The role of NBS's Institute for Basic Standards in

Planning for Better Measurement Accuracy

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TO PROVIDE a background for discussion of the management problems which involve the National Bureau of Standards (and particularly the Institute for Basic Standards), other Government agencies, and industry in our common concern with accuracy in measurement, we must first review briefly the technical role of government with respect to calibration and measurement services in the U.S.

First, NBS (and now specifically IBS) is charged by Congress to *maintain* the standards of weights and measures, but is not given any powers of enforcement. IBS neither has, nor seeks, any authority to dictate standards or procedures for industrial standards laboratories or those of the 50 states.

We do, however, promote and assist in various ways the dissemination of accuracy from international and national standards to all measurements, whether in scientific laboratory, standards and calibration laboratory, on the bench, or in a satellite. We do this by providing calibrations and measurement services at the highest levels (free to the states, at cost to the public); by research and development on standards and measurement techniques; by publication of results of general utility in science and engineering; by consultation with persons and organizations needing help on measurement standards problems or on difficult measurement problems; by arranging seminars at NBS for qualified personnel to see at first hand how their instruments are calibrated at NBS; by assisting and sponsoring the National Conference of Standards Laboratories (NCSL); by professional support of ISA and other appropriate engineering and scientific societies and committees; and by many other methods such as exhibits, publications of reviews on measurement techniques, and specialized conferences.

Beyond this, we try to provide the increasing accuracy needed for national or international standards, so that the results of precision measurement may be interchangeable throughout the world. But in spite of our best efforts, our services are inadequate to meet all demands, and we are exploring many avenues to find ways to improve them.

In 1964, the National Bureau of Standards was reorganized into four Institutes: the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, and the Central Radio Propagation Laboratory. Each of the Institutes is largely autonomous in developing and conducting programs in its area, but all receive general policy direction from Dr. A. V. Astin, Director of NBS, and they utilize administrative and supporting services in common.

This reorganization, it is hoped, will focus more efficiently the technical and administrative direction in each of the large, but separate, program areas, and will facilitate better public understanding of the NBS role in each.

The Institute for Basic Standards has the primary

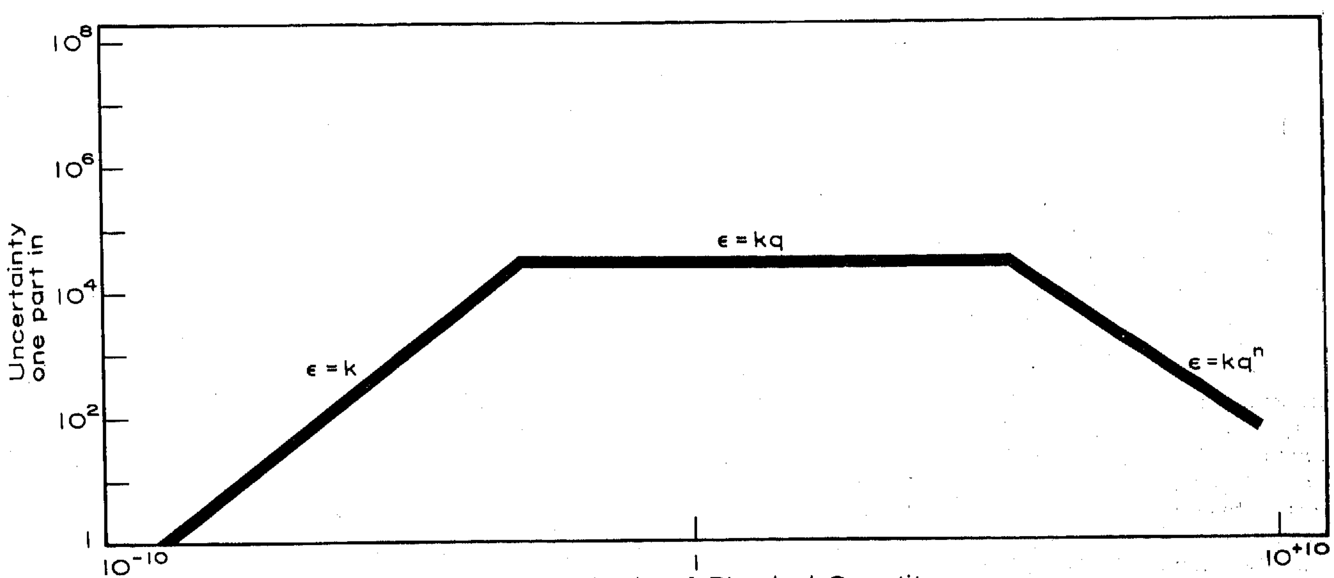

Figure 1. Generalized uncertainty chart.

responsibility for measurement standards and calibration, and has also the responsibility for a new National Standard Reference Data program. In addition, it carries on basic research programs on nuclear, atomic, and molecular phenomena.

