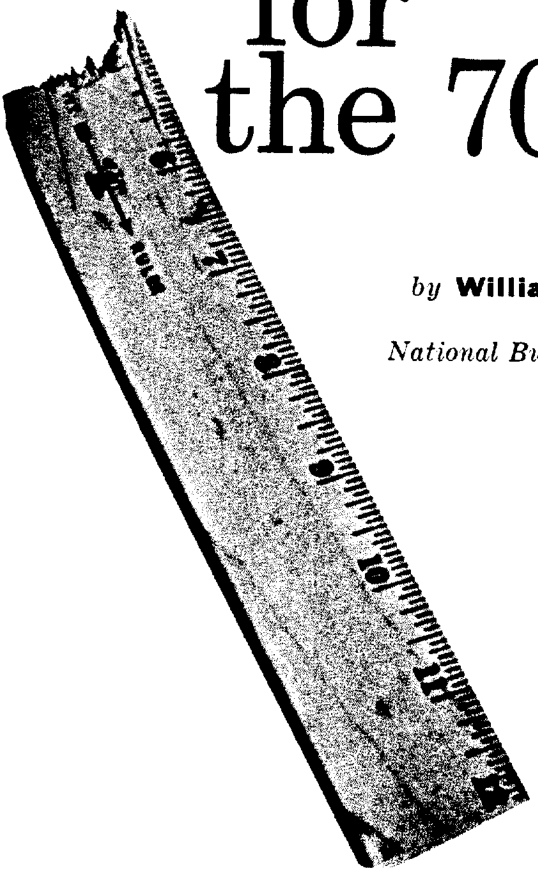
Reliability demands are turning old standard accuracies into anachronisms, and the NBS is scouting fundamental properties of matter for measuring sticks such as krypton wavelengths and the atomic clock.

Standards for the 70s



by **William A. Wildhack,**
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WEIGHTS AND MEASURES, John Quincy Adams told Congress in 1821, "are necessary to every occupation of human industry, to every transaction of trade and commerce, to all the exchanges of peace, and all the operations of war."

These considerations are as valid today as they were more than 141 years ago. In fact, the advancement of science, the exploration of space, the progress of technology, and the economic growth of the nation are all critically dependent on our ability to make measurements with sufficient accuracy to meet the demands of this modern age.

Unfortunately, a recent survey of the measurement requirements of military and space programs conducted by the Aerospace Industries Assn., has shown serious deficiencies in U. S. measurement capabilities. However, basic research in the physical sciences is providing answers to many measurement problems and promises more answers in the near future.

This physical research need not be aimed specifically at solving measurement problems, as advances made in a wide variety of disciplines often have bearing on the field of measurement. A recent example of such carry-over is the laser, which is being investigated by scientists in many laboratories. Not developed specifically as a measurement tool, the laser may contribute to improved determinations of length, and already has been used at the National Bureau of Standards for measurement of lengths longer than 100 ft with a precision previously available only up to a few feet.

The keeper of standards

The National Bureau of Standards, a part of the Department of Commerce, is the official custodian of the national standards of weights and measures, and as such must provide high accuracy calibrations for the reference standards used in scientific laboratories, industrial operations, and commercial transactions.

In order to calibrate the measurement devices developed by industry, the bureau is engaged continuously in physical research to discover or adapt new principles.

These tasks call for close cooperation with industry and with government agencies charged with great national programs of defense, space, health, and atomic energy, coordination of research on a broad spectrum of measurement problems, and prompt dissemination of the standards and techniques required for accurate measurements.

All measurements involve, in effect, the process of comparing the quantity being measured, or some quantity representative of it, with some sort of reference. This is true whether it be a housewife measuring liquid shortening with a measuring cup or a scientist calibrating gage blocks in terms of a wavelength of light.

Absolutes for accuracy

The accuracy of a measurement depends on the accuracy of the reference standard used for calibration, the precision and stability of the instrument used to make the measurement, and the technique employed during the measurement process. Continuous refinements of these three factors are essential if our measurement capabilities are to satisfy demands of technology.

At present, four quantities — length, mass, time, and temperature —are the starting points from which all other quantities may be defined. Therefore, the entire measurement system depends essentially on the stability of standards used for these four basic quantities.

Efforts are being made to define these standards in terms of fundamental properties of matter. Standards so defined would eliminate the possibility of change as can occur in a physical standard, and would make equivalent standards available to all laboratories having the requisite equipment.

