
6.3	1.071	.989	.904	.817	.739	.668	1
8	1.363	1.248	1.152	1.042	.942	.834	1.25
10	1.703	1.576	1.442	1.318	1.191	1.055	1.5
12.5	2.127	1.968	1.801	1.648	1.476	1.307	1.75
16	2.709	2.502	2.290	2.076	1.900	1.683	2
20	3.409	3.120	2.855	2.613	2.369	2.121	2.5
25	4.325	3.912	3.580	3.246	2.971	2.635	3
30	5.140	4.704	4.305	3.930	3.533	3.164	3.5

NOTE: RRPP = root radius in proportion to thread pitch.

4. DIAMETER/PITCH COMBINATIONS

TABLE – Diameter/pitch

Dimensions in millimetres

Nominal diameters			Pitches										
Col. 1 1st choice	Col. 2 2nd choice	Col. 3 3rd choice	coarse	fine									
				3	2	1.5	1.25	1	0.75	0.5	0.35	0.25	0.2
1			0.25										0.2
	1.1		0.25										0.2
1.2			0.25										0.2
	1.4		0.3										0.2
1.6			0.35										0.2
	1.8		0.35										0.2
2			0.4									0.25	
	2.2		0.45									0.25	
2.5			0.45								0.35		
3			0.5								0.35		
	3.5		0.6								0.35		
4			0.7							0.5			
	4.5		0.75							0.5			
5			0.8							0.5			
		5.5								0.5			
6			1						0.75				
		7	1						0.75				
8			1.25					1	0.75				
		9	1.25					1	0.75				
10			1.5				1.25	1	0.75				
		11	1.5					1	0.75				
12			1.75			1.5	1.25	1					
	14		2			1.5	1.25*	1					
		15				1.5		1					
16			2			1.5		1					
		17				1.5		1					
	18		2.5		2	1.5		1					
20			2.5		2	1.5		1					
	22		2.5		2	1.5		1					
24			3		2	1.5		1					
		25			2	1.5		1					
		26				1.5							
	27		3		2	1.5		1					
		28			2	1.5		1					
30			3.5	(3)	2	1.5		1					
		32			2	1.5							
	33		3.5	(3)	2	1.5							
		35**				1.5							
36			4	3	2	1.5							
		38				1.5							
	39		4	3	2	1.5							

* Only for spark plugs for engines.
** Only for locking nuts for bearings.

Avoid as far as possible pitches in brackets.

TABLE – Diameter/pitch (*concluded*) Dimensions in millimetres

Nominal diameters			Pitches					
Col. 1 1st choice	Col. 2 2nd choice	Col. 3 3rd choice	coarse	fine 6	fine 4	fine 3	fine 2	fine 1.5
		40				3	2	1.5
42			4.5		4	3	2	1.5
	45		4.5		4	3	2	1.5
48			5		4	3	2	1.5
		50				3	2	1.5
	52		5		4	3	2	1.5
		55			4	3	2	1.5
56			5.5		4	3	2	1.5
		58			4	3	2	1.5
	60		5.5		4	3	2	1.5
		62			4	3	2	1.5
64			6		4	3	2	1.5
		65			4	3	2	1.5
	68		6		4	3	2	1.5
		70		6	4	3	2	1.5
72				6	4	3	2	1.5
		75			4	3	2	1.5
	76			6	4	3	2	1.5
		78					2	
80				6	4	3	2	1.5
		82					2	
	85			6	4	3	2	
90				6	4	3	2	
	95			6	4	3	2	
100				6	4	3	2	
	105			6	4	3	2	
110				6	4	3	2	
	115			6	4	3	2	
	120			6	4	3	2	
125				6	4	3	2	
	130			6	4	3	2	
		135		6	4	3	2	
140				6	4	3	2	
		145		6	4	3	2	
	150			6	4	3	2	
		155		6	4	3		
160				6	4	3		
		165		6	4	3		
	170			6	4	3		
		175		6	4	3		
180				6	4	3		
		185		6	4	3		
	190			6		3		
		195		6	4	3		
200				6	4	3		
		205		6	4	3		
	210			6	4	3		
		215		6	4	3		
220				6	4	3		
		225		6	4	3		
		230		6	4	3		
		235		6	4	3		
	240			6	4	3		
		245		6	4	3		
250				6	4	3		
		255		6	4			
	260			6	4			
		265		6	4			
		270		6	4			
		275		6	4			
280				6	4			
		285		6	4			
		290		6	4			
		295		6	4			
	300			6	4			

4. SCREW THREADS

TABLE 1.