Accuracy Charts

IBS has been making special efforts to inform the technical public of the present capabilities for precision measurement and calibrations. The figures illustrate one particularly useful form for presenting such information in broad perspective. Figure 1 is a generalized chart showing features common to specific charts for each physical quantity. This is generally called an *accuracy* chart, although the ordinate may represent *precision* rather than absolute accuracy (when the basic standards themselves are not reproducible, or realizable, within equally close limits, or when systematic errors have not been sufficiently evaluated).

Actually, the variable plotted along the ordinate scale is the *uncertainty* associated with the measurement or calibration over the indicated range of measurement. Normally, this is expressed as one part in a hundred, a thousand, a million, etc., so that a logarithmic scale is appropriate. For many quantities, the accuracy may be a million times, or more, better in the usual range than at very small or very large values.

Another feature of such charts is the use of the logarithmic scale to encompass a range of magnitude of physical quantities over millions or billions of times smaller or larger than the customary unit for the particular quantity.

The major sources of uncertainty in making measurements with a particular instrument or technique are frequently the "least reading" or some other fixed error, leading to a characteristic line with unit slope. Over some ranges, some techniques have approximately a constant ratio error (or percentage error) represented by a horizontal line on this log-log chart. Under some conditions, uncertainty arising from effects of the physical quantity itself on the measuring equipment leads to a decline in accuracy at higher ranges.

Figure 2 shows by line segments the accuracy of calibration with the various devices or techniques used at NBS for the most accurate measurement of distance or length, over a wide range. Notable here is the measurement of very small separations, or the thickness of very thin films, within the range of one wavelength of light; and the pending expansion to large-distance measurement by the laser. Already, NBS has obtained laser interferometry patterns stable over several hundred feet — 100 times longer than previously possible. It is probable that stable operation might be obtained over lengths many times greater, even in air, although higher absolute accuracy would require measurement in vacuum.

Below the lines representing *best* accuracy in measurement or accuracy of standards, we can plot the *usual* accuracy attained in calibration of other instruments or devices suitable for plant or laboratory standards, or for precision use in the field. For example, the calibration of geodetic tapes is done against an invar strip on a long table which has been graduated by the use of the 5-meter bar. Thus the accuracy shown in the figure is somewhat below that indicated for the 5-meter bar itself, which in turn is somewhat less than the accuracy with which 1-meter bars can be compared.

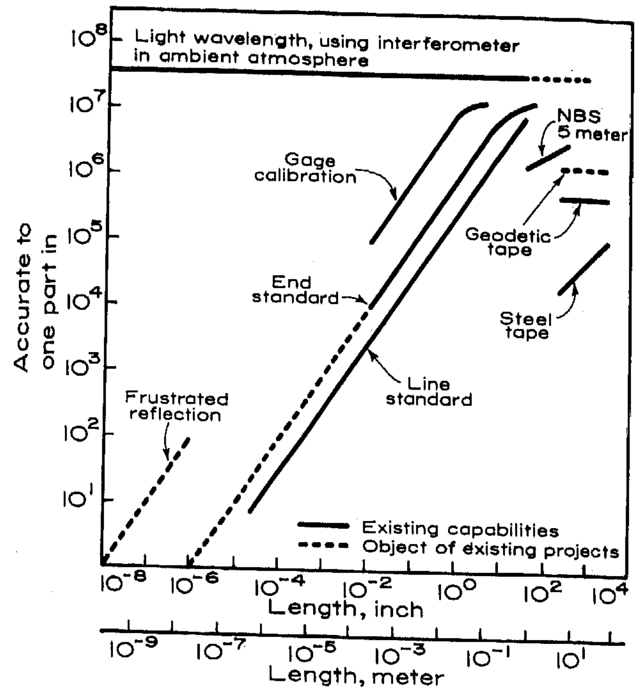

Figure 2. Accuracy of length measurements at National Bureau of Standards in 1962.

The need for development and calibration of standards for measuring electrical quantities is especially acute in the radio-frequency area, where the various ranges of frequency add another dimension to the problem. Figure 3 shows NBS capabilities and estimates of industrial capabilities for the measurement of voltage in high-frequency CW coaxial systems. A family of curves is necessary to portray various frequencies. Here the shaded area is above one of the present NBS curves, indicating a serious lag in providing needed calibration accuracy in some frequency ranges.