The road toward conversion to natural standards was paved in October 1960 when the International General Conference on Weights and Measures defined the meter as equal to 1,650,763.73 wavelengths of the orange-red light of the krypton 86 isotope. For 70 years prior to this action, the meter had been defined as the distance between two lines scribed on a platinum-iridium bar maintained at the International Bureau of Weights and Measures in Paris. Calibration of length standards in industry and scientific laboratories still will be accomplished by comparison with physical standards, and only when extreme accuracy is needed will krypton 86 be used in actual measurements.

Big Ben won't do

The unit of time, the second, is defined presently as a subdivision of the year (1/31,556,925.9747 of the tropical year 1900). A more convenient, dependable periodic phenomenon is desired, with extreme constancy in its period. Oscillations of atoms within molecules, the precession of spinning nuclei within atoms, or radiation accociated with transitions of atomic energy levels exhibit the desired constancy to varying degrees.

The problem is to devise apparatus in which the periodic phenomenon may be kept going indefinitely and coupled with an output system to count the total number of periods. Such a device may be regarded as either an atomic clock or an atomic frequency standard, as frequency is defined as the number of periods per unit time.

The first atomic frequency standard or clock, based on microwave absorption in ammonia gas, was placed in operation in 1948. Continued research since that time has resulted in improved atomic clocks (for example, cesium), utilizing transitions in a beam of ions, that have stabilities of 1 in 10^{11}. A clock based on such a device would deviate less than one second every 3000 years. Continued development of atomic clocks probably will lead to adoption of some particular transition as the standard of frequency and time, perhaps at the 1966 meeting of the General Conference of Weights and Measures.

The present standard of mass, the kilogram, a cylinder of platinum-iridium kept at the International Bureau, can be compared with other standards accurately enough to meet the needs of precision mass determinations. However, the possibility of change or damage to any such arbitrary and material stan-

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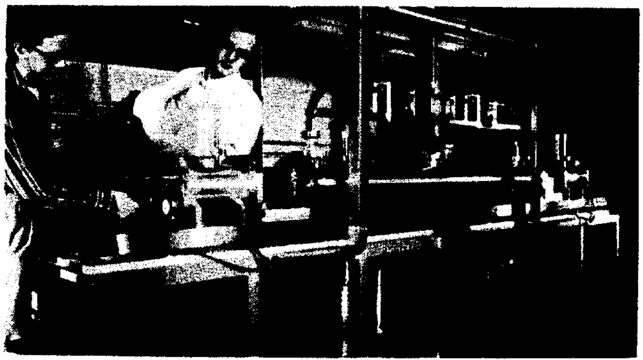

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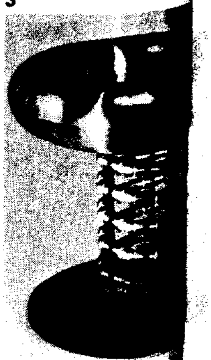

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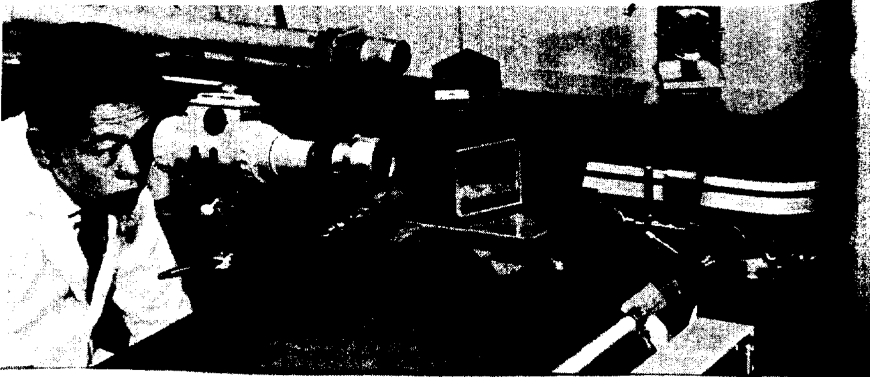

dard invites conversion to an atomic mass standard.

Possible means—but of doubtful feasibility at present—for using atoms as a mass standard might involve the use of a mass spectrometer to count individual atoms of the same atomic weight, and collect a sufficiently large number of atoms to establish a conversion factor with respect to the kilogram. However, little more than speculation has been done to establish a direct relationship between the kilogram and a known number of particular atoms.

