NCSL 66

SESSION 6: THE MEASUREMENT SYSTEM OF THE UNITED STATES

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Today I should like to introduce to you a new way of looking at the measurement activities of the Nation. In this approach we consider all these activities as parts of a system. We shall talk about the National Bureau of Standards as a functional element of that system, and then we shall look at the role of the NBS Institute for Basic Standards within that functional element. Finally, once we have painted this picture for purpose of understanding, we shall turn to some of the policy questions that the picture raises.

I am sure that when I have finished many of you will say there is nothing really new in the systems approach to measurement. And in a sense that is true; the systems concept is simply a way of describing much that is going on, but it does provide a logical, systematic way of looking at measurement activities in this country.

A Society of Systems

Let us begin our discussion by considering the nature of the highly complex technological society now existing in the United States. How does life in this society differ from the life of the frontiersman 200 years ago? The essential difference, I believe, is that as individuals in our society we interact with a number of what might be called social systems, such as the communication system, the education system, the fiscal-monetary system, the legal-penal system, and the transportation system. I could go on and name more of these systems, but I shall mention only one more, and that is our National Measurement System which we shall discuss shortly.

In their interactions with one another through their interfaces, these systems, it seems to me, are characteristic of our society. They have a great influence on the lives and activities of individual citizens. In fact, one might think of our present American society as a sort of supersystem composed of all these systems.

Diverse as these systems are, they do have certain elements in common, and I think this should be emphasized. You recall that in English we use the word "standards" for two different concepts—standards of physical measurement, and standards of practice. In like manner we find ourselves using the term "system" to refer to two independent concepts involved in each of the systems comprising our society.

If we look up the term "system" in Webster we find that among the definitions given there are two very concise ones that relate to the present discussion. One of the definitions considers a system as "an aggregate of essential *principles* or facts arranged in a rational dependence to form a coherent whole." The other definition refers to "an assemblage of interdependent or interacting *functional elements* working together under guidance from some central source to accomplish a common mission." The first type of system, which we shall call the *intellectual system,* forms the basis for the design of the second type, which we may call the *operational system.*

If we now look at the social systems we are discussing, we find that in each case they comprise two interwoven systems. One is an intellectual system which in a sense does not operate—it consists of the set of rules and conventions that govern the operation of the system. This type of system is universally applicable, much like the laws of physics and chemistry. Then, for each intellectual system, there is an operational system consisting of a set of functional elements, a set of inputs, a set of outputs, and a spectrum of activities.

An example of an intellectual system is the International System of Units (abbreviated SI for Système International)—an intellectual concept, a set of rules regarding units. This system in universal; not only is it international, but it could be used on other planets if we ever succeed in communicating with them.

The operational systems, on the other hand, are national in scope. But they have interfaces with the corresponding systems of other nations, and of course they have interfaces with the other systems that make up our national society.

The National Measurement System

Let us now try to look at our National Measurement System in this way. The first thing we need to recognize is that we do in fact have such a system even though it may not have been formally recognized. It has grown up in this country and most of us have taken it for granted without really being aware of its existence. But its influence on our national life is tremendous. Let me give some figures that will indicate the magnitude of the system with which we are dealing.

If we stop to think about it, we realize that on the average every citizen is involved in some 15 to 50 measurements a day—reading his watch or speedometer, or buying gasoline by the gallon. If we add to these all the measurements that are made in science and industry, we arrive at a rough estimate—good perhaps to a factor of 2 in the first significant figure—of 20 billion measurements being made every day in this country. To be consistent and compatible, all such measurements must be traceable back to a set of national standards.

To get some idea of the amount of money invested in the Nation's total measurement activity, we estimate that we have some $25 billion invested in measuring instruments alone, and we are increasing this investment by some $4½ billion a year. We have some $20 billion invested in research to provide measurement data, and we are adding about $3 billion a year to this amount. Altogether our investment in the system is about $50 billion. The payment to personnel to operate the system is roughly $10 billion a year. It is important to note that the entire National System is 99 percent self-financed through its own internal system of charges and fees.

Table 1 shows the impact of this Measurement System on our national economy in figures taken from the 1963 census. Here we are looking at totals for those industries and services that account for $396 billion of our gross national product. These industries invest $13.9 billion a year in measurement—in using the output of the Measurement System and working with it—and they devote 1.3 million man-years to measurement; so you can see that the National Measurement System is a very sizeable and important system in our economy. Looking at these figures we see that if we can improve the efficiency of the measurement process sufficiently to increase the GNP due to these industries by 0.1 percent, then we will have saved about 10 times the annual budget of the National Bureau of Standards.