The rapid development of atomic beams, masers, lasers, and their many applications requires special effort to develop measurement techniques and standards for evaluating and calibrating such "optical-radio" devices. Major improvements in frequency standards are coming out of this work. Figure 4 shows the progress in accuracy in recent years, but where it will level off is hard to say.

Some Problems

Our purpose in showing these charts is not to discuss in detail the technical problems, the many advances in recent years, or even the many unmet and continuing demands for more accurate calibrations of more quantities over wider ranges. Rather, it is to use them as a background in discussing some of the problems inherent in the relationships between IBS and the other Government agencies operating large national technical programs: Army, Navy, Air Force, NASA, AEC; and between NBS and the industrial contractors or manufacturers. In part, we hope to explain why NBS does not always have the answers ready at the time the demands appear!

On any such accuracy chart, any laboratory or plant can plot the probable maximum inherent accuracy of their instrument *as used* (somewhat less than the accuracy with which it is calibrated!), and the accuracy of the measurements or calibrations made with it (somewhat lower still!).

Likewise, the designer, or the user, can also plot

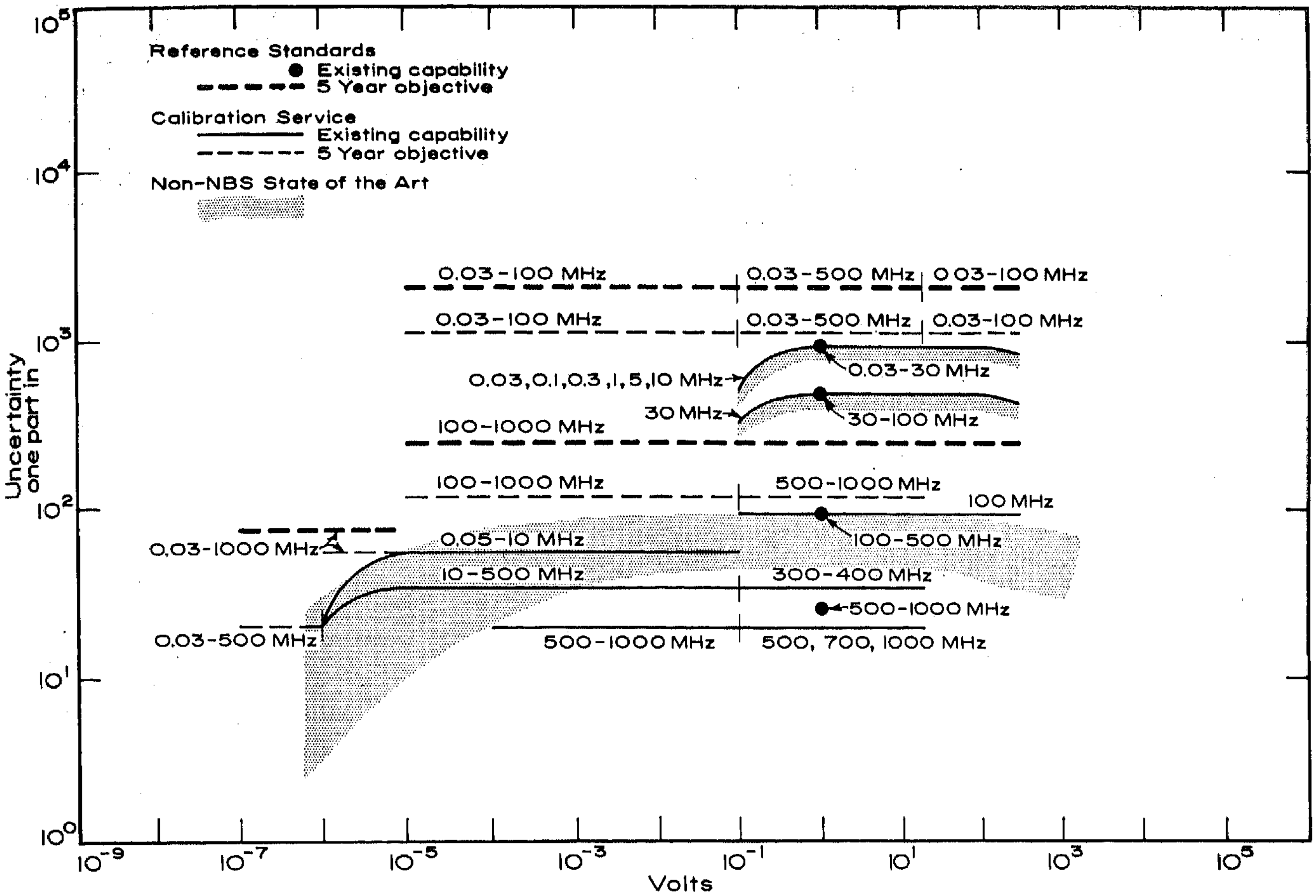

Figure 3. High-frequency voltage measurement accuracy for CW, coaxial systems.

