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# STRUCTURE AND FUNCTIONS OF THE NATIONAL MEASUREMENT SYSTEM

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Raymond C. Sangster

Technical Report in connection with the  
IBS Study of the National Measurement System  
1972-1975

Office of the Deputy Director  
Institute for Basic Standards  
National Bureau of Standards  
Boulder, Colorado 80302

July 1977

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**U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary**

Sidney Harman, Under Secretary

Jordan J. Baruch, Assistant Secretary for Science and Technology

**NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Acting Director**

## FOREWORD

The concept of a National Measurement System has, for many years, provided a useful focus for the considerations important to physical measurements in our technology intensive economy. Dr. R. D. Huntoon, in his October 6, 1967, article in Science, emphasized the basis for a systems viewpoint in interrelated measurements activities and the idea has continued to evolve. Today, we think of the U.S. National Measurement System in terms of all the intellectual, functional and institutional activities which enter into measurements throughout our society. Moreover, we seek to understand more completely the structural nature of this system and its architectural needs.

There have been a number of approaches to the study of our national system for physical measurements. The present series of studies was initiated in 1972 by Dr. Ernest Ambler, then Director of the Institute for Basic Standards. It was Dr. Ambler's purpose to organize the essential information necessary for the effective management of NBS resources and to promote the direct interaction between IBS staff members and the communities of users they serve.

This document reflects the results of the intensive studies carried out during the period from 1972 - 1975. It is one of a series of 27 reports describing various aspects of these studies; most of these are now in print and available from NBS or the National Technical Information Service. It is important to recognize that the National Measurement System is extremely complex having widely distributed elements and impacts. The detailed analysis of this system is well beyond the state-of-the-art of econometric modeling, and therefore, any study, no matter how intensive, is necessarily incomplete. Nevertheless, the information which is now in hand provides an important addition to our capability for planning and implementing the programs of IBS. It also represents a growing foundation upon which we can continue our efforts to build a more effective structure.

A. O. McCoubrey  
Director, Institute for Basic Standards  
National Bureau of Standards  
June 1977



## PREFACE

The 1972-75 Study of the National Measurement System by the NBS Institute for Basic Standards has been a massive effort involving many people in all divisions of the Institute. The Study was organized around a central coordinator and a group of "National Measurement System Study representatives". The initial central coordinator was Dr. James R. Seed, a Presidential Interchange Executive from Dow Chemical Company, on temporary assignment to the National Bureau of Standards. Dr. Seed carried the project through to the generation of a complete set of comprehensive reports on the structure and operation of the various portions of the System, in December 1973. In August 1974, I took over the central coordinator position, and worked with the Study representatives from the divisions of the Institute, to round out the pattern of the Study and to develop the final reports for the different areas of measurement interest.

During this 1972-75 Study, a substantial amount of insight was developed into the structure and functions of that System. This insight is the subject matter of this report. The report proper describes the technical and institutional infrastructures of the System, the international context in which it operates, and the basic impacts and trends of the System. The balance of this document contains appendices and an extended bibliography, which provide detail regarding specific aspects of the System.

No report of this sort could be generated without many hours spent at the typewriter. This one would not exist without the competent and unstinting efforts of my secretaries and everyone else whom they could obtain to support them, and I wish to thank them, one and all: Carol Ciufolo, Marty Tyner, Pamela Killian, Angela DiGiallonardo, Sheila Aaker, Sue Randolph, Nancy Mills, Kay Stephenson, Shirley Deeg, and Dorries Schaffner.

We trust that the availability of this document will be useful to many readers who need only an overview of the results of our Study of the National Measurement System. For those who want more detailed information about any part of this study, we have provided a "Report Request Card" at the back of this document, which can be used to request the specific reports wanted.

Raymond C. Sangster  
July 1977

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# STRUCTURE AND FUNCTIONS OF THE NATIONAL MEASUREMENT SYSTEM

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July 1977

## EXECUTIVE SUMMARY

The National Measurement System consists of all of the activities and mechanisms--intellectual and operational, technical and institutional--used to provide physical measurement data to allow the creation of the objective, quantitative knowledge required by our society. This report describes the structural and functional aspects of the System.

Measurement is necessary in conduct of the life of the individual, pursuit of science, operations of society, and employment of technology. Measurements allow human beings to describe, predict, communicate, decide, control, and react in dealing with the physical universe. The process of measurement requires intellectual comprehension of the phenomenon, quantity, or property to be measured; definition of a reference unit in terms of which the measurement will be made; existence of a means of comparing the unknown to be measured with the reference unit; establishment of a physical reference standard which embodies the measurement unit; agreement within the human community on all aspects of the measurement process; and mechanisms to enforce honesty and clarity in measurements.

Our model of the National Measurement System involves five structural levels.

I. Conceptual System of measurement phenomena, quantities, units, and definitions.

II. Basic Technical Infrastructure to provide tools, techniques, and agreements that allow the conceptual system to be reduced to practice.

III. Realized Measurement Capabilities, abilities to measure specific quantities to known accuracies under defined conditions.

IV. Dissemination and Enforcement Network, institutions that disseminate realized measurement capabilities to users and enforce their use.

V. End-use Measurements.

The base phenomena or quantities to be measured include length, mass, time, electric current, temperature, amount of substance,

and luminous intensity. Many subsidiary units are derived from the basic units. The United States uses both the customary "English" system of units and the modernized metric system, SI.

The technical means required to make measurements include both physical hardware and intellectual software. Software aspects include documentary specifications and standards, descriptions of measurement techniques, educational materials, reference data, predictive methods, and the basic recorded knowledge of science. Hardware aspects include basic artifact standards, transfer and working standards, reference materials, and measurement instruments.

Documentary standards and specifications in the broad sense include international treaties and conventions; Federal and state constitutions; Federal, state and local laws and ordinances; engineering standards; and procurement specifications.

Suitable instrumentation is an indispensable element in any measurement process. Both physical apparatus and the techniques by which it can produce the desired results must be available.

When a given aspect of matter, material, or fabricated product is sufficiently stable, well defined, and of wide enough interest, measurement data that characterize it can become useful as reference data. Existence of reference data takes a substantial load off the operational measurement system, since it eliminates much repetitive measurement. Measurements of unknown systems are often performed by comparison with known systems, using reference data. Such data may also be used to calibrate measurement equipment. Further, properties of materials may be used to define the measurement process itself, as in use of properties of water to define the temperature scale.

Reference materials complement and supplement reference data in the Measurement System. Their function is very similar to that of reference standards, and for some

phenomena, such as density, the reference standards are reference materials.

In some measurement circumstances, the volume of data needed may be so large, or the experimental circumstances so inaccessible, that it is not physically or economically feasible to measure all of the desired data. Predictive methods--models of the phenomena being measured--then become an essential element of the Measurement System.

The central core of the Measurement System consists of knowledge or science and of the people who employ it. In some newer measurement fields, there is no further institutional infrastructure.

The institutional elements of the system include the documentary specifications and standardization organizations, the instrumentation industry, central measurement standards authorities, state and local offices of weights and measures, standards and testing laboratories and services, and technical regulatory agencies.

Institutions that produce documentary standards operate at levels from the international to the individual company or local governmental unit. Major relevant bodies are the International Organization for Standardization, International Electrotechnical Commission, American National Standards Institute, American Society for Testing and Materials, Department of Defense, and General Services Administration.

Over 5000 U.S. companies are known to produce measurement instrumentation. The instrumentation industry was at an \$8 billion level in 1974 and has been predicted to grow to \$15 billion in 1980.

Legal responsibilities for enforcement of justice in the use of weights and measures in our domestic commercial marketplaces lie with the state and local offices of weights and measures; the National Conference of Weights and Measures is the central coordinating unit. Its paid staff and executive secretariat are employees of the NBS Office of Weights and Measures.

Standards and testing laboratories and services provide physical standardization services to specific portions of the National Measurement System. The most highly developed institutional structures are in the military services. The National Conference of Standards Laboratories provides a central forum for this portion of the measurement system. NBS provides its central secretariat.

Promulgation, enforcement, compliance, and adjudication with respect to the regulatory actions of technical regulatory agencies require a substantial measurement base and comprise a significant portion of the System, making the regulatory agencies the newest recognizable institutional structural element of the System.

The National Bureau of Standards is the principal authoritative central measurement standards institution in the United States. Its calibration and related measurement services provide access to the national standards of physical measurement; it operates the National Standard Reference Data System and provides Standard Reference Materials; it provides coordination services to the System through the Offices of Weights and Measures and Measurement Services, and through the Standards and Applications Division, the Office of International Standards, and the Office of International Relations; and it provides a variety of information services.

The U.S. National Measurement System is embedded in and is part of an international measurement system, for which the International Bureau of Weights and Measures (BIPM) is the central institution.

The major trends of our National Measurement System are toward increased complexity, increased integration, improved quality control, improved information resources, automation, metrication, and an expanded scientific base. The increasing complexity of our society is reflected in the Measurement System. Increased integration of the System is required to improve its ability to provide most economically and effectively the needed measurement data. Improved quality control of the measurement process, through such mechanisms as the NBS Measurement Assurance Programs, is needed to control complexity and effect integration. Automation is vastly expanding the technical power of the System. Passage of the Metric Conversion Act of 1975 recognizes a major trend in the System, which will have a permanent impact on this country. The scientific developments of the past quarter century have nearly put us in a position to realize the goals of the founders of the metric system, namely a universal system for physical measurements founded on natural law and a single constant of nature.



## 1. INTRODUCTION

### 1.1 Background

The ability to measure is part of the basic fabric of human society [2] †. Regulation by law of weights and measures used in commercial transactions dates back far into antiquity [136,3,10,16,17,29,61,73,79,236]. With the maturing of the science-based phases of the later industrial revolution around the end of the nineteenth century, governmental participation in the field of measurement expanded in the major industrial countries to cover many areas of science and technology relevant to the mass production of goods and services [46]. During the past decade or so, still another major governmental involvement in the field of measurements has grown out of the rapid expansion of governmental regulation of our economy in areas such as health and safety and consumer and environmental protection.