	Final demand (GNP) $ billions	Cost of measurement $ billions	Man yrs. spent on measurement thousands
Manufacturing	225	7.8	845
Construction Mining and farming	21	1.1	120
Transportation communications and utilities	39	0.9	98
Medical and Educational services	28	1.4	103
Government and other services	83	2.7	139
Totals	396	13.9	1305

Table 1

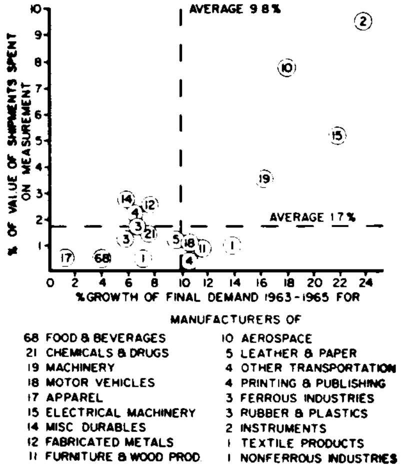


Figure 1 is also of interest here. The ordinate shows, for a number of industries, the percentages of the total value of all shipments that were spent on measurement; the abscissa shows the growth of these industries over the 1963–65 interval. Note that the fastest growing industries are those that have the greatest need for measurement. I do not say that measurement makes them grow faster, but I do say that the fastest growing industries are those that are most closely coupled to the output of the Measurement System, and that therefore our industrial growth is in fact tightly coupled to our measurement sophistication and capability.

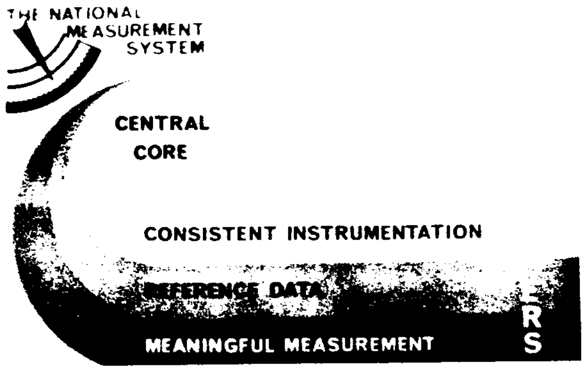
Now I should like to discuss the functions of our National Measurement System. The essential function of the system is to provide a quantitative measurement basis for interchangeability and decisions for action in all aspects of our daily life—public affairs, commerce and industry, science and engineering.

Interchangeability is of fundamental importance in modern society. Once we have a measurement system with a set of agreed-upon units and standards, we have a firm basis for the interchange of goods and services in the mass markets of modern commerce, of machine parts and devices in industry, and of scientific and technical information. Such a system makes it possible for any plant to mass-produce materials, parts, and systems that are interchangeable with those made in plants in other parts of the country. Without this basis for interchangeability, our industrial economy as we know it today could not exist. Likewise, if results obtained in one laboratory are to be useful in another, they must be expressed in a measurement system common to both laboratories; otherwise, each laboratory would have to operate on its own and confusion would result when they attempted to exchange information.

Modern society requires us to make numerous decisions throughout the day, and many of these decisions are based on measurement. For example, we are continually looking at a clock or watch to measure time so that we can decide whether to leave, stay, or stop what we are doing. An aircraft pilot must read a number of measurement output dials in order to make vital decisions during a flight.

To provide a basis for decisions throughout the Nation, all measurements must be compatible with each other. For example, the airplane pilot's decisions based on his instruments must be compatible with those of others who are making similar measurements if he is to stay on course, avoid collisions, and arrive on time. The key words here are *compatibility* and *consistency:* the Measurement System must make all sorts of diverse activity compatible and, at the interfaces, consistent; otherwise we should have a very chaotic situation.

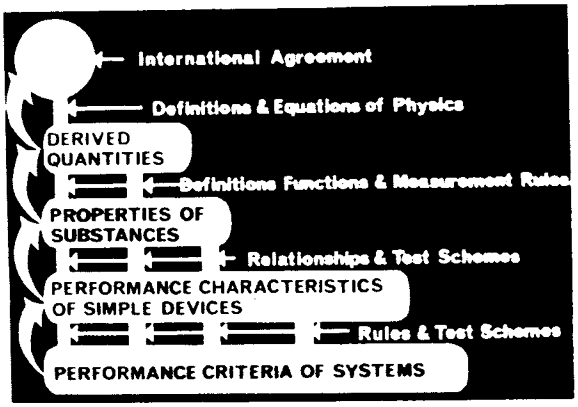
Figure 2 shows the four outputs of the National Measurement System. First is the *central core*, consisting of the national standards, about which I shall say more later. Next there is the provision of calibrated, *consistent instrumentation*, traceable to the national standards, to all the multitude of users whose measuring needs it serves. (Here, of course, I am thinking of the calibration activities of the whole system—not just the work of NBS.) Another output is a supply of *reference data* that provides all users with ready-made answers for measurements—these data can be used over and over again once they have been recorded and published. Finally, we have an important output that really involves the effective use of the other two—criteria for *meaningful measurement.* We might think of the Measurement System as having three spigots which the user can turn on. One spigot is labelled "instrumentation" and another is labelled "reference data." If the user does not know which of the first two spigots to try, he turns on the third spigot. This third spigot represents a part of the NMS through which people throughout the system can be told how to make use of the capability generated in the other two activities—how to measure what they set out to measure rather than something else.