Triple point for temperature

The standard of temperature on the thermodynamic scale is the temperature of the triple point of water—the temperature at which ice, water, and water vapor are in equilibrium. The value of 273.16 K is assigned to this point. Thus, any laboratory having a carefully constructed "triple-point" cell can define the thermodynamic scale in terms of a natural constant.

While other quantities in theory derive from these four basic units, nonetheless, precise physical standards or standard measuring devices are necessary for comparisons, and a variety of these standards have been derived from experiment and theory.

Viscosity, for example, may be defined in terms of forces and dimensions, force may be defined in terms of mass and acceleration, acceleration may be defined as change of velocity in unit time, and velocity may be defined as a change of distance (length) per unit time. In practice, selected fluids are used as comparison standards whose viscosity has been measured carefully by apparatus in which all other factors have been precisely determined.

Alternatively, devices whose dimensional and force characteristics are known accurately also may be used as "standard" instruments for computing the viscosity from the time or force variable related to the viscosity by the operating principle of the instrument.

Thus, it is not enough for NBS to provide calibration services only for the basic quantities. It must provide "derived standards" or help develop practical techniques to be used by others for accurate measurement of all derived physical quantities or for calibration of instruments designed for such measurements.

Transducer techniques

Except where human senses make direct estimates, standards or instruments of one type or another are involved in the measurement process. In measurements, instruments detect or respond to changes in some property related to the quantity being measured.

This transducer response usually is transmitted from the point of origin to a point of indication, often

(1) **WORLD'S LARGEST** *proving ring, capable of measuring forces up to 1.2-million lbs, undergoes calibration at NBS. Present bureau gear can calibrate such devices only to 110,000 lbs with deadweights. Beyond that, indirect methods are used, with a resulting loss of accuracy.*

(2) **MEASURING TIME** *by a beam of atoms is one of the propositions for improved standards. This cesium beam atomic clock at the Boulder Laboratories measures frequency and time intervals to an accuracy equivalent to the loss of less than one second in 3000 years.*

(3) **THIS HIGHLY STABLE** *shielded resistor has been designed and constructed at the bureau for use in the precise measurement of high voltages. It has been found suitable for measuring d-c voltage up to 100 kv. Designers expect it to serve as a standard for evaluating other high-voltage resistors.*

(4) **A GASEOUS LASER** *is being used in research aimed at extremely accurate measurement of distances. Experiments indicate the possibility of using the device to measure 100-kilometer distances (62 miles), precise to one part in a million.*

(5) **A HIGH-TEMPERATURE** *plasma arc developed at NBS to obtain data for the country's space program is adjusted by a bureau scientist. Operating at extreme temperatures near 15,000 K, this arc duplicates processes that occur in the sun.*

(6) **KRYPTON-86 LAMP** *in its liquid nitrogen bath is checked by an NBS scientist. The wavelength of the orange-red light emitted by the lamp has been adopted recently as the international standard of length. The lamp is operated at the triple point of liquid nitrogen, 63 K, to increase wavelength stability.*

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with amplification or further conversion along the way. In addition to the direct function of measurement, instruments may aid the measurement process through recording, storing, reducing, and analyzing the data. Other instruments may use the measurement signal to initiate automatic control of the measured quantity.

The provision of standards, instruments, and measurement techniques does not of itself insure the required level of accuracy for all measurements. Judgment and skill of the observer are other important factors.

In many measurement processes, unexpected errors may arise which can be detected and corrected only by properly trained personnel. Although these men are in great demand today, all too little effort is being made for their preparation. However, there is a growing awareness of this need, and industry, the military, and universities are taking steps to provide the opportunity for such training. One example is the George Washington Center for Measurement Science, with a curriculum leading to degrees in measurement science. Many other schools and instrument manufacturers offer short courses of more limited or specialized scope.

The rapidly increasing demand for precision measurement has led to a large number of standards laboratories. These include "in-house" or company laboratories that service only groups within the concern, several levels of laboratories within the military services, and firms which provide a wide variety of calibration services for their customers.

A recent outgrowth of this increased interest in measurements was the formation of the National Conference of Standards Laboratories, an organization designed to identify and help solve some of the problems associated with the operation of laboratories engaged in precision calibration and measurement.