The National Bureau of Standards was established in 1901. An oft-quoted statement by the House Committee on Coinage, Weights and Measures gives the flavor of the context in which the Bureau was created:

"It is therefore the unanimous opinion of your committee that no more essential aid could be given to manufacturing, commerce, the makers of scientific apparatus, the scientific work of Government, of schools, colleges, and universities than by the establishment of the institution proposed in this bill." [46]

The Bureau was established as the source of national standards for physical measurements and their custodian. In carrying out this role, it seems fair to say that NBS over the years has developed a more comprehensive view of the role of measurements in our society than any other organization in this country.

About fifteen years ago, Dr. R. D. Huntoon and others in the National Bureau of Standards began to formalize their understanding of the measurement activities in this country around the concept of a "national measurement system" [56,82,15,24,34,38,40,43-45,47,48,52,54,55,58,59,65,111,221,222]. In 1972, Dr. Ernest Ambler, then Director of the NBS Institute for Basic Standards, initiated an extensive Institute-wide study of the national measurement system, to accomplish an across-

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† Numbers in brackets refer to the references listed in the Bibliography at the end of this report.

the-board analysis of the entire scope of Institute measurement and dissemination concerns. The approach to the study involved analysis of the totality of the physical measurements performed in this country to answer the question of the quality of the measurements being made by the system and whether NBS dissemination procedures are adequate for its needs [133,134,144]. This is one of the reports of the results of that study.

The overall study was subdivided into a series of "microstudies" of specific measurement fields (see fig. 1). In addition, a macroeconomic study was performed of measurements in our economy [327,173,200,218]. The overall design and specific findings of the study have been presented in a Final Summary Report [307]. Individual reports are being issued for the microstudies and other aspects of the total study [254,263,269,282,294,295,298-305,312,313,317-28]. Readers interested in a total overview or any of the specific areas studies, are invited to use the request card bound in the back of this document to obtain the reports desired. There will be no systematic attempt made here to summarize the contents of these other reports.

The purpose of this report is to describe the structural and functional aspects of the national measurement system as a whole. Its content has been derived inductively from analysis of the reports from the different specialized study areas and from reading of the literature in this field. The intent is to assemble in one document in a unified fashion material that is otherwise found only in a multitude of sources. The author's contribution has been that of compilation, analysis, integration, and organization. He is indebted to the many sources cited in the Bibliography for establishment of the facts and observations upon which this report is founded.

### 1.2 Functions of Measurements

The functions of measurements include all of the uses made by human beings of knowledge of the physical universe. Measurement is necessary in the conduct of life of the individual, in the pursuit of science, in the operations of society, and in the employment of technology.

Measurements allow human beings  
to describe,  
to predict,  
to communicate,  
to decide,  
to control,  
to react,

in dealing with the physical universe. Of this set of six descriptors, two are most

# Chart of Measurement Quantities

## and Selected Applied Measurement Subsystems covered by the IBS Study of the National Measurement System 1972-75

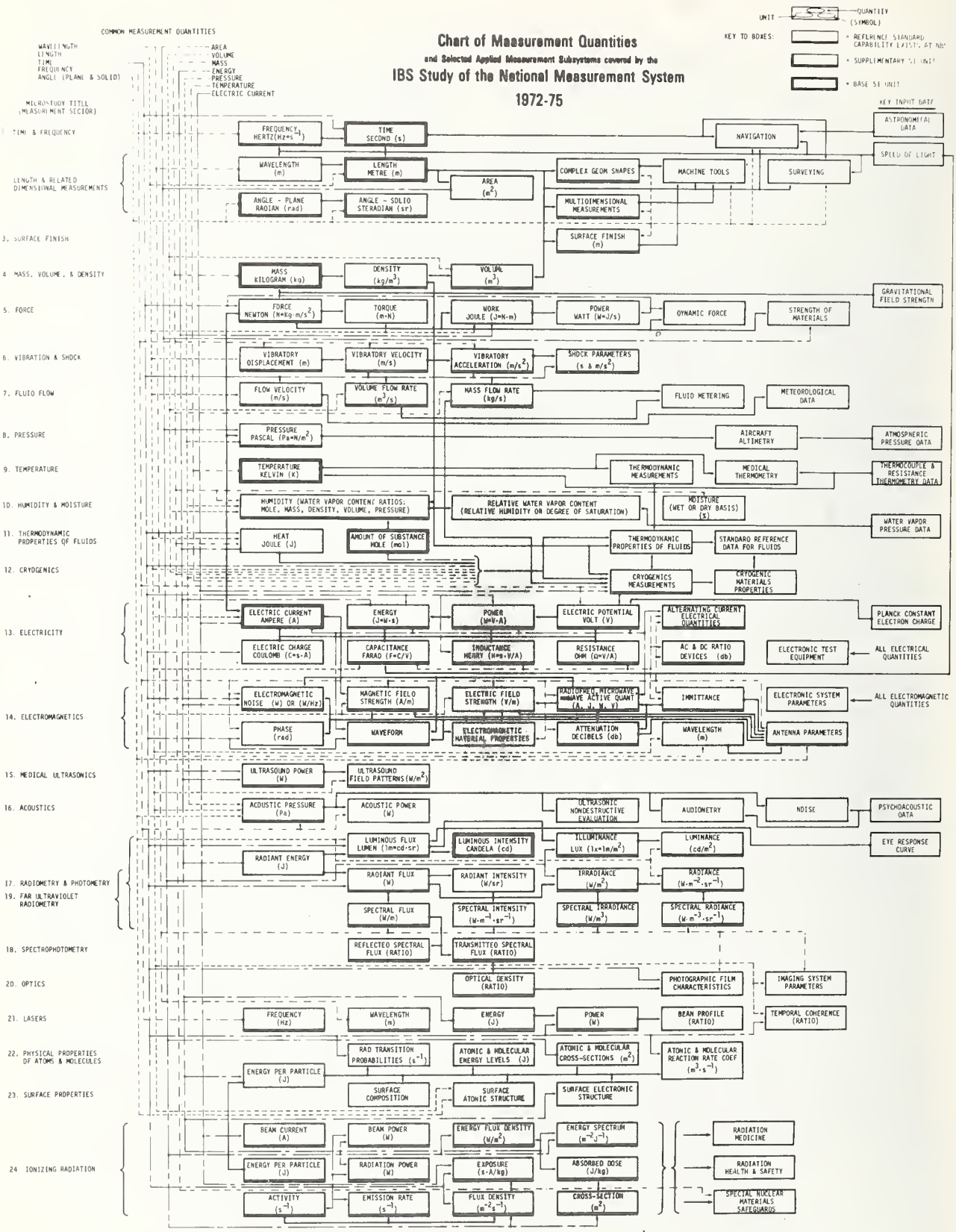


Figure 1. Chart of measurement quantities.



Table 1. Functions of measurements.

	<u>SCIENCE</u>	<u>PERSONAL</u>	<u>SOCIAL EFFICIENCY</u>	<u>TECHNOLOGY IMPLEMENTATION</u>
TO UNDERSTAND	To Describe	Knowledge	Data Bases, Maps & Charts	Resource Location
	To Predict	Prediction of Future	Public Planning & Forecasting	Engineering Design
	To Communicate	Human Communication	Property Ownership & Political Boundaries	Interchangeability
	To Decide	Decision Making (Action Selection)	Adjudication, Equity in Trade & Taxation, Payment of Wages	Quality Assurance
	To Control	Action Initiation	Regulation & Policing	Process Control
	To React	Hazard Warning	Hazard Warning	Fault Diagnosis

TO UTILIZE

fundamental: To communicate and to decide. In the broadest sense of the words, *to communicate* can encompass communication to both the self and others, regarding past, present or future. Similarly, *to decide* can encompass both selection among alternate courses of action and maintaining a selected course of action or reacting in a predetermined fashion when faced with alternatives.

The functions of measurements are summarized in table 1, the development of which will be described in section 4.

### 1.3 Process of Measurement

The process of measurement involves a number of different activities. First and most fundamental, is the *intellectual comprehension and definition* of the phenomenon, quantity, or property to be measured. The travail involved here is often soon forgotten once the issues have been resolved, and the measurement process has become habitual. But in new fields of science, resolving the issue of just what to measure is often more difficult than learning how to make the measurement.

Second, it is necessary to define a *reference unit* in terms of which the measurement will be made. Expressing the results of a measurement in terms of a number requires answering the question, "Number of what?" The reference units may be naturally occurring, such as a day, or man-made, such as an hour.

Third, there must be a *means of comparing* the phenomenon, quantity, or property to be measured with the reference unit. For some purposes, such as determining the number of

days on the trail or the number of people in the tribe, this can be achieved by simple counting of natural units. For other purposes, such as determining the number of hours until dawn, more elaborate methods are needed.

The third activity often leads naturally to the fourth, the establishment of a *physical reference standard* which embodies the measurement unit. The cubit may have been defined in terms of the dimensions of the Pharaoh's body, but there was no way that the Pharaoh himself could be used directly to make the measurements needed for building a pyramid. Hence, a physical reference standard was derived from the basic definition and used to control the ancient Egyptian construction industry (fig. 2).

Individual resolution of the issues surrounding these four preceding aspects of measurement will allow an individual to obtain for himself the quantitative knowledge that he needs as an isolated human being, whether it be for the conduct of his personal life or the pursuit of the interests of science. However, when he proceeds to relate his measurements to those of other human beings he finds that something more is needed, namely *agreement* within the human community on the definitions of what is to be measured and the units of measurement, and the measurement process in general. This fifth aspect of the measurement process requires social mechanisms to create and record agreement on the previous four aspects of measurement, so that communication among individuals in society is possible.

Measurements are used for more than purely personal, scientific, or communication

EGYPTIAN ROYAL CUBIT OF AMENHETEP I (C1550 B.C.)