Our system is made compatible with other national systems of measurement through its interface with the international system, set up through international agreement. The Convention of the Meter, established in 1875 through regular diplomatic channels, is made effectual through various technical agencies, beginning with the general Conference on Weights and Measures, which elects especially competent individuals to an International Committee. The latter supervises the work of the International Bureau of Weights and Measures, through seven committees dealing respectively with units, length, time, temperature, electricity, photometry, and ionizing radiations. The International Bureau provides the mechanism for intercomparison of the more important standards of the National Laboratories of the industrialized countries. Thus, compatibiltiy in world technology and trade is assured. The National System feeds back its extensions and comparisons to the international system, which in turn provides compatibility for the vast body of users around the world. Users in the National System establish their measurement capability and generate a pool of unmet needs which feeds back into other parts of the National System.

The Intellectual System

Figure 3 illustrates the "universe of measurables," the intellectual system that provides a basis for the operational measurement system. This intellectual system is international in scope and everyone involved in modern science or industry is concerned with it. In the figure we start with four independent, arbitrarily defined units for the base quantities—length, mass, time, and temperature.* Adding another decimal place to the defined size of any one of them will have no effect on the size of any of the other three.



From these four "base units," we derive the units for all other physical quantities in accordance with the definitions and equations of physics. Take the quantity force for example; force equals mass times

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*The International System of Units includes two additional basic units: the ampere and the candela. The ampere has been given this status as an aid to dimensional analysis, although it is defined in terms of length, mass, time, and a particular value of the magnetic constant Γ_m which is taken as $4\pi 10^{-7}$ henries per meter. The candela, which is used for measurements of visible light, is not purely physical since its definition involves an average human observer.

acceleration, and acceleration is length over time squared. So once we have defined units of length, mass, and time, we can define a unit of force in such a way that the constant of proportionality in the equation

$$f = ma$$

is unity. Our unit of force is then a derived unit, dependent in size on the size of the units of length, mass, and time. In the same manner, the unit of density is derived from the units of mass and length. Continuing in this way, we eventually arrive at what is called a consistent system of units; that is, a system that is consistent with the equations of physics as we know them today. Once we have this consistent system for physical quantities we can proceed with a set of definitions, functions, and measurement rules to establish another category of measurables: the properties of substances (for example, density), relating their units back to the base and derived units. (The properties of substances are really functional relations among the physical quantities as these relations are characterized by a particular kind of matter. Density, for example, is the relationship between mass and volume that is characteristic of a specific substance, say lead or mercury.)

Similarly, by means of definitions, relationships, and test schemes, we can go from the properties of substances to the performance characteristics of simple devices—for example the amplification factor of a vacuum tube. Then proceeding on in the same way, we can go to the performance criteria of systems, feeding in test schemes and formulations to form a progressive, coherent set of measurable quantities.

At each stage as we go down the chart, the degree of knowledge and sophistication involved decreases, not through want of effort but because we are still developing the system. At the top we are concerned primarily with very precise measurement; the important exact definitions have been agreed upon. As we go lower we find we are more concerned with the meanings of terms and definitions. In the lower stages we want to know what it is meaningful to measure, in order to specify firm understandable performance criteria.

The feedback up the chain that is shown in the figure takes place in two ways. First there is local feedback regarding the needs for refinement of the various kinds of measurables. Then there is the feedback of capability and knowledge developed in the rest of the system. For instance, information on properties is essential to the development of physically realizable standards for the four base units and to the measurement of the derived units. Likewise, information obtained by use of devices or systems enables us to improve the part of the system shown in the upper blocks, which can then be transmitted down to the lower blocks.

The Operational System

Now let us turn from the intellectual system to the operational system—consisting of people and organizations—which is national in scope and which interacts with the other systems of the Nation. One way of subdividing the system is to split it into three major networks. First there is the *instrument* network, which provides the calibrated instrumentation for making the measurements. Then there is the *data* network which gives ready-made answers to measurement problems. Finally, there is the *techniques* network which tells the user how to make meaningful measurement. In a very general way, this illustrates how the National Measurement System operates in this country.

Figure 4 shows the details of the instrument network. At the top we have the development of new instrument ideas and designs by the instrument industry, research institutes, NBS, and other Government and industrial laboratories. These ideas and designs are disseminated by the publishers of technical literature and by the Patent Office. Ultimately they take the form of measurement hardware which must be accurately calibrated. This may be done by NBS directly, or by other standards laboratories whose master standards have been calibrated against the national standards maintained by NBS.