Your accuracy is slipping

There is a loss of accuracy at every step in the measurement chain. Consider, for example, the gage block used to check micrometers and calipers on a production line. This working gage block was checked against the plant standard block, which in turn may be checked against a company master standard, which probably was calibrated at the National Bureau of Standards.

Two means of minimizing errors arising in such a chain are to improve the accuracy of comparison at each step in the chain or better still, to eliminate some intervening echelons between the working standard and the National Bureau of Standards. Also, any decrease in the uncertainty associated with the national standard provides a potential increase in accuracy down the line. Furthermore, if the national standard can be generated readily in calibration laboratories other than NBS—and this is one argument for atomic standards—then the ultimate accuracy is provided closer to the point of measurement.

In almost every area of measurement there are demands for greater accuracy and a greater range than NBS now is able to provide. Let's consider some problem areas.

Krypton lengths

In the area of length, measurements for the space age require gage blocks accurate to one 10-millionth of an inch. The best that NBS presently can do is about 1-millionth of an inch on a 1-inch block. Advances are needed on several fronts to improve this capability.

First, gage blocks themselves must be of sufficient dimensional stability to justify and maintain such a calibration. Most blocks tend to change length due to changes in fabrication stresses. Recent bureau research with nitrided, annealed 410 stainless steel has resulted in gage blocks exhibiting a change of only 2×10^{-7} inch per inch per year—a considerable improvement over previous values.

The adoption of a wavelength of krypton 86 as the new standard of length provided an improvement in realizable accuracy of measurement over that attainable with the meter bar. However, the krypton standard is no cure-all. One limitation is that its "coherence length," the length over which useful interference fringes can be produced, is rather limited. Therefore, work is being pursued at the bureau on a mercury 198 atomic beam, which will provide a greater coherence length and possibly higher accuracy than the krypton standard. As already mentioned, the laser shows promise of usefulness over very long paths.

Measurement instrumentation and techniques also are being improved to provide greater accuracy in gage block calibration. Such devices as an electro-mechanical comparator, an interferometer for determining the parallelism of gaging surfaces, and an automatic fringe counting device have contributed or will contribute to faster, more accurate calibrations.

Despite progress in accurate length measurements, there still exist problems in measuring such quantities as flatness, surface roughness, shaft diameter, and particularly small hole diameter. Another major concern is measuring dimensions of screw threads and gears. Present measurement techniques are slow, inefficient, and use a considerable amount of the allowable tolerance. The bureau recently has established a gear metrology laboratory in an attempt to help improve measurements in this field.

Temperature is another problem area. Advances in such fields as rocket and nuclear technology have extended operating temperatures beyond the present range of accurate temperature measurement. To overcome this deficiency, the NBS is conducting research on the spectrographic determination of high temperature.

Pyrogenic problems

Stable arc plasma sources have been developed that produce temperatures to 15,000 K, and means for accurately determining such high temperatures are being investigated. One method that has proven successful depends upon a measure of the broadening of the Balmer lines of hydrogen injected into the arc. Temperatures determined in this way are accurate within 1%. Recently, an analogue computer has been developed that determines the spectral contribution of any portion of the arc almost as fast as the data are obtained.

At the other end of the scale, an ultrasonic thermometer is being used to establish an absolute temperature scale over the range 4 to 14 K. This device provides a measure of the speed of sound in helium gas—the speed being a function of the temperature—and will be the basis for calibration of secondary devices. The bureau also is investigating the accuracy and stability of germanium resistors for use as secondary thermometers.

Thermal conductivity has its difficulties too. Accurate knowledge of heat transfer by metals and insulating materials is vital for design of space vehicles. Accurate measurement of thermal conductivity (and thermal diffusivity) is a difficult task, compounded by the fact that values have not been known well enough for any materials to permit their use as a standard. Conductivity measurements recently were made on two materials that promise to become useful reference standards, a chromium-nickel alloy and a monocrystalline glass. Measurements made by three different methods agree within a few percent where the temperature ranges overlapped.

Gases, more or less

Pressure and vacuum are of great concern today. Extremely high pressures are opening new vistas in both science and industry. For example, the application of high pressure to solid materials causes changes in the crystalline structure of matter, and shifts chemical equilibria. These effects offer great promise as means of developing new materials with special properties. Artificial diamonds already have been produced, and other superdense, super-hard materials can be expected. However, these high pressure techniques cannot be used fully without a well defined scale of pressure.