Sizes: Primary	Sizes: Secondary	Basic Major diameter (in)	Series with graded pitches: Coarse thread series * UNC	Series with graded pitches: Fine thread series * UNF	Series with graded pitches: Extra-fine thread series UNEF	Series with constant (uniform) pitches: 4-thread series UN	6-thread series UN	8-thread series UN	12-thread series UN	16-thread series UN	20-thread series UN	28-thread series UN	32-thread series UN
1	2	3	4	5	6	7	8	9	10	11	12	13	14
No. 0		0.060 0		80									
	No. 1	0.073 0	64	72									
No. 2		0.086 0	56	64									
	No. 3	0.099 0	48	56									
No. 4		0.112 0	40	48									
No. 5		0.125 0	40	44									
No. 6		0.138 0	32	40									UNC
No. 8		0.164 0	32	36									UNC
No. 10		0.190 0	24	32									UNF
	No. 12	0.216 0	24	28	32							UNF	UNEF
1/4		0.250 0	20	28	32						UNC	UNF	UNEF
5/16		0.312 5	18	24	32						20	28	UNEF
3/8		0.375 0	16	24	32					UNC	20	28	UNEF
7/16		0.437 5	14	20	28					16	UNF	UNEF	32
1/2		0.500 0	13	20	28					16	UNF	UNEF	32
9/16		0.562 5	12	18	24				UNC	16	20	28	32
5/8		0.625 0	11	18	24				12	16	20	28	32
	11/16	0.687 5			24				12	16	20	28	32
3/4		0.750 0	10	16	20				12	UNF	UNEF	28	32
	13/16	0.812 5			20				12	16	UNEF	28	32
7/8		0.875 0	9	14	20				12	16	UNEF	28	32
	15/16	0.937 5			20				12	16	UNEF	28	32
1		1.000 0	8	12	20			UNC	UNF	16	UNEF	28	32
	1 1/16	1.062 5			18			8	12	16	20	28	
1 1/8		1.125 0	7	12	18			8	UNF	16	20	28	
	1 3/16	1.187 5			18			8	12	16	20	28	
1 1/4		1.250 0	7	12	18			8	UNF	16	20	28	
	1 5/16	1.312 5			18			8	12	16	20	28	
1 3/8		1.375 0	6	12	18		UNC	8	UNF	16	20	28	
	1 7/16	1.437 5			18		6	8	12	16	20	28	
1 1/2		1.500 0	6	12	18		UNC	8	UNF	16	20	28	
	1 9/16	1.562 5			18		6	8	12	16	20		
1 5/8		1.625 0			18		6	8	12	16	20		
	1 11/16	1.687 5			18		6	8	12	16	20		
1 3/4		1.750 0	5				6	8	12	16	20		
	1 13/16	1.812 5					6	8	12	16	20		
1 7/8		1.875 0					6	8	12	16	20		

* Selected series for screws, bolts and nuts, and first choice for general engineering applications.

(continued)

TABLE 1. – *(concluded)*

Sizes: Primary	Sizes: Secondary	Basic major diameter (in)	Number of threads per inch: Series with graded pitches: Coarse thread series * UNC	Fine thread series * UNF	Extra-fine thread series UNEF	Series with constant (uniform) pitches: 4-thread series UN	6-thread series UN	8-thread series UN	12-thread series UN	16-thread series UN	20-thread series UN	28-thread series UN	32-thread series UN
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	1 15/16	1.937 5					6	8	12	16	20		
2		2.000 0	4 1/2				6	8	12	16	20		
	2 1/8	2.125 0					6	8	12	16	20		
2 1/4		2.250 0	4 1/2				6	8	12	16	20		
	2 3/8	2.375 0					6	8	12	16	20		
2 1/2		2.500 0	4			UNC	6	8	12	16	20		
	2 5/8	2.625 0				4	6	8	12	16	20		
2 3/4		2.750 0	4			UNC	6	8	12	16	20		
	2 7/8	2.875 0				4	6	8	12	16	20		
3		3.000 0	4			UNC	6	8	12	16	20		
	3 1/8	3.125 0				4	6	8	12	16			
3 1/4		3.250 0	4			UNC	6	8	12	16			
	3 3/8	3.375 0				4	6	8	12	16			
3 1/2		3.500 0	4			UNC	6	8	12	16			
	3 5/8	3.625 0				4	6	8	12	16			
3 3/4		3.750 0	4			UNC	6	8	12	16			
	3 7/8	3.875 0				4	6	8	12	16			
4		4.000 0	4			UNC	6	8	12	16			
	4 1/8	4.125 0				4	6	8	12	16			
4 1/4		4.250 0				4	6	8	12	16			
	4 3/8	4.375 0				4	6	8	12	16			
4 1/2		4.500 0				4	6	8	12	16			
	4 5/8	4.625 0				4	6	8	12	16			
4 3/4		4.750 0				4	6	8	12	16			
	4 7/8	4.875 0				4	6	8	12	16			
5		5.000 0				4	6	8	12	16			
	5 1/8	5.125 0				4	6	8	12	16			
5 1/4		5.250 0				4	6	8	12	16			
	5 3/8	5.375 0				4	6	8	12	16			
5 1/2		5.500 0				4	6	8	12	16			
	5 5/8	5.625 0				4	6	8	12	16			
5 3/4		5.750 0				4	6	8	12	16			
	5 7/8	5.875 0				4	6	8	12	16			
6		6.000 0				4	6	8	12	16			

* Selected series for screws, bolts and nuts, and first choice for general engineering applications.

ANNEX F - MEMBERSHIP OF IFI TECHNICAL COMMITTEES

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J. F. Morrow	The National Screw and Manufacturing Company
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H. G. Muenchinger	Continental Screw Company
J. S. Orlando	H. M. Harper Company
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R. B. Belford, Secy.	Industrial Fasteners Institute

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ANNEX G - REFERENCES

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