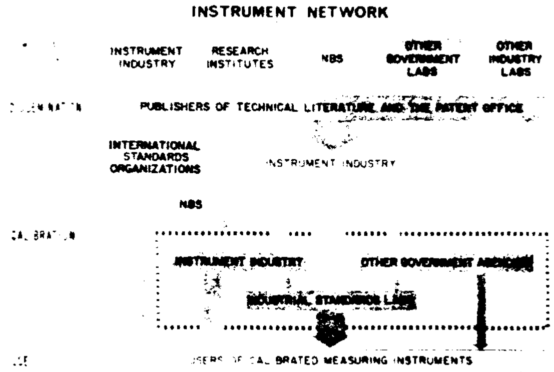
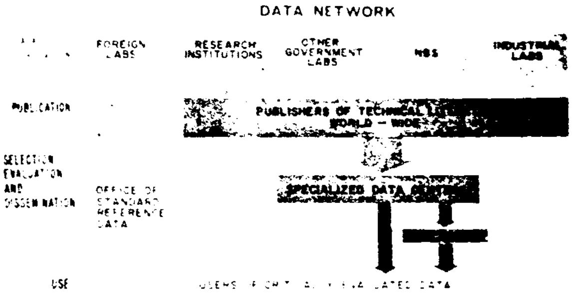
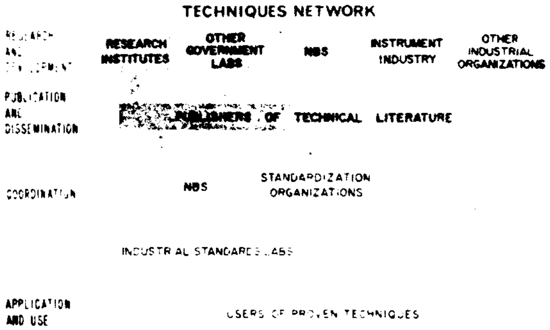


Figure 5 illustrates the data network. Here we have various laboratories contributing to a pool of technical literature which in turn feeds into a number of specialized data centers. The centers in turn funnel evaluated data into the NBS Office of Standard Reference Data. The users obtain their ready-made answers from the Office of Standard Reference Data and the publications of the specialized data centers.

Figure 6 shows the techniques network, which operates in a similar way, telling the user first how to measure, then what it is meaningful to measure. Many of the physical quantities in the universe of measureables are now so well defined that it is not difficult to determine how they should be measured in practical situations. This is presently true of the quantities expressed in SI units, although it was



not always so. But with performance characteristics and performance criteria, the situation is quite different; here we still want to know how to specify precisely what we want to measure.



The System as a Black Box

Now let us go back and look again at the general concept of a system. If we consider a system as a black box characterized by inputs, a statement of function, and outputs, then any segment within the black box may be thought of as a subsystem which we can in turn examine for inputs, function, and outputs. And we can continue this subdividing process until we get down to the smallest structural elements of the system. Each subsystem can be divided into interacting elements, and each of these elements into interacting components.

Now consider one segment of the system with its inputs and outputs. A satisfactory statement of function requires that we recognize interface filters on either side of the segment, because these are the points where policies are set up that characterize the activity of the segment. An input interface filter determines which of all possible inputs will be accepted, and an output interface filter determines which of many possible outputs the segment will deliver. If we know the inputs and outputs and some of the policies that govern the filters, we can characterize the system segment in a functional statement.

With that by way of background, let us return to the National Measurement System. This System has as its main function to provide the central basis in the United States for a complete, consistent system for physical measurement. What then is the role of NBS as a functional element in the National Measurement System? This role is one of central Federal leadership—to guide the System as it continues to operate through the voluntary cooperation of American science and industry. As we see it, the Bureau must maintain this leadership through general acceptance, based on proven capability—not on laws or regulations. So the Bureau exerts its leadership through its outputs—by developing and maintaining the national standards which serve as a central core for the three networks, by providing calibration services and standard reference materials for the instrument network, by generating and evaluating data for the data network, and by developing techniques of meaningful measurement for the techniques network.

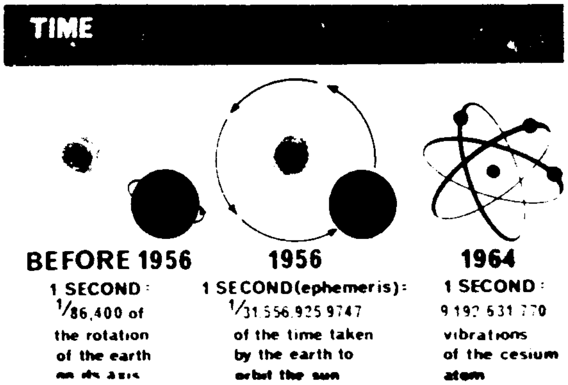
Now let us consider the Institute for Basic Standards as a functional subelement of the System. Its inputs come from the pool of unmet needs, from the international coordination to which it is tightly coupled, and from the various activities throughout the Nation which supply materials information—in particular from our own Institute for Materials Research. Its ourputs are the central core of national standards (essentially an in-house output), calibration services to disseminate this core, ready-made answers in the form of key reference data and a mechanism for disseminating them, a set of standard reference materials, consulting and advisory services, and publications on meaningful measurement.