Providing standards and measurement techniques over the pressure range of current interest is a formidable task, as the upper limit extends to above 50-million psi. Present capabilities are adequate to about 2-million psi. Efforts are being made to extend this figure, and to establish values of "fixed point" on which to base a high-pressure scale. The resistance of bismuth, for example, changes abruptly at about 365,000 psi, 385,000 psi, and 1,700,000 psi, but more accurate values for these changes are needed.

Below 200,000 psi, pressures are measured by dead-weight loaded pistons in which the clearance between piston and cylinder is small enough to keep leakage within a few cubic inches per month. A program is underway to extend the range of this type of apparatus, and they may be usable to as high as 400,000 psi.

Calibrations for space

The extremely low pressures existing in outer space, interest in adsorption phenomena, and the operating conditions of particle accelerators have stimulated interest in vacuum technology. Fresher measurement devices in the region 10^{-12} to 10^{-15} mm mercury are likely to be uncertain by a factor of 10 or even 100. Improved accuracy would permit more meaningful interpretation of satellite drag data and give valuable information on conditions in outer space.

Within the past few years, the bureau has initiated a program on vacuum standards and measurements, aiming at the development of devices which measure pressure directly as a force-area ratio to provide a calibration capability to 1/10,000,000 mm. Several devices under development show great promise, but it will be some time before calibration services can be offered with the required range and accuracies.

Greater precision in this range will increase the extrapolation reliability of other gages, such as ion gages, operating on different principles. It is hoped that precise measurements of the vapor pressures of certain gases will lead then to a series of fixed points for this portion of the pressure scale.

We can conclude this survey of problem areas with a quick look at the fields of radio electronics and voltage.

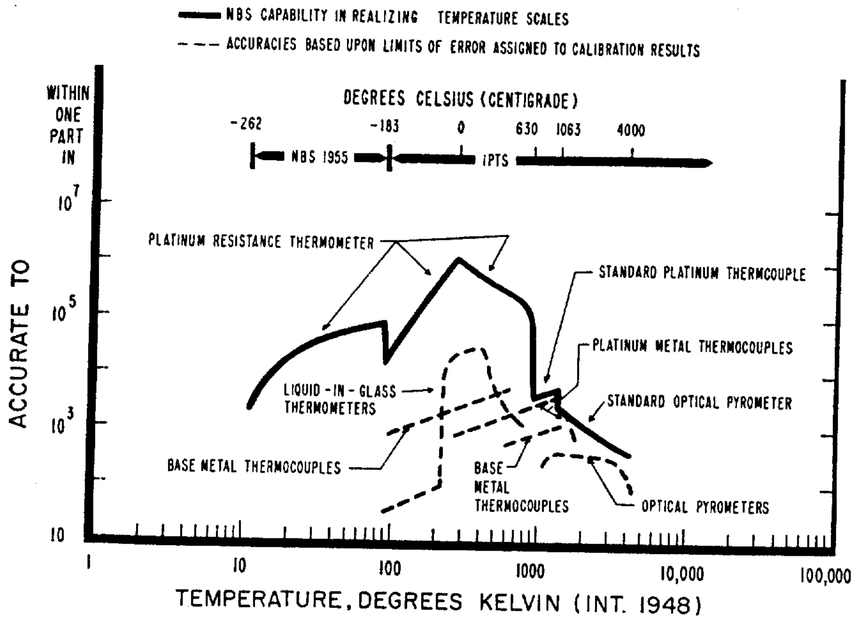
The rapid growth of the electronics industry and demands for improved instrumentation and communications brought about by space exploration have stimulated bureau research on radio and electronic standards. A large portion of the current "measurement lag" exists in these critical areas, and widespread efforts are being made to improve upon present capabilities.

Cycles and volts

Recent developments include a new technique for determining the power level of a high frequency pulse. Measurements can be made at ½ to 10 kilowatts and frequencies ranging from 30 kilocycles to 1000 megacycles per second with a limit of error of 3%. A new set of standard resistors for use at lower radio frequencies has been completed; calibration services now are being offered for such important quantities as waveguide noise sources; and radio-frequency voltage calibration services have been expanded to include 500, 700, and 1000 Mc/s. Many problem areas still exist however, including such measurements as radio frequency attenuation, shielding effects, phase angle, and others.