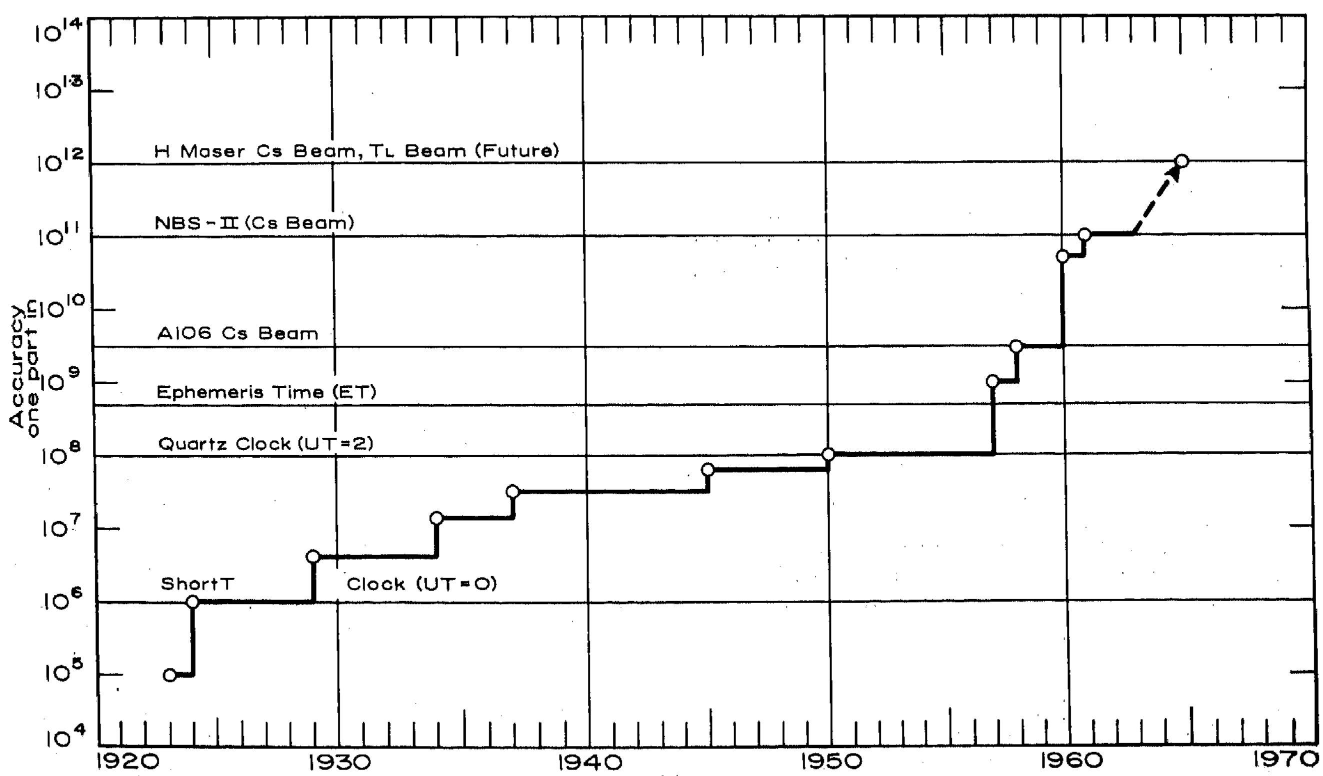

Figure 4. Improvements in accuracy of the U.S. frequency standard (USFS).

on such charts the accuracy requirements involved in advanced designs. If his "requirement" curve is not sufficiently below the "capability" curve for the appropriate calibrating echelon — and remember, the design must provide for *maintainable* as well as *makable* accuracy — there is a "measurement pinch," and somebody ought to do something! When somebody "does something," the "pinch" is to some extent passed on up as a greater demand on the higher echelon calibrations. Sometimes it becomes necessary to bypass one or more echelons, with disrupting economic and scheduling complications.