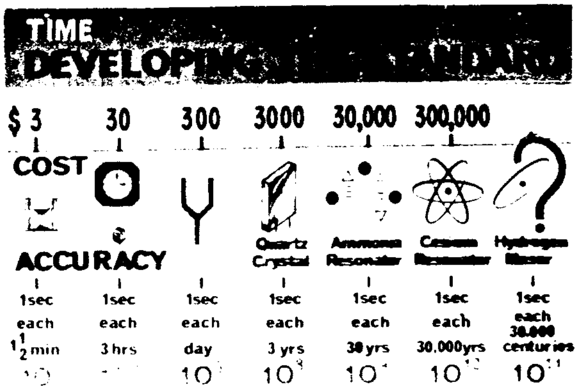
The Central Core

Let us begin with the central core, which consists of six base standards—national standards coordinated internationally—and thirty or forty derived standards. The six base units of the International System of Units are specified for the quantities mass, length, frequency or time, temperature, electric current, and luminous intensity. Four of these have been mentioned earlier. The central core is developed by starting with a knowledge of materials as a basis for conceiving and defining a unit, then proceeding to a material realization of this definition, and finally to the standard.

This process involves a feedback loop that operates continuously. While the units themselves are static—in that their values are changed only in the last few decimal places—there is a great deal of dynamics in the process of realizing these units with increasing accuracy and precision to meet the needs of science and industry.

A brief discussion of one of these units—the second—will illustrate the dynamic nature of measurement standards (Fig. 7). Before 1956 the second





was defined as 1/86,400 of a mean solar day. Thus its definition was based on the rotating earth as a clock. Of course, any periodic phenomenon can be used as a clock, and the more stable its period, the better clock it makes. We thought we had a pretty good clock in the rotating earth—it had been used for centuries. But by 1956 it had become evident that the rotation of the earth was subject to irregularities, and so the second was redefined as a fraction of the annual trip of the earth around the sun. (This redefinition did not change the *size* of the second, only the way in which it was defined.) The second thus defined is known as the ephemeris second, and it is possible to realize this second to about 2 parts in a billion, given some five years of astronomical measurements. But work with cesium-beam-controlled clocks had already surpassed this precision, so a new definition was needed. In October 1964, the 12th General Conference of Weights and Measures authorized an atomic definition of the second. The International Committee on Weights and Measures, acting for the Conference, temporarily based the definition on an invariant transition of the cesium-133 atom, in expectation of a more exact definition in the future. The value of 9,192,631,770 hertz was assigned to the cesium transition selected. It now appears that we can compare the second in terms of this definition to 1 or 2 parts in 10^{13} (equivalent to 1 sec in 30,000 years). These changes in the definition of the second are a good illustration of the way in which the units are continually being refined so that we can better say what it is we are trying to measure.

I might add that each time we replace an older unit with a new one of lesser uncertainty we are careful to define the new unit with the zone of confusion of the old. So long as we do it this way, the results obtained by previous measurements will still be valid within the range of indeterminacy associated with the older unit.

Figure 8 shows the progression in the development of standards for the second. We begin in ages past with the hour-glass which kept time to about a second in a minute and a half; it probably cost $3 and was accurate to about a part in 100. Next we have a pendulum clock, which costs about $30, and keeps time to a second in three hours or one part in 10^4. Next we have a well-made tuning fork, accurate to a part in 10^5 and costing perhaps $300; then the quartz frequency generator, accurate to a second in three years or a part in 10^8; the ammonia molecular clock, good to a second in 30 years, or a part in 10^9; then the new cesium resonator previously mentioned, accurate to a second in 30,000 years, or one part in 10^{12}; and finally the hydrogen maser, now under development, which may go to a part in 10^{14} at a cost as yet unknown.

Now note the progression in the cost of the standards. With each improvement in accuracy, the cost of research for further improvement spirals upward. Someone may ask, "Do we really need a clock that keeps time to a second in 30,000 years?" However, the need for timing accuracy in such fields as satellite tracking, rocket control, and astronomical observations is far from being met. We must remember that there are almost 10^{11} microseconds in a day and that a radio signal travels 300 meters in a microsecond. We use radio waves to measure distances and to track satellites which incidentally move at the rate of nearly a meter every microsecond. So we must have clocks that can keep in step to within a few microseconds over an extensive time interval. As a matter of fact, we are now under pressure to improve our present time-keeping accuracy of 1 part in 10^{12} by two more orders of magnitude. Still we must admit that the present accuracy in time measurement is fantastic. If two cesium clocks such as we have now had been started at the dawn of history, they would differ by no more than an eyeblink today.

The Instrumentation Network

Once a unit has been selected for a particular quantity and a national standard for this unit has been realized, we must establish techniques that will provide for measuring the entire range of magnitudes that must be dealt with. In mass, for example, the range extends from the mass of the earth, or even beyond, down to the mass of the electron, neutron, or subparticle (fig. 9). So we have a vast spectrum of some 50 orders of magnitude that must be connected through a measurement chain to the defined unit, the kilogram. Some of these magnitudes can be measured directly by taking multiples or submultiples of the standard, but as we leave the central part of the range we find it necessary to use indirect methods, with a corresponding reduction in accuracy.