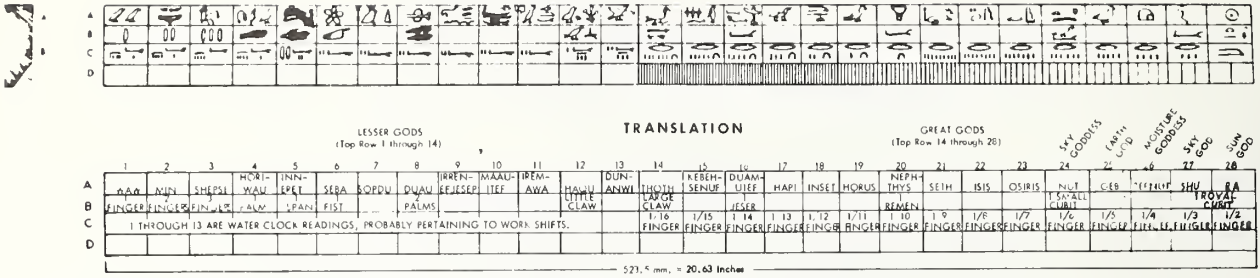


Figure 2. Egyptian Royal Cubit. Five thousand years ago, the Egyptians laid the foundation for all this is embraced by modern linear dimensional control. They produced the first master standard of linear measurement, the Cubit, meaning forearm. This standard was equivalent to the length of the forearm of the Pharaoh, about 20.63 inches long, and was known as the Royal Cubit. This master was subdivided by scribed lines which divided the cubit into two spans, six palms and 24 digits or finger breadths. The digits, in turn, were divided into halves, thirds, quarters, and down to sixteen parts. The Royal Cubit Master was made of black granite and placed in the custody of the royal architect. "Working" cubit sticks made of wood were duplicated from the Royal Cubit and used by artisans in building the Great Pyramid, tombs, and temples [32].

reasons. From time immemorial, goods and services have exchanged hands on the basis of physical measurements. From equally ancient times, cheating and confusion have existed. Both are resented. Societies react to suppress them. These reaction mechanisms to *enforce honesty* and clarity in measurement constitute a sixth major aspect of the measurement process.

#### 1.4 Concept of a National Measurement System

In 1967, Dr. R. D. Huntoon wrote [56]:

"Concurrently with the growth and industrialization of this nation, there has developed within it a vast, complex system of measurement which has made possible the very growth that brought the system into being. This National Measurement System stands today as one of the key elements in a world-wide measurement system that links all major nations together in a consistent, compatible network for communications and trade."

Today, we understand the U.S. National Measurement System to comprise all of the activities and mechanisms--intellectual and operational, technical and institutional--used by this country to produce the physical measurement data needed to create the objective, quantitative knowledge required by our society.

The use of the term *system* in the phrase "the national measurement system" is appropriate. There is a high degree of functional interdependence among the different elements of the system, and the interactions are

numerous, subtle, and complex. The fact that many occur in an automatic or quiet fashion tends to obscure the reality of their existence.

Historically, the word *system* has been used in discussions of measurements since at least as early as the days of Thomas Jefferson [1] and John Quincy Adams [2]. Often, the word has been applied to the array of units and reference standards used for measurement purposes. On the other hand, both the Congressional directive to Adams and his response involved what we today would describe as a systems approach to analysis of the measurement activities in this nation.

The National Measurement System is conceptually similar in nature to a number of other social systems that provide to the individual and to society at large the means for achieving individual and collective goals. In this case, the goals are support to the acquisition of new knowledge of the physical universe, and the benefits that can come from application of such knowledge.

#### 1.5 Structure of This Report

In the next section, a model of the National Measurement System is presented, followed by a discussion of its component parts, with special emphasis on the technical and institutional infrastructural elements. The international measurement system is summarized in section 3, and section 4 discusses the current status and trends of the U.S. national system. Appendices contain background information about the component elements of the system.



## 2. ELEMENTS OF THE SYSTEM

### 2.0 Model of the System

The model of the National Measurement System developed by induction from interim microstudy reports prepared in December 1973 [177-197] and from previous literature on this subject [56,82,15,43,44,47,54,65,172] can be considered to have five major levels:

I. The *intellectual foundation* is the conceptual system that defines the measurement quantities and units.

II. The basic technical infrastructure provides the tools and techniques and agreements that allow the conceptual system to be reduced to practice.

III. Realized measurement capabilities - the ability to measure specified quantities to known precisions and accuracies under defined circumstances - form the heart of the measurement system. Levels I and II are meaningful only as they result in realized measurement capabilities. Levels IV and V can achieve no more than these capabilities allow.

IV. The dissemination and enforcement network exists to make the realized measurement capabilities available to the ultimate users and to enforce the adequacy of their use where this is called for by law or accepted practice. This network provides the *institutional infrastructure* of the system. Since one function of the national measurement system is to allow compatibility in international commerce, both national and international institutions are relevant.

V. The ultimate level in the system consists of the end-use measurements made and used in the "measurements market-place". It is this level that all other elements in the system exist to support.

Figure 3 is a flow diagram version of the model of the National Measurement System used in this report. Many different paths can be traced through this model to show the interrelationships of the different functional elements. Table 2 describes one such traverse. Sections 2.1 through 2.5 below discuss the five major levels of this model.

Other approaches to diagramming the National Measurement System exist. Appendix A contains examples of charts resulting from one such approach in current use in NBS [314].

### 2.1 Measurement Quantities, Units, and Standards

The measurement system of the United States is founded upon one basic conceptual system of measurement phenomena, quantities and properties, and two systems of measurement units, the "Customary" system based on old English measurement units, and the modernized metric system, the *Système International* (abbreviated SI) (see fig. 4 and App. B) [232,15,24,66,1,2,7,9,13,17,27,28,39,41,42,57,73,79,118,199,219,236,260].

Standards are maintained by the international and national standards laboratories for only a limited selection of all of the useful measurement quantities. For the numerous derived quantities, whether or not standards are maintained depends upon a number of factors.

(1) The utility of the standard. For example, standards of volume are maintained, but not standards of area. Area can be determined more accurately by a series of linear and angular measurements than it could be determined by comparison of an unknown area with a reference area. Therefore, while measurement of area, e.g., of land, is of great importance, an area standard is of little practical value. In contrast, while volume can be and sometimes is determined by length and geometrical measurements, volumes can be determined far more accurately, as a rule, by comparison of an unknown volume with a precisely standardized one. Further, volume has great technical and commercial importance--among other things, measurement of volume is often used as a surrogate for measurement of mass or amount of matter. The combination of importance and precision of measurement makes volumetric standards among the most important of all derived standards.

(2) Some quantities are not easily susceptible of embodiment in a physical standard, speed or velocity for instance. Physical realization of a standard for speed is a conceivable, but not an attractive idea. Since distance and time can both be measured with exceedingly high precision, there is usually little or no attractiveness in the idea of establishing a reference standard for speed. The value of the speed of light is, of course, an important and exceptional case.

(3) Some quantities simply are not needed urgently enough to justify the economic cost of developing and maintaining a physical reference standard. In the radio frequency and microwave spectrum, for instance, absolute power calibrations may be needed at a wide variety of frequencies, but economic constraints prevent the construction of absolute reference standards for every frequency

Table 2. Traverse of the National Measurement System Model.

The NATIONAL MEASUREMENT SYSTEM consists of a

- I. CONCEPTUAL SYSTEM of measurement phenomena, quantities, and units,
  - II. BASIC TECHNICAL INFRASTRUCTURE
    - A. Science and knowledge, as recorded in publications.
    - B. Documentary Specifications System of international agreements, laws, engineering standards, mil specs, etc.
    - C. Instrumentation System of artifact stds. and meas. tools and techniques,
    - D. Reference data, or
    - E. Reference materials,
  - III. REALIZED MEASUREMENT CAPABILITY for specified ranges of quantities, subject to certain conditions and accuracies.
  - IV. DISSEMINATION AND ENFORCEMENT NETWORK
    - A. People, often organized in professional societies, who acquire knowledge by education and from instrumentation suppliers.
    - B. Central Standards Authorities,
    - C. State and Local Offices of Weights and Measures and equivalent agencies;
    - D. Standards, Calibration, and Testing Laboratories and Services;
    - E. Regulatory Agencies.
  - V. ORGANIZATIONAL INPUT-OUTPUT TRANSACTIONS in the Measurements Marketplace,
    - A. Costs
    - B. Suppliers with certain capabilities
    - C. Users with certain needs,
    - D. Ultimate Benefits
- which is implemented by a
- that consists of a number of elements built around a central core of
- What to measure, how, when, and why is established and recorded by the
- Physical realization and implementation is achieved by the
- which can be applied to specific physical systems or materials to generate
- which in turn become supporting elements of the technical infrastructure, to create a
- This measurement capability is used by a
- which employs
- These people work in an institutional framework, which consists of
- such as the National Bureau of Standards;
- plus
- plus other
- The end effect of all these structural elements is support to the
- whereby useful measurements are delivered at certain
- by
- to
- who realize the
- of the National Measurement System.

of interest. Instead, standards are constructed for a limited number of key frequencies, and measurements at intermediate frequencies are made by interpolation.

Figure 5 displays an array of the physical measurement standards of the type maintained by NBS. Appendix C lists the physical reference standards maintained by NBS.

Application of this basic conceptual system of measurement quantities, units, and standards to the real world of useful measurements requires a number of connecting elements in the National Measurement System. For present purposes, these can be most easily sorted into two categories, those that belong to a technical infrastructure and those belonging to the institutional infrastructure. The technical infrastructure comprises all of the technical means or tools needed, the institutional infrastructure contains all of the organizations required to make these tools adequately available at the point of end use.

## 2.2 Technical Infrastructure

The technical means or tools required to make measurements include both physical hardware and intellectual software, e.g., both measurement instrumentation and instruction manuals. The software aspects include documentary specifications, descriptions of measurement techniques, educational materials, reference data, and the basic recorded knowledge of science. Hardware aspects include transfer and working standards, reference materials, and measurement instruments. Since the software and hardware are functionally inseparable, the discussion will focus on the technical "tool" aspects of the structural elements of figure 3, handling both the software and hardware aspects together. The institutional aspects of these same elements will be discussed shortly.