When the "pinch" really presses on NBS capabilities, we need to undertake crash programs of research and development to discover, develop, or adapt new techniques and instruments to provide greater accuracy or greater range in calibration. This takes time, money, special equipment, and specialized competence — none of which are usually supplied directly by the persons or organization needing the improved services. (Public fees for IBS calibration are set to cover only calibration-related costs; not the cost of the underlying research.)

As was evident from the accuracy charts, for most physical quantities there is no one instrument or technique that is "best" over the entire range of importance. So different, for example, is the measurement of vacuum at 10^{-10} torr from the measurement of pressure at one atmosphere (10^3 torr) and super-high pressures (10^{10} torr) that these are really specialized fields. Likewise, the design of an acoustic thermometer requires experts with different competences than are needed for optical pyrometers. The point here is that the problems of keeping abreast of measurement requirements for any one of the thirty-odd physical quantities (for which we have some calibration services) involve several groups of people working on different projects comprising different designs or aimed at different ranges. Each such project may entail several persons working 3 to 4 years on research and development before the results are available, either in the form of extended calibration services or in the publication of an improved measurement technique available for use by others as well as by NBS.

From a study undertaken by the Aerospace Industries Association's Quality Control Committee several years ago, from continuing inputs from other Government agencies, and from scientific and industrial laboratories, it is clear that NBS is lagging too far behind the calibration and measurement needs in too many areas. Thus considerably more research and development effort is needed to get ahead of, or even to catch up with, the present requirements. How long the fast pace of advances in science and technological progress will keep us from getting ahead in the race is, of course, unknown. What *is* known is that we are not now catching up fast enough.

This leads to two aspects of the management problem: first, how to determine which *needs* are really the most critical for the nation — since not all *wants* can be met — and second, how to get resources to bear upon these needs while at the same time keeping a reasonable amount of longer-range research going to meet the probable needs of the future.

Some dollar figures may be of interest: In Fiscal Year 1964, calibration payments from the public and DOD totaled:

Public	(60,164 items)	$1,127,104
DOD	(6,101 items)	$1,077,845

For other agencies, IBS conducted R&D programs of mutual interest more or less directly relating to standards totaling $2.7 M. Approximately $6.5 M of appropriated funds for Research and Technical Services, supplemented by the other-agency transfers for R&D and by the fees collected, gave a total of about $11.3 M for research, development, procurement and construction of standards, and for the calibration work. Very little program increase is possible in FY 1965.

One of the DOD-NBS administrative problems relates to cooperative programs. Some DOD agencies have definite needs for calibration improvements, but are not themselves funded in a way to help support the R&D entailed. On the other hand, it has appeared that the "major systems" concept, which might have been a mechanism for funding specific needs, has in practice failed to make adequate provision for advance R&D on improved techniques for calibrating the advanced instrumentation to be developed as part of the system.

To some extent, this may apply for other agencies as well. We hope, through joint committees and liaison channels, to continue work on these problems.

Another problem is that of utilization of services where made available. Obviously, if a large investment goes into providing a service, which is critically but not widely needed, and which is then used infrequently or only for a short time, the fees required to recoup even the equipment cost will be rather high. If the high fees then discourage others from using the service, or lead to stretching out recalibration periods, the fees must remain high, the equipment is only partly used, and the potential contribution to accuracy is not fully realized. What a logical over-all consideration of the national interest might lead to in regard to this problem may be quite different from equally logical considerations of immediate interests, or needs, of any given laboratory or agency.

The decision as to what classes of standards or instruments to calibrate at NBS is also a difficult one. This year's highest-accuracy instrument may be next year's second or third highest. At what point should NBS discontinue calibration of less-than-the-highest-accuracy instruments?

Our present policy is to continue service until there appear to be other calibration sources (the manufacturers, for instance, and commercial calibration labs serving the technical public), and then discontinue the NBS service. Working with Committees of NCSL, other agencies, instrument manufacturers, and others, we hope to continue a reasonable balance of adequate service. We encourage other standards laboratories wishing to develop their competence to perform calibrations for others, as appropriate, on those devices for which the NBS calibration is not essential.

Obviously, there are many other problems of adjustment to be found in the voluntary system of utilizing standards and calibrations that we have in this country. None are insoluble; all require thought, reasonable negotiation, and channels for communication.

It is clear that accuracy in measurement plays a vital role in achieving new levels of performance and reliability. It is also clear that the importance of accuracy is often overlooked, misunderstood, or neglected by management (in both government and industry) in the planning of programs for reliability, value analysis, and performance evaluation.