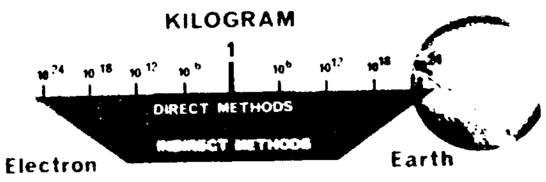
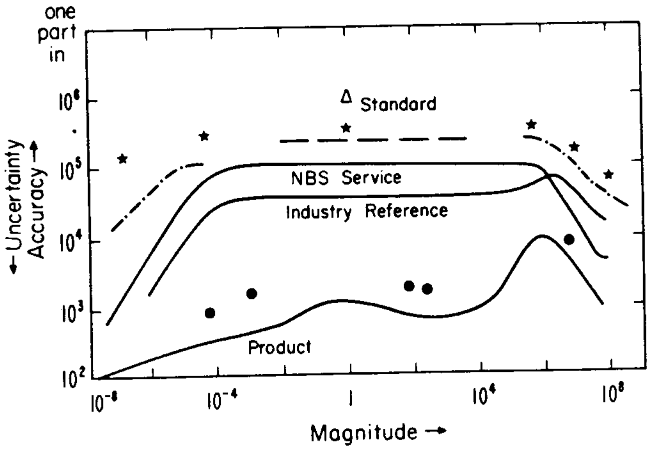
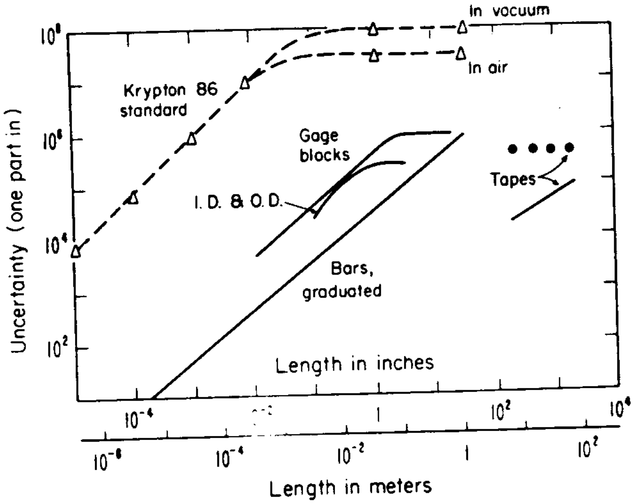


Figure 10 is a generalized version of the "accuracy charts" which the Bureau is using to assess its measurement capabilities over typical ranges of magnitude in various areas. The upper solid line indicates the accuracies presently available in regular NBS calibration service; the next lower one, what good industrial laboratories can do; the lowest one, the tolerances generally called for at the ultimate user's level—at the factory bench or in the finished product. The dots indicate the accuracies the factory's customers say they need, the horizontal dashes show what can be obtained by special arrangement with NBS, and the dash-dot lines show where NBS activities now under way will carry us. Finally, the stars represent the occasional demands expressed by important segments of our customers.



We can use this type of chart to show graphically where we are putting our major efforts, to indicate our goals, and to decide where to concentrate our further efforts. We need to resolve such questions as whether it is more important to raise the line representing NBS capability, and thereby bring up the line representing industrial capability, or whether to try to bring the latter up closer to the former by tightening up the system, perhaps by reducing the number of echelons between the NBS standard and the ultimate user.

Figure 11 is an up-to-date accuracy chart for length and diameter measurements, showing the different devices used in different ranges of magnitude and the accuracies achieved in NBS calibrations. Using recently developed equipment, and taking special pains, we can measure length to about a part in 10^8 for magnitudes from 1 to 0.01 meter.



Of course it is seldom possible for a single institution such as NBS to make calibrations over the complete range which might be needed in the National Measurement System. So we have to make basic decisions as to how far to go and how much to do. Our policy is to pick calibration points at appropriate intervals so that the measurement activities of the country can be coupled to NBS at these points by means of ratios, differences, and interpolations. In this way the national standards in the central core are disseminated over the calibration network.

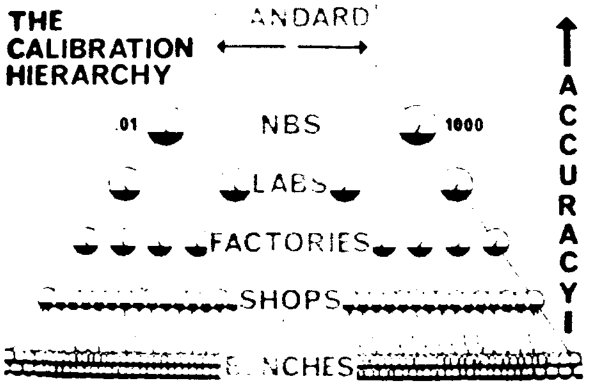
Calibration of an instrument involves comparing it directly with a standard so as to obtain corrections to the instrument readings.

Table 2—NBS CALIBRATION PROGRAM BUDGET
(In thousands of dollars)

	1965	1966	1967 est
Electrical	720	770	830
Mechanical	350	370	430
Radiation	750	820	880
Radio	710	770	830
Thermal	260	320	380
	2,790	3,100	3,400

Table 2 shows the magnitude of the Bureau's calibration program, which amounts to about $3 million per year. The customer pays the out-of-pocket NBS expense of making his calibrations, but he does not pay for the research and development that makes the calibration possible.