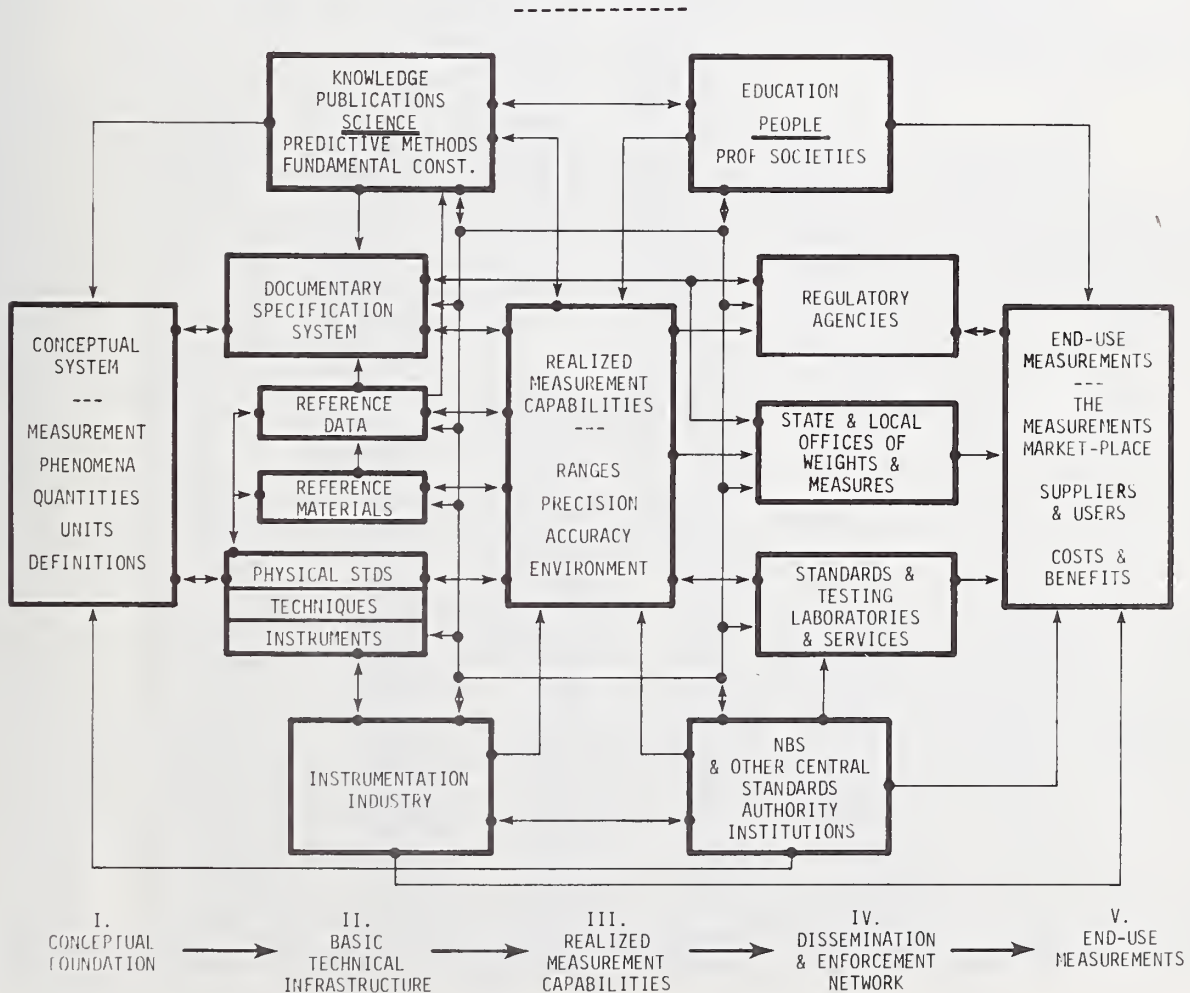


Figure 3. Flow diagram of the National Measurement System.





## SEVEN BASE UNITS

### meter - m

#### LENGTH

The meter (common informational spelling, metre) is defined as 1,650,763.73 wavelengths in vacuum of the orange-red line of the spectrum of krypton-86.

The SI unit of area is the square meter (m<sup>2</sup>).  
The SI unit of volume is the cubic meter (m<sup>3</sup>). The liter (0.001 cubic meter) although not an SI unit, is commonly used to measure fluid volumes.

### kilogram - kg

#### MASS

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures at Paris. A duplicate in the custody of the National Bureau of Standards serves as the mass standard for the United States. This is the only base unit still defined by an artifact.

U.S. prototype NO. 2000

The SI unit of force is the newton (N). One newton is the force which, when applied to a 1 kilogram mass, will give it an acceleration of 1 (meter per second) per second.  
1N = 1kgm/s<sup>2</sup>

The SI unit for pressure is the pascal (Pa).  
1Pa = 1N/m<sup>2</sup>

The SI unit for work and energy of any kind is the joule (J). 1J = 1Nm

The SI unit for power of any kind is the watt (W).  
1W = 1J/s

### second - s

#### TIME

The second is defined as the duration of 919,263,170 cycles of the radiation associated with a specified transition of the cesium-133 atom. It is realized by using an oscillator to the resonance frequency of cesium-133 atoms as they pass through a system of magnets and a resonant cavity into a detector.

TRANSITION IN CESIUM-133 ATOM  
CESIUM ATOM  
MAGNETS  
RESONANT CAVITY  
DETECTOR  
OSCILLATOR  
SCALE SYSTEM

The ampere is defined as that current which, if maintained in each of two long parallel wires separated by one meter in free space, would produce a force between the two wires (due to their magnetic fields) of  $2 \times 10^{-7}$  newton for each meter of length.

The SI unit for acceleration is the (meter per second) per second (m/s<sup>2</sup>).  
1N = 1kgm/s<sup>2</sup>

The SI unit for speed is the meter per second (m/s).

The SI unit for frequency is the hertz (Hz). One hertz equals one cycle per second.

The number of periods or cycles per second is called frequency. The SI unit for frequency is the hertz (Hz). One hertz equals one cycle per second.

The SI unit for electric resistance is the ohm (Ω).  
1Ω = 1V/A

### ampere - A

#### ELECTRIC CURRENT

The SI unit of voltage is the volt (V).  
1V = 1W/A

The SI unit of electric resistance is the ohm (Ω).  
1Ω = 1V/A

1A

FORCE =  $2 \times 10^{-7}$  N

1m

### Kelvin - K

#### TEMPERATURE

The kelvin is defined as the fraction 1/273.15 of the thermodynamic temperature of the triple point of water. The temperature 0°K is called "absolute zero".

TRIPLE POINT CELL

WATER VAPOR  
WATER  
ICE  
THERMISTOR  
ELECTRONIC TEMPERATURE MEASUREMENT SYSTEM

On the commonly used Celsius temperature scale, water freezes at about 0°C and boils at about 100°C. The °C is defined as an interval of 1 K, and the Celsius temperature 0°C is defined as 273.15 K.

1.8 Fahrenheit degrees are equal to 1.0 °C, or 1.0 K; the Fahrenheit scale uses 32° as a temperature corresponding to 0°C.

The standard temperature at the triple point of water is provided by a special cell in which the water is cooled into pure water. When the cell is cooled into a mantle of ice, ice forms around the entrance well, the temperature at the interface of solid, liquid, and vapor is 273.15 K. Thermometers to be calibrated are placed in the entrant well.

### mol - mol

#### AMOUNT OF SUBSTANCE

When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The SI unit of concentration (of amount of substance) is the mole per cubic meter (mol/m<sup>3</sup>).

### candela - cd

#### LUMINOUS INTENSITY

The candela is defined as the luminous intensity in a given direction of a source that emits monochromatic radiation of frequency 540 THz and has a power of 1/683 watt per steradian in that direction.

The SI unit of light flux is the lumen (lm). A source having an intensity of 1 candela in all directions radiates a light flux of 4π lumens.

### radian - rad

#### PLANE ANGLE

The radian is the plane angle with its vertex at the center of a circle that is subtended by an arc equal in length to the radius.

The steradian is the solid angle with its vertex at the center of a sphere that is subtended by an area of a spherical surface equal to that of a square with sides equal in length to the radius.

### TWO SUPPLEMENTARY UNITS

## steradian - sr

### SOLID ANGLE

### Figure 4. The modernized metric system - SI base and supplementary units.



## 2.2.1 Documentary Specifications

Our measurement system both supports and is supported by a documentary specifications system [109,6,88,95,99,121,128,139,224,251,129,279]. The field of documentary specifications and standardization (broadly interpreted) interfaces with the field of metrology and measurement standards in a number of ways:

a. The international basis of the national measurement system is established by an international treaty.

b. The legal basis of the national measurement system is established by the U.S. Constitution and by federal, state, and local laws and ordinances.

c. Engineering standards exist which specify various measurement definitions, instruments, procedures, and processes, i.e., there are engineering standards which apply directly to specification of aspects of the field of metrology itself.

d. Many engineering standards specify test methods, which require metrological capability for their implementation.

e. Many engineering standards are dimensional, design, or process standards, which use convenient multiples of basic measurement units in use in a country as the specified dimensional, design, or process factors.

f. Specifications used in procurement and quality control are often very similar to engineering standards, in that they involve or require test methods, which depend on metrological capabilities, and they are phrased in terms of locally accepted measurement units.

Some examples of kinds of documentary standards and specifications upon which the operations of portions of the national measurement system is based include:

### A. The Constitution of the United States

"The Congress shall have the power...To coin money, regulate the value thereof, and of foreign coin, and fix the standard of weights and measures" (art. 1, sect. 8).

### B. International Treaties and Conventions

The Convention of the Metre of May 20, 1875, established the metric system as the international language for physical measurements. It created the international machinery for implementation and evolution of this system. The Convention was ratified by the United States on May 28, 1878. Currently, 43 nations adhere to it. [250,9,57,232]

The International Organization for Legal Metrology (OIML, from its French initials) is a treaty organization not under the United Nations, which was established in 1955. The United States joined it in August 1972. It

is concerned for the most part with standards for instruments and measurement techniques involved in legal determinations of quantity and quality. The decisions of the organization have the character of recommendations, not the force of law. However, members of the organization are morally obligated to implement these decisions as far as possible, and this moral obligation is taken seriously.