The voltage standard for voltage measuring devices is the saturated standard cell, which has a potential of 1.0182 volts at 82 F. The present standard is inconvenient in that it must be handled with extreme care and compared periodically with like cells whose average voltage is known

When William A. Wildhack was appointed associate director of the National Bureau of Standards in 1961, he assumed duties as coordinator of NBS measurement services to science, industry, and other federal and state agencies. Prior to this, Wildhack had been assistant director, exploring the needs for precision standards, calibration services, and improved measurement. After taking a BS and MS from the University of Colorado, he spent four years as a professor of physics before joining NBS as a physicist in the Aeronautical Instruments Section. From 1950 to 1960, he was chief of the Office of Basic Instrumentation, directing a considerable number of successful R&D projects in measurement and calibration—including his pioneering the practical development of the "Peek-a-Boo" retrieval system for the instrumentation reference center.



A CALIBRATION OF TEMPERATURE *measuring instruments, this chart describes the National Bureau of Standards' present state of the art in temperature measurement.*

through intercomparison with standard cells at NBS. The emf of the reference group at the bureau is related periodically to absolute measurements through careful experiments involving the current balance and the standard ohm.

A more rugged, stable standard is needed, but as yet no satisfactory replacement is in sight. Although Zener diodes show some promise as standards, their accuracy falls short of the saturated standard cell by a factor of from 10 to 100.

Recent NBS advances in the high voltage field include development of a highly stable shielded resistor, accurate to 0.004%, for use in measuring direct current to 100 kilovolts, and a 350,000 volt capacitor, accurate to 0.002%, used to determine the voltage ratio and phase angle correction of a large transformer.

In many laboratories there are occasions when calibration of an instrument can be avoided—or performed in essence—by using a material of known property or composition. These reference or "standard" materials also are used in the development of new analytical techniques, and as the basis for control of precision processes. Currently, NBS makes available over 500 different standard materials, with a yearly sale of some 80,000 items.

Examples of these standards include steels of certified composition, pH standards, metals of known freezing temperature for use in precision thermometry, color standards, radionuclides of known emission rate, and many others. This program must be expanded if the bureau is to provide the standards that are needed in the search for exotic fuels, heat resistant alloys, and other critical materials.

Expensive Inaccuracy

It is extremely difficult to place a dollar value on accuracy. A better appreciation of its importance can be gained by considering the other side of the coin—the cost of inaccuracy.

A lack of accuracy lowers reliability, with attendant high costs of repair or replacement. As an example of the demands of modern technology, an error of one-millionth of an inch in the bore hole of a missile-guiding gyroscope could result in the vehicle missing the moon by thousands of miles. The reduction of such errors, of course, depends in large part on the ability to measure accurately.

High accuracy is essential not only to the manufacture and assembly of a product, whether it be washing machine or weather satellite, but also is required if the product's performance is to be measured reliably. If such performance checks are inaccurate, either at the time of manufacture or during the life of the device, a satisfactory alarm clock could be rejected by an assembly line inspector, or a faulty missile could be approved for installation on a nuclear submarine.

Increased accuracy will have effects far beyond the realm of the standards laboratory, in greater efficiency and value in all phases of manufacture, evaluation, and usage.

Atomic standards plus

In addition to development of basic standards resting on fundamental constant atomic properties, advances in practically any physical science and engineering may lead to improved accuracy in practical engineering measurements. The automation of measurement processes, where feasible, will not only release skilled manpower, but in many instances may result in more accurate and rapid measurements, and will eliminate human errors from the measurement process.

There undoubtedly will be a continuing trend to automatic recording of measurement data, often in some format for input to a computer, and high speed data reduction processes will greatly speed the production of useful information. The growing development and application of statistical techniques provide a powerful tool in the proper interpretation of a series of measurements, and these techniques can be used as a basis of control in automated measurements.

The need for information on accuracy has led the bureau to develop a series of accuracy charts that are becoming widely used. NBS is urging other measurement laboratories to prepare similar charts showing their capabilities of measurement and calibration.

It is not likely that the time ever will come when all our measurement problems are solved. Demands for measurements and standards relating to recently discovered or newly important phenomena and extension of accuracies of the old will evolve as long as science and engineering continue their growth. Refinements in measurement techniques often provide the key to new discoveries, and precision measurement will continue to be a critically important sector of all fields of technology. ■