Compatibility requires that there must be a chain of measurement traceable from the base of the pyramid (Fig. 12) all the way up to a common reference standard. Unless each chain finally reaches the same apex, the system will lack compatibility. There is an interesting story about a man who set the town clock by the factory whistle. It turned out that the factory whistle was always in good agreement with the town clock. Upon investigating he found that the man at the factory was reading the town clock to find out when to blow the whistle. So they had set up a small feedback loop between themselves but they had no means of achieving compatibility with timekeepers elsewhere.

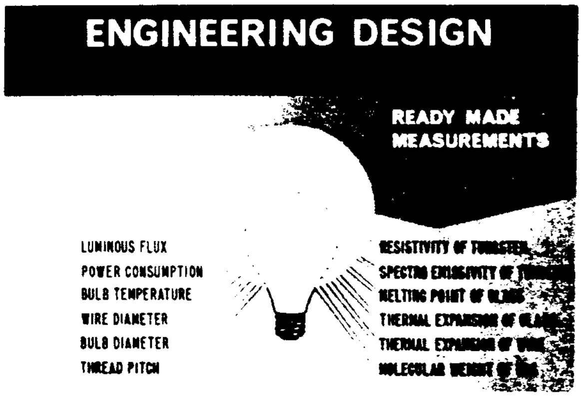


The standard reference materials program is unique to the United States, although some of the samples are sold to users in foreign countries. Standard reference materials are well characterized substances with accurately determined properties. The Bureau certifies them either for chemical composition or with respect to some specific physical or chemical property. They obviously provide a basis for equitable interchange of articles of commerce. Also, samples of these materials are sold to an individual so that he can calibrate his own measuring process. A great advantage of the program is that it enables the user to do self-calibration "on-site." Thus he ties his measurement to the National System and evaluates his results in terms of his own capability and his own instruments and procedures. If he sends his instrument to NBS for calibration, he does not obtain any knowledge of his own capability for using the instrument to the accuracy with which it has been calibrated.

We are now moving into self-calibration in other areas. Ways are being considered for tying standards laboratories into the National Measurement System on a self-calibration basis by means of measurement agreement comparisons, often called round-robins. The laboratories would do most of the work with their own instruments, their own staffs, and their own technologies. Having done so, they would have a measure of their own capabilities and would know how closely their accuracies are related back to the national standards.

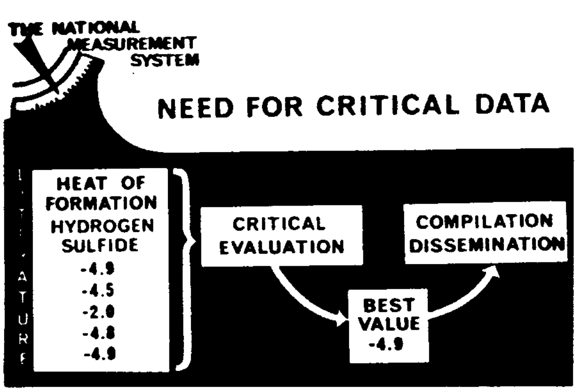
The Data Network

Now let us turn to the data network. Figure 13 is a good illustration of the fundamental importance of this type of activity. Consider an engineer who has set out to design a new competitive light bulb. What does he have to know? First of all, he has to be able to make direct measurements; he must have instruments to measure the diameter of the bulb, the pitch of the thread, the weight of the materials, the diameter of the wires, and so on. But even though he has the capability of making these measurements in production, he is still a long way from an adequate design. He needs information on the electrical resistivity and spectral emissivity of tungsten and other competitive materials, the melting point and thermal expansion of glass—in fact, maybe some 50 types of data of this kind—in order to make a competitive design. If he has to stop and measure all these properties, he will be investing several million dollars in a research program before he can start his design. On the other hand, if ready-made answers are already available for the data he needs, because someone else has already measured them, then he can save this vast investment. Once he has found the numbers, he can proceed with the design, provided that he can trust the numbers to be correct.



Another important point to consider here is that when sufficient data have been obtained to characterize a substance, then that substance can serve as a reference material for the calibration of instruments that measure the properties of substances. These properties are often temperature-dependent, and the International Practical Temperature Scale is based on fixed points at 1063, 960.8, 444.6, 100, 0.01, and minus 182.97 degrees Celsius, related to gold, silver, sulfur, steam, water, and oxygen respectively. If the substance is sufficiently well characterized, the reference sample can be purchased from the usual sources of supply and certified standard samples will not be necessary. Today practically all the instruments that are used to measure properties of substances are calibrated in-house by manufacturers or users, using standard data on the measured property. These calibrations are related to the national standards through the key data on properties which NBS provides. People outside NBS can work with these data, so the existence of ready-made answers takes a vast load off the instrument network of the Measurement System.