### C. Laws

"Act of 28 July 1866 (14 Stat. 339)--An Act to authorize the Use of the Metric System of Weights and Measures.

"Be it enacted...That from and after the passage of this act it shall be lawful throughout the United States of America to employ the weights and measures of the metric system; and no contract or dealing, or pleading in any court, shall be deemed invalid or liable to objection because the weights or measures expressed or referred to therein are weights or measures of the metric system."

"Act of 3 March 1901, 31 Stat. 1449 (Public Law 177-56 Congress)--An Act to establish the National Bureau of Standards."

### "15 U.S.C. 272. Functions of the Secretary

The Secretary of Commerce is authorized to undertake the following functions:

(a) The custody, maintenance, and development of the national standards of measurement, and the provision of means and methods for making measurement consistent with those standards, including the comparison of standards used in scientific investigations, engineering, manufacturing, commerce, and educational institutions with the standards adopted or recognized by the Government.

(b) The determination of physical constants and properties of materials when such data are of great importance to scientific or manufacturing interests and are not to be obtained of sufficient accuracy elsewhere.

(c) The development of methods for testing materials, mechanisms, and structures, and the testing of materials, supplies, and equipment, including items purchased for use of Government departments and independent establishments.

(d) Cooperation with other governmental agencies and with private organizations in the establishment of standard practices, incorporated in codes and specifications.

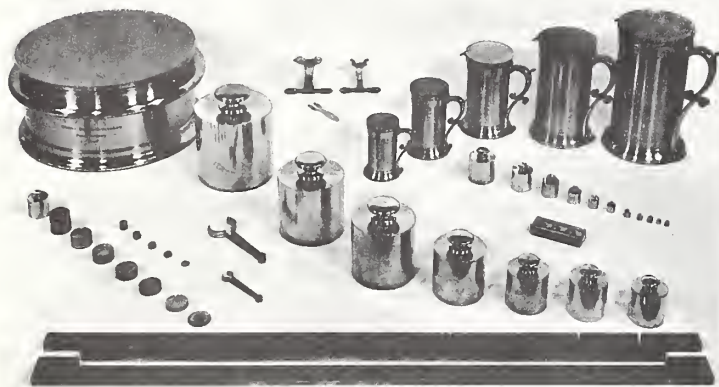
(e) Advisory service to Government agencies on scientific and technical problems.

(f) Invention and development of devices to serve special needs of the Government...."

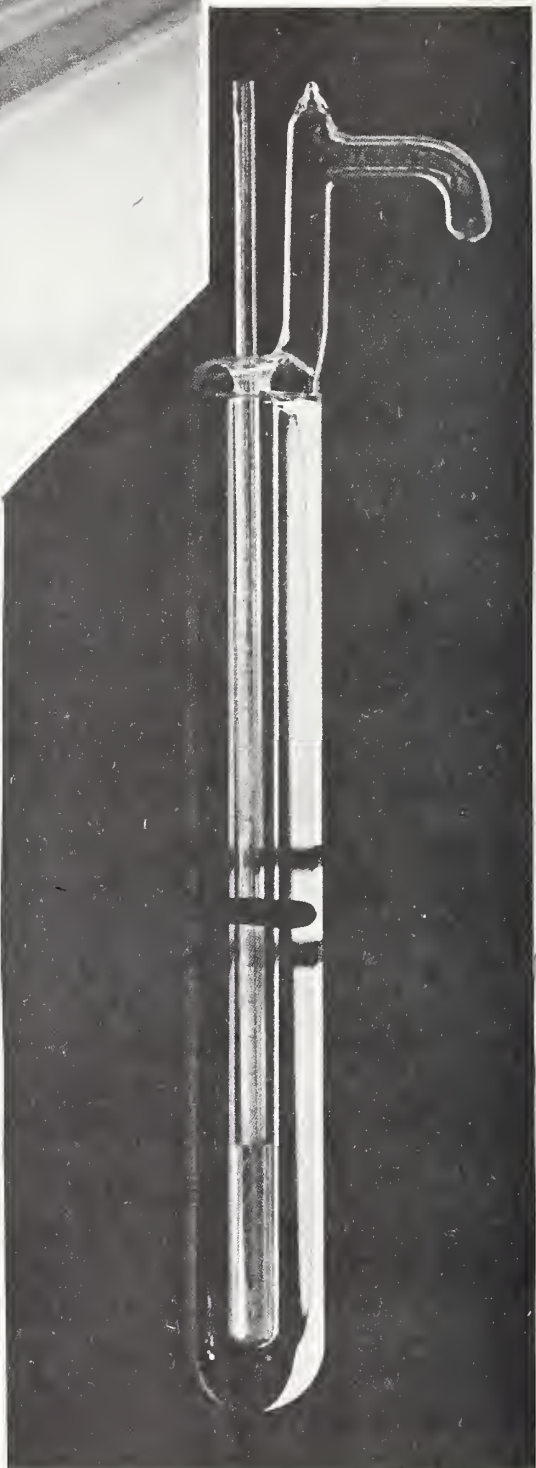
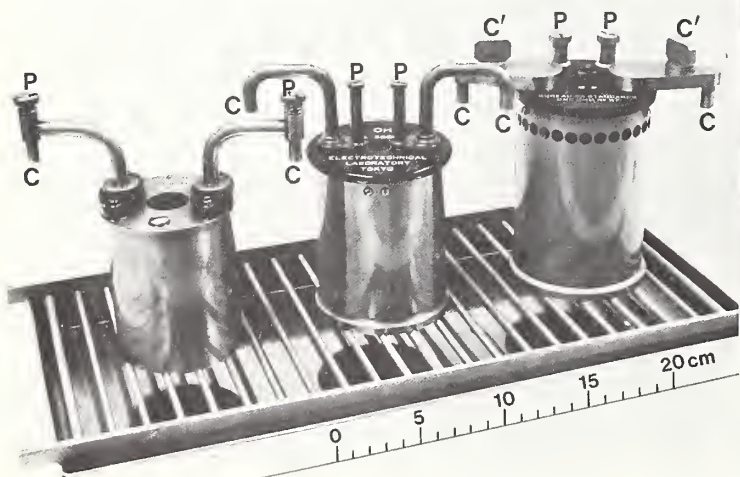


Triple-point cell --  
the temperature  
standard. ↓

International metre and international kilogram of 1889 (life-size front views).



Standards of length, mass, and capacity provided States under Congressional resolution of 1836.



← One ohm resistance standards.

Figure 5. Standards of physical measurement.



#### D. Administrative Regulations

Mendenhall Order of April 5, 1893 [46]:

"...The Office of Weights and Measures, with the approval of the Secretary of the Treasury, will in the future regard the International Prototype Metre and the Kilogramme 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. State and Local Laws and Ordinances

NBS Handbook 44 [119] is the basic model code that is adopted as the weights and measures law of 50 states, Puerto Rico, and the District of Columbia. The National Conference of Weights and Measures is responsible for the decisions regarding changes in this Handbook.

#### F. Engineering Standards

An Engineering Standard is "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, methods of test for sulphur in oil, and codes for highway signs." [109, p.12] Engineering standards may cover materials, items, features of items, processes, codes, symbols, type designations, definitions, nomenclature, test, inspection, packaging and preservation methods and materials, define and classify defects, and standardize the marking of material, items, parts, and components of equipment, etc.

About 25 percent of the internationally recommended engineering standards in 1969 focused on dimensional specifications, about 15 percent were quality standards, 45 percent dealt with methods of test, and about 15 percent were descriptive standards. Measurement units are important in dimensional specifications since sizes are usually simple multiples or submultiples of the customary measurement units employed in a particular country. The measurement process, but not the measurement language, is important in quality specifications and methods of test [109, p.3].

Engineering standards function in procurement through the medium of specifications. *Standards per se* disclose or describe

the technical features of an item in terms of what it is and what it will do; in contrast, the *specification* for the same item describes it in terms of the requirements for procurement. As an example of the relationship of specification to standards, a specification for spark plugs would reference the screw thread standard to ensure the interchangeability of that feature of spark plugs produced by different manufacturers. By referencing other documents, additional essential interchangeability features and performance characteristics can be established, or they can be established by the text or figures, as appropriate.

There are thousands of commercial and industrial standards in existence. A basic reference source is NBS Special Publication 329, An Index of U.S. Voluntary Engineering Standards [95]. This work and its supplements [139,251] contain more than 30,000 permuted titles covering standards, specifications, test methods and recommended practices published by over 360 technical societies, professional organizations and trade associations. The General Services Administration *Index of Federal Specifications and Standards* [280] is the basic compendium in its field. It includes over 40,000 specifications and standards.

Between them, the two major international standards bodies (ISO and IEE-see sect. 4) have published through 1974 approximately 2800 Recommendations. It is generally agreed that in a highly industrialized society the total need of national and international standards is of the order of 15,000 to 20,000 [99,109].

#### 2.2.2 Measurement Instrumentation

The heart of any measurement operation is appropriate instrumentation [19,201,218,237,286]. This is the only element in the technical infrastructure of the measurement system that must always be present in any measurement operation if it is to be successful.

The instrumentation categories listed in the annual *Guide to Scientific Instruments* [272] and in the 1976 *Buyer's Guide* issue of *Instruments and Control Systems* [274] have been analyzed and sorted [328]. The goal was to achieve a level of aggregation that approximates the measurement categories of the national measurement system study microstudies (see Fig. 1), one that would be optimally useful in understanding the product output of the instrumentation industry.

Table 3. Measurement instrumentation categories and suppliers.

Instrumentation Category	Numbers of:		(code categories in:)			
	Vendors [328]	SIC Codes [141-2,146]	Science [272]	Inst/Cont [274]	Sys [274]	Quality [329]
Counting (non-nuclear)	575	17	12	3		5
Time	652	40	29	3		1
Frequency (incl. tachometers)	566	18	9	5		7
Length & related dimensional measurements	1161	119	60	12		150
Surface area, porosity, finish	99	1	5	2		4
Surface properties	60	2	16			1
Volume	385	49	22			
Level (liquid, et al)	295	6	4	3		
Mass, macroscopic (weights, balances....)	194	18	31			1
Mass, atomic & molecular	65		26			
Density	126	5	8	4		3
Force & work	193	5	10	1		7
Torque & balancing	169	6	4			7
Shock & impact	67		2			1
Mechanical properties of solids	415	10	35	8		32
Mechanical properties of liquids	76	2	16	4		
Acceleration, linear & angular	110	3	4	1		2
Velocity & speed	131	5		3		3
Fluid flow	566	26	19	6		3
Leaks	138	2	4	1		2
Vacuum	162	1	2	2		1
Pressure	565	22	29	4		5
Temperature	883	25	47	6		11
Heat & heat flow	106	2	5	3		2
Thermodynamic properties	67		13	3		
Vibration	233	1	4	1		6
Acoustics & noise	283	2	13	2		5
Seismology & sonar	44	6	4			2
Ultrasonics	99	3	10			7
Electricity	1633	105	67	20		47
Magnetism	135	3	15	1		5
Electromagnetics (rf & microwave)	897	30	26	8		27
Laser quantities	32	2	4			
Optical reflect/refract/polar/scattering	185	23	26	4		2
Radiometry & photometry	480	25	41	3		4
Spectrophotometry & colorimetry	323	5	78	3		8
Densitometry	125		7			2
X-rays	175	10	27	1		6
Nuclear radiation	253	27	59	2		
Humidity & moisture	323	9	12	4		10
Oxygen	141	1	20			
Other gases	282	4	25	2		4
Aqueous ions	169	9	47	4		1
Chemical composition/properties, other	353	8	74	2		4
Air & water quality & pollution*	473	5	11	9		2
Biomedical phenomena*	188	20	50	1		
Boiler, furnace, & combustion instr.*	120	12		2		
Building environment & appliance control*	66	16				
Geophysics, environmental, & astronomy*	269	11	11	1		2
Ordnance & fire control*	25	45		1		
Process control*	379	16		3		1
Telecommunications*	256	2		1		
Transportation equipment*	184	46	1	4		1
Sampling*	69		11	2		
Data acquisition systems*	448	2	3	3		
Telemetry	201	2	1	2		
Unspecified or ambiguous or very broad	226	13	1			3
*entries not classifiable in categories above	TOTALS: 5332	847	1060	160		397



The main instrumentation categories and an approximate count of the number of supplier companies for each category are displayed in table 3. Note that all measurement instrumentation categories are accounted for, whether or not they were covered during the 1972-75 study by the NBS Institute for Basic Standards; indeed, some are outside either the mission or the technical competence of this Institute. Further, there is some redundancy built into this analysis; specifically, category W "multiparameter measurements" includes instrumentation that could be classified under earlier categories in the sequency, if adequately detailed data were available. Table three also indicates the numbers of specific product categories appearing in the two sources cited, which were aggregated to establish each of the major instrumentation categories.

The final column of numbers in table three defines the counts of Standard Industrial Classification (SIC) measurement product categories which were obtained from analysis of the following sources [328]: U.S. Bureau of Census, Alphabetic List of Manufactured Products, 1963 Census of Manufacturers; Alphabetic List of Manufactured Products (1967 SIC Basis), 1972 Census of Manufacturers [142]; Numerical List of Manufactured Products (New (1972) SIC Basis), 1972 Census of Manufacturers [146]; and Office of Management and Budget, Standard Industrial Classification Manual, 1972 [141].

In the language that has grown up with the computer field, measurement instrumentation involves both hardware and software. Both physical apparatus and the techniques by which it can produce the desired results must be available. Therefore, in this discussion, physical instrumentation and measurement techniques will be handled as part of the same subsystem.

The most basic level of physical instrumentation and techniques is that involved in realizing the conceptual definitions of the measurement units. Next is that required to disseminate or transfer the realized units so that they are accessible for reference purposes to those involved in making useful measurements. Finally, there is the working level of instrumentation and techniques which produce the end-use measurement data.

The instrumentation system begins with the equipment and techniques needed to realize the seven base SI units. Of these only one, the kilogram, is defined by an artifact. The others are all defined in terms of physical phenomena or processes, and are realized by physical instrumentation.

A Krypton-86 lamp by means of which the metre is today realized is sketched in figure 6. One of the primary national frequency standards is shown in figure 7. A schematic diagram of its operating principles is given in figure 8. Figure 9 is a diagram of the experimental realization of the candela, the unit of luminous intensity. A standard voltage reference source is pictured in figure 10 (the volt, while not a base unit, is one commonly maintained for reference standard purposes).

Realization of a base unit in a central laboratory is but a first step. In general, the working standards and instruments at the point of end-use-measurement cannot be directly compared against the prototype reference standards or instruments. For one thing, there are simply too many of them. For another thing, the implied intensity of use of the prototype standards is not compatible with maintaining the stability that is one of their most essential features. So, transfer standards, instrumentation, and techniques are required, that allow the connection to be made between the ultimate reference standards and the working end-use instrumentation.

Table 4. Calibration chain example: tire inflation pressure [301]

<u>Operator</u>	<u>Object/Instrument</u>	<u>Required Accuracy</u>	<u>Accuracy Lost In Transfer</u>
You and I	Tire	1 psi	factor 3
You and I	Tire gage	.3 psi	factor 3
Tire gage manufacturer	bench standard (Bourdon)	.1 psi	factor 3
Tire gage manufacturer	working standard (Bourdon)	.03 psi	factor 3
Tire gage manufacturer	plant standard (piston gage)	.01 psi	-
Pressure gage manufacturer	instrument sold (piston gage)	100 ppm	30 ppm
Pressure gage manufacturer	working standard (piston gage)	70 ppm	20 ppm
Pressure gage manufacturer	plant standard (piston gage)	50 ppm	20 ppm
National Bureau of Standards	NBS primary standard (controlled clearance piston gage)	30 ppm	

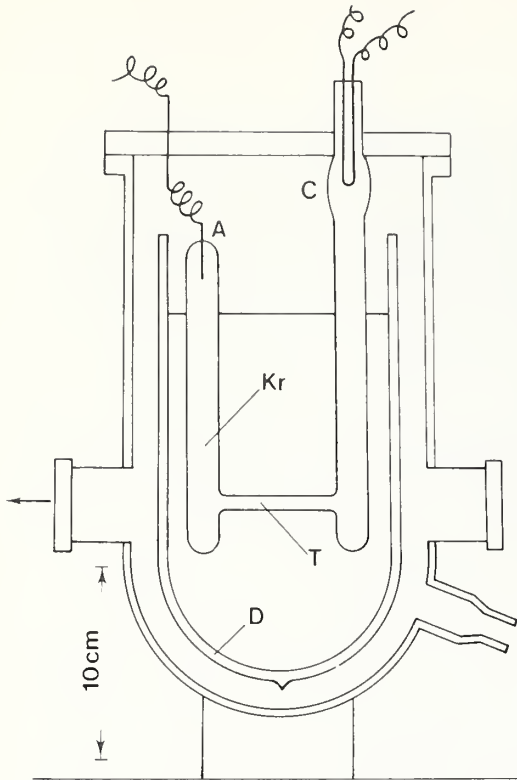


Figure 6. Krypton-86 lamp in its cryostat.

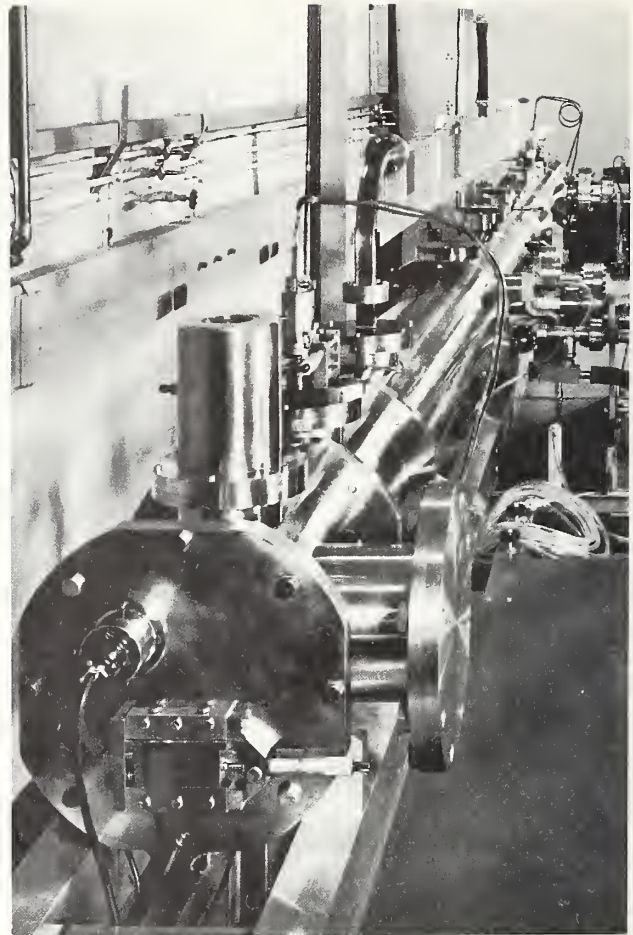


Figure 7. Cesium-beam atomic clock.

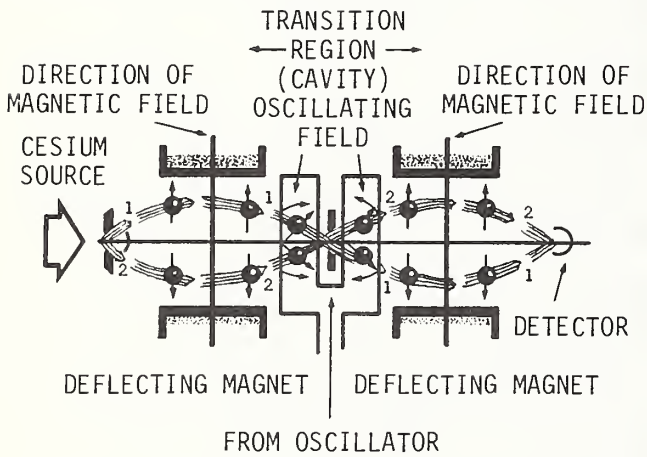


Figure 8. Schematic of an atomic beam clock.

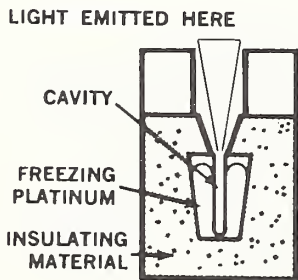


Figure 9. Experimental realization of the candela.

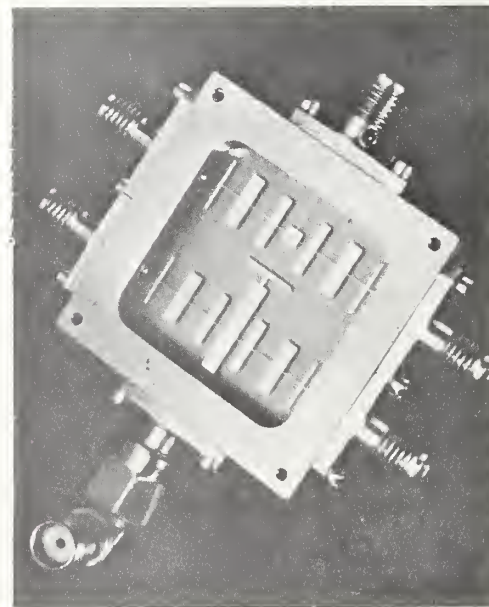


Figure 10. Josephson junction standard voltage source



Transfer standards must be stable, portable devices, capable of being compared with the reference standards or instrumentation at a central laboratory and with working standards or instrumentation at a number of remote locations. Since, in many cases, a hierarchy of comparisons may be made, with different accuracy requirements at different steps, different kinds of transfer standards may be appropriate at the different steps. The calibration chain example of table 4 illustrates these points [304].

The calibration of a transfer standard may be against a reference standard which is a physical object very similar to the one being calibrated. This is typically the case for mass. There is no essential difference in kind between the prototype kilogram and mass transfer standards ("weights") or many ultimate end-use mass standards, such as the sets of weights used in chemical laboratories.

In other cases, the transfer standard may be of a very different nature from the reference standard, as in the case of voltage where a bank of standard electrochemical cells is the traveling transfer standard which is compared against the national Josephson junction reference standard. In intermediate cases, the transfer and reference standards may operate on the same physical principle, but be substantially different in design and appearance.

The instrumentation used to compare reference and transfer standards displays an even wider variation in nature than do the standards themselves. Precision balances are used in the case of mass. Elaborate optical instrumentation (fig. 11) is used in the case of length. Complex measuring and comparison systems are used in the case of millimeter wave noise power (fig. 12). Multi-story dead-weight machines (fig. 13) are used to transfer a gravitational force calibration to a proving ring (fig. 14) or load cell which may be only a few inches on a side.

The instrumentation used for end-use measurement and control purposes is even more diverse [328]. Just the members of *categories* of instruments listed in various buyers' guides is staggering: over 150 for *Instruments and Control Systems* [274] and over 1050 for *Science* [272]. Over 840 SIC measurement product categories have been identified for the manufacturing industries and more than 200 for non-manufacturing industries [328].

### 2.2.3 Reference Data

One basic function of measurement instrumentation and techniques is to enable the characterization of the properties of matter and materials and of a whole array of fabricated products ranging in complexity from "parts" to "devices" to "equipment" to "subsystems" to "systems". When a given aspect of matter, a given material or a given fabricated product is sufficiently stable, sufficiently well defined, and of wide enough interest, the measurement data that characterize that aspect of matter, material, or fabricated product can become useful as *reference data*. The existence of reference data takes a substantial load off other aspects of the measurement system. Once these data have been established and made widely available, it is no longer necessary to remeasure the relevant aspects of matter, materials, or fabricated objects every time information is needed about their properties.

The National Standard Reference Data System was established in 1963 by the Federal Council for Science and Technology, as a Federal agency with responsibility to compile, evaluate and disseminate data for the American technical community to use [50,84, 137,267]. The National Bureau of Standards was requested to assume administrative responsibility for this System. The ability of NBS to carry out the program was enhanced by passage of legislation by Congress specifically authorizing this program [84,267]. "Standard Reference Data" have been defined to be critically evaluated, quantitative information relating to a property of a definable substance or system. In practice, this means that the program is not concerned with substances of complex or variable composition, for example, concrete, most commercial alloys, or most commercial polymers. Similarly, if the property under consideration is sensitive to the presence of unknown impurities or unknown structural features, that property is not included within the scope of the formal Standard Reference Data system.

Since the data evaluation must necessarily be done by a specialist, and since these experts are located in laboratories all over the country, the National Standard Reference Data System is conducted as a decentralized set of data centers and related activities. Within the National Bureau of Standards, a small program management office coordinates the various activities, allocates funds to individual projects, and takes appropriate action to ensure that products of the system are adequately available to the technical community in the United States.



Figure 12. Automated Y-factor mm-wave noise measurement system.

Figure 11. Photoelectric interferometric comparator.

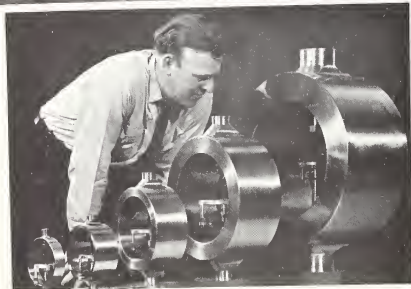
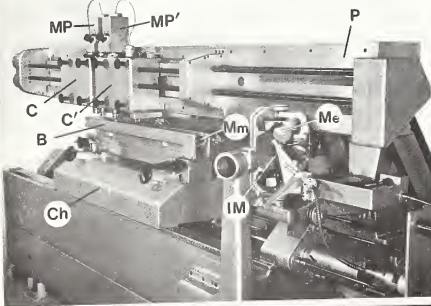


Figure 14. Proving rings.

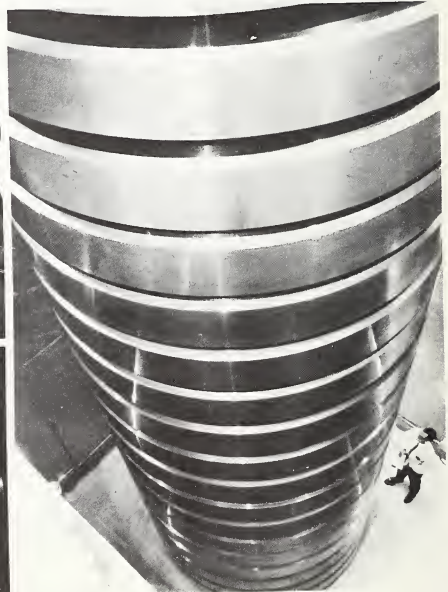


Figure 13. Deadweight machine.



Products of the standard reference data centers include:  
Classified bibliographies  
Indexed bibliographies  
State-of-the-art reports  
Critical reviews  
Compilations of property data  
Compilations of critically evaluated data on properties and functions derived from data  
Correlations of observations with theory  
Compilations of computed properties or functions used in interpretation of experiments.

Appendix D tabulates the published output of the National Standard Reference Data System.

A byproduct of the standard reference data program has been an increase in scientific measurement discipline. During some of the early data studies, it became apparent that perhaps only one paper out of five in a given field could be used as a source of data. For the rest, either the measurement methods used or the printed descriptions were too vague or unreliable to allow the data published in the paper to be used. Substantially, this meant that perhaps 80 percent of the apparently relevant literature was of no value. As a result of the standards set by the publications from the standard reference data system, this situation has significantly improved.

The emphasis in the preceding discussion on *standard* reference data is not intended to deprecate the importance of reference data of lower precision and more transitory character. The vast bulk of our national engineering activities, particularly in civil engineering, structural engineering, and construction, depends upon the existence of a large body of engineering data concerning the properties of materials and a wide variety of fabricated products. Further, every table of specifications for a commercial product is a table of reference data about that product.

The function of the measurement system in generating reference data is obvious. The fact that such "reusable" data can take a major load off of the routine operations of the measurement system is almost as obvious. Less obvious are the roles that reference data play as a major structural element in the measurement system itself. These roles come in several varieties.

(1) It is often possible to measure the properties of an "unknown" specimen with greater precision or greater ease by comparison of its properties with that of a

known material, than it is to measure these properties in an absolute sense. This requires that reference data be available concerning the "known" reference material. An example is the sorting of mineral specimens into different density ranges based on their sinking or floating in a series of liquids of known densities.

(2) The known properties of readily available reference materials may be used to calibrate measurement instrumentation. For example, air bubbled through water held at a known temperature can be used to generate a known humidity atmosphere, for the calibration of humidity meters. This application requires that the reference data regarding water vapor pressure versus temperature be available.

(3) The properties of materials may be used to define the measurement process itself. Units for four of the base SI quantities are defined in this manner: temperature, for which the kelvin is defined in terms of the triple point of water; the candela, which depends upon the luminosity of molten platinum at its freezing point; and length and time, which are defined in terms of data regarding certain atomic transitions. However, it is in the International Practical Temperature Scale (see table 5) in which the interplay between reference data, reference materials, and the foundations of the measurement system becomes most dramatically apparent.

Temperature is defined in theoretical thermodynamic terms, with the size of the unit defined by one arbitrary fixed point, the triple point of water, where ice, water, and pure water vapor coexist in equilibrium. However, theory alone is not very useful for determining how hot it is. It has to be embodied in established data and hardware. The International Practical Temperature Scale is such an embodiment. Reference data have been established for a number of materials, which data represent the closest approximation that is currently feasible to applying the absolute thermodynamic theory to the determination of the temperatures of real materials under defined conditions. These data are then used to establish a practical temperature scale. Use of this practical temperature scale allows enhanced precision in day-to-day temperature determinations. If the practical scale is ever revised because of achievement of greater precision in the reference data base, these revisions can also be applied to measurements made with the current scale, so that their accuracy is further improved.

Table 5. Primary fixed points on International Practical Temperature Scale IPTS-68.

State	$T_{68}(k)$	$t_{68}(^{\circ}C)$
thermodynamic zero of temperature	0	-273.15
equilibrium hydrogen triple point	13.81	-259.34
equilibrium hydrogen, $p = 33,330.6 \text{ N/m}^2$	17.042	-256.108
equilibrium hydrogen boiling point	20.28	-252.87
neon boiling point	27.102	-246.048
oxygen triple point	54.361	-218.789
oxygen boiling point	90.188	-182.962
water triple point	273.16	0.01
water boiling point	373.15	100.00
zinc freezing point	692.73	419.58
silver freezing point	1235.08	961.93
gold freezing point	1337.58	1064.43

Figure 15 tells a similar story [158]. Only the optical pyrometers (radiation detection) temperature measuring instruments depend upon absolute physical properties that are substantially independent of the particular materials used, as are the length of a meter bar or the mass of a kilogram standard. The rest--thermocouples, resistance thermometers, thermistors, mercury-glass thermometers, and bimetallic devices--depend for their functioning directly upon material properties that vary widely from substance to substance. In some cases, such as mercury-glass or bimetallic thermometers, devices are usually individually calibrated so that the user has no need to be aware of the reference data regarding material properties. For others, especially thermocouples and resistance thermometers, the user may be reading an electrical value and converting it into temperature by consulting a table of reference data for the material system that he is employing.

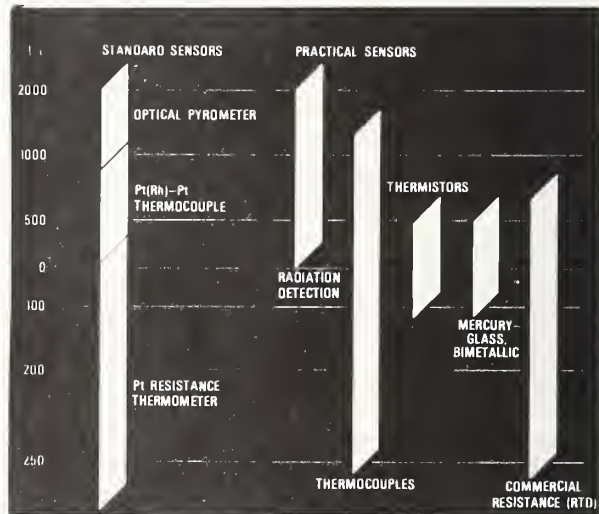


Figure 15. Temperature measurement sensors

#### 2.2.4 Reference Materials

Reference materials represent another facet of the national measurement system [240,83,87, 111,131,235,241], one both distinct from and closely related to reference data. Reference materials complement and supplement reference data. The very concept of *reference material* implies the existence of reference data regarding that material, and many kinds of reference data describe properties of substances that could be used as reference materials.

Taken in its broadest sense, the word *material* can include any physical object. Reference materials may be materials of measured composition, measured properties, or measured dimensions, or materials that when acted upon produce specific and measured effects. From this

point of view, there are few physical reference standard or measurement techniques that do not involve reference materials, and some physical reference standards, such as those for density, are reference materials.

Some reference materials, such as highly pure water or high purity hydrogen, can be prepared by the user. Others can be purchased from commercial sources. However, the uncertainties associated with preparing and characterizing reference materials are sufficiently great that there is a substantial need for standard reference materials (SRM's) prepared and characterized in the most definite possible manner. The National Bureau of Standards and other national standards laboratories often function as sources for such standard reference materials [240] (see table 6).



Table 6. Table of Contents from catalog of NBS standard reference materials [252].

	<u>page</u>		<u>page</u>
GENERAL INFORMATION . . . . .	1	Magnetic Standards: magnetic susceptibility	54
PREPARATION AND AVAILABILITY OF STANDARD REFERENCE MATERIALS: Ordering, Terms, Domestic Shipments, Foreign Shipments . . .	1	Optical Standards: Spectrophotometry (color standards for spectrophotometric tristimulus integrator systems, glass filters, liquid filters, quartz cuvette), Thermal emittance, Reflectance, Refractive index . . . . .	55
CHEMICAL COMPOSITION STANDARDS . . . . .	10	Radioactivity Standards: Alpha-particle standards; Beta-particle and gamma-ray gas standards; Alpha-particle, beta-particle, gamma-ray, and electron-capture solution standards; Contemporary standard for carbon-14 dating laboratories; Environmental standards; Low energy photon sources; Gamma-ray "point-source" standards; Radium gamma-ray solution standards; Radium solution standards for radon analysis; Radioactivity standard reference materials currently not in stock . . . . .	58
Steels (chip form): plain carbon, low alloy, high alloy, stainless, tool . . .	10	Metallurgical . . . . .	61
Steels (granular form) . . . . .	13	Mössbauer . . . . .	61
Steels (solid form): special ingot irons and low alloy, stainless, specialty, high-temperature alloys, tool . . . . .	14	X-ray Diffraction . . . . .	61
Steelmaking Alloys . . . . .	19	Permittivity . . . . .	62
Cast Irons (chip form) . . . . .	20	Reference Fuels . . . . .	62
Cast Steels, White Cast Irons, Ductile Irons and Blast Furnace Irons (solid forms) . .	21	Resistivity . . . . .	62
Nonferrous Alloys (chip form): aluminum, cobalt, copper, lead, magnesium, nickel, nickel oxide, selenium, tin, titanium, zinc, zirconium . . . . .	22	ENGINEERING TYPE STANDARDS . . . . .	63
Nonferrous Alloys (solid form): copper, lead, nickel, tin, titanium, zinc, zirconium . . . . .	24	Standard Rubber and Rubber-Compounding Materials . . . . .	63
Gases in Metals . . . . .	28	Reference Magnetic Tapes . . . . .	63
High-Purity Metals . . . . .	29	Sizing Standards: glass spheres for particle size, turbidimetric and fineness (cement) . . . . .	64
Electron Probe Microanalytical Standards Primary, Working, and Secondary Standard Chemicals . . . . .	31	Color Standards: the ISCC-NBS centroid color charts; paint pigment; light-sensitive papers; light-sensitive plastic chips . .	64
Microchemical Standards . . . . .	31	X-ray and Photographic Standards . . . . .	65
Clinical Laboratory Standards . . . . .	32	Surface Flammability Standards . . . . .	65
Biological Standards . . . . .	32	Smoke Density Chamber Standards . . . . .	65
Environmental Standards: analyzed gases, analyzed liquids, analyzed solids, permeation tubes, trace elements in fossil fuels . . . . .	33	Water Vapor Permeance . . . . .	66
Forensic Standards . . . . .	35	Internal Tearing Resistance Paper . . . . .	66
Hydrocarbon Blends . . . . .	35	Tape Adhesion Testing standard . . . . .	66
Metallo-Organic Compounds . . . . .	36	RESEARCH MATERIALS: High-Purity Materials, SEM Resolution Test Specimen, Phosphors . .	67
Fertilizers . . . . .	36	GENERAL MATERIALS: Hydrogen in Steel, Nickel and Vanadium in Residual Oil, Absorbent Clay (ASTM D2007) . . . . .	68
Ores . . . . .	37	COMPUTER PROGRAMS FOR METRIC CONVERSION . . .	68
Cements . . . . .	38	OTHER SERVICES OF THE NATIONAL BUREAU OF STANDARDS: Calibration and Test Services, Standards Information Services, Standard Reference Data, Technical Publications. . .	69
Minerals, Refractories, Carbides, & Glasses	38	GUIDE FOR REQUESTING THE DEVELOPMENT OF STANDARD REFERENCE MATERIALS . . . . .	72
Trace Element Standards . . . . .	40	INDEXES	
Nuclear Materials: Special nuclear materials (plutonium assay, plutonium isotopic, uranium assay, uranium isotopic), Neutron density standards, Fission track glass standards . . . . .	41	Alphabetical Index . . . . .	73
Isotopic Reference Standards . . . . .	43	Numerical Index to SRM Certificates . . . .	80
PHYSICAL PROPERTY STANDARDS . . . . .	44		
Ion activity Standards: pH standards, pD standards, ion selective electrodes . . .	44		
Mechanical and Metrology Standards: coating thickness, glass, elasticity, density, polymer . . . . .	45		
Heat Standards: Superconductive thermometric fixed point devices, Freezing points (defining fixed points, determined reference points), Melting points, Calorimetry (combustion, solution, heat source, enthalpy and heat capacity), Differential thermal analysis, Vapor pressure, Thermal conductivity, Thermal expansion, Thermocouple materials . . . . .	51		

The 1975 NBS price list for Standard Reference Materials lists some 892 items [275]. Of these, over 650 are bulk materials, whose utility and properties are either substantially unaffected by or can be readily calculated after subdivision. An example of the former is SRM 43<sub>h</sub> Zinc, freezing point standard, and of the latter, SRM 4963 Radium solution standard, 50  $\mu\text{g Ra}$ .

Approximately 100 more can be described as "two-dimensional" bulk materials, such as glass optical filters or specimens with coatings of various kinds. Another seventy or so are of value for physical properties that depend upon specimen dimensions, such as thermal expansivity or conductance, emittance, and magnetic susceptance, or else involve properties that limit the ability to subdivide the materials usefully--such as those associated with single crystal specimens or samples of beads.

The remaining 50 or so standard reference materials are basically physical reference standards as discussed earlier in this report. About half are radiation sources, in the gray area between "materials" and "devices." The rest are physical measurement standards or devices, or even computer software packages, made generally available to the public through the SRM marketing mechanism. Examples include SRM's 932 Quartz cuvette for spectrophotometry; 933 and 934 Clinical laboratory thermometers; 1001 X-ray step tablet; 1010a Microcopy test chart; 1600 Tape, magnetic, secondary standard, cassette; and 2106 ISCC-NBS color charts.

The significant point for present purposes is that measurement instrumentation, measurement techniques, physical reference standards, standard reference materials, and standard reference data form a continuum in the technical infrastructure of the measurement system. Each element complements and supplements all of the others, and any or all may be needed in any given measurement situation.

### 2.2.5 Predictive Methods

One more element needs to be added to the technical infrastructure continuum of the previous paragraph, namely *predictive methods*, i.e., theoretical models which