Figure 14 illustrates, perhaps even more graphically, the need for critical evaluation of such data. When an engineer turns to the scattered literature in search of design data, he is likely to get a wide range of values for each property he looks up. Suppose, for example, that he is designing an industrial process that involves the heat of formation of hydrogen sulfide. In the literature he may find an array of values ranging from 2.0 to 4.9. Uncertainty in such a measurement can have far-reaching economic effects. If he accepts the value "2.0" for the heat of formation of hydrogen sulfide, he might conclude that his planned process will not work, and that hence there is no point in going further. On the other hand, if he accepts the value "4.9" he may find that his process will be highly productive and should be pushed. Which value should he accept? In the absence of critically evaluated data on the heat of formation of hydrogen sulfide, he can only do what is usually done in industry today—seek expert advice if he can find it, make an educated guess, or measure it again himself, adding another value to the list. Unless he is an expert in the measurement of heats of formation, the value he obtains will probably be no better than those already in the literature, and may be much worse.



The solution is to get together a group of experts who know the field and can evaluate the various measurements from the literature so as to obtain a "best value"—the most acceptable and trustworthy value—and will make this value generally available. This is the process of critical data evaluation and compilation. To carry out this function on a nationwide basis, the President's Office of Science and Technology has established the National Standard Reference Data System (NSRDS), and NBS has been given the responsibility for planning and coordinating its projects. A central headquarters, known as the Office of Standard Reference Data, has been established at the Bureau under the Institute for Basic Standards, and contracts aimed at establishing coherent and comprehensive coverage are now being let to various data centers throughout the country. The NSRDS seeks to pull the best values from the literature and to get them into the hands of the users of the System through publication and other means of dissemination.

This is an enormous task, for the 10 technical journals of the year 1699 grew to 100 in 1799, to more than 1000 in 1899, and is expected to reach 10,000 by the year 1999. The papers appearing in these journals have also increased ten-fold in each century; there will probably be 1,000,000 by 1999. Data compilation and evaluation activities presently carried on can now take care of only about a fifth of the annual increment of papers. IBS activities account for about 7 percent, and the other data centers of the country handle about 14 percent. So the backlog of unevaluated data is growing, the situation is getting more confused, and it is becoming increasingly difficult for scientists and engineers to find the data they need.

There is thus a strong economic need to get all these data critically evaluated and then disseminated to users. If we can succeed somehow in getting the resources that will enable the NSRDS to do this job, we estimate it will pay back into the economy between $20 and $200 for every dollar invested.

A primary task of NBS in data generation is to put key data into the reservoir. Others can use these data for extending their work into related areas. Users who recognize the value of this effort then feed more raw data into the data centers scattered throughout the Nation. The data centers evaluate and compile these data, which are then fed back into the data reservoir for further use. The key definitive data supplied by NBS permit the National Measurement System to grow and expand. The Bureau gains competence through research, and links its findings to the system so that compatibility will be provided to resolve conflicts. These activities are important to the proper functioning of the Measurement System. For example, judicious duplication of measurements by several users shows whether or not the instrument network is performing in a consistent, compatible way. At the same time, the research on materials that is part of the data acquisition activity provides a firm basis for the development of measurement standards for the central core.

Inputs, Outputs, and Filters

In the few minutes remaining I should like to say a few words about some of the inputs, outputs, and policy filters that influence NBS activities. Obviously there are a great many inputs to NBS from the other social systems of the country as well as from other parts of the Measurement System; I shall mention only a few of these.

One important input is the research being done at other laboratories on the frontiers of science. This work is developing the knowledge needed to improve the measurement process within the System. A related important output takes the form of scientific contributions from NBS scientists who are working in frontier science to provide a base for the measurement activities.

A continuing input problem of major dimensions is our need for trained metrologists. Here there is tremendous suction in the input pipeline but very little input to flow through it.

Another input to NBS consists of the new measurement needs and new measurement problems with which we are constantly being bombarded. As our resources are necessarily limited, we are hoping that we can meet some of these needs and problems by use of what we call the Research Associate Plan. Under this Plan, which we have had for years but which we are now extending, an industrial group, a trade association, or even a private company can send an employee to work at NBS on a problem which is of special interest to the sponsor, which also has public significance. The sponsor pays the employee's salary, while the Bureau makes available its laboratory facilities and the advice of its specialists. In this way wider use may be made of NBS instrumentation and of the measurement competence of the NBS staff. When the employee returns to the laboratory from which he came, he should be a more effective worker because of the better understanding he will have of measurement techniques and their use in the solution of problems.

On the output side, there is always the problem of deciding what calibration services are required to feed the System properly. Taking the "systems" point of view, the Bureau's policy is to undertake those tasks that will make the Measurement System function most effectively and economically in serving the interests of the country and the economy as a whole. From time to time we get feedback which indicates that some people do not understand this policy. Apparently they think that the Bureau is withdrawing from calibration activity and retiring into an ivory tower. Nothing could be further from the truth. Our objective is to ensure the calibration of every instrument whose calibration has any meaning. If the calibration is within the Bureau's capabilities and if it can be done more effectively at the Bureau, then we should do it; if it can be done more effectively outside the Bureau in other parts of the System, then it should be done there. We feel that we should do enough calibration work to keep our existing facilities reasonably well utilized; at the same time we should not attempt to compete with the private standards laboratories which have the important role of taking over from NBS and disseminating the standards throughout the rest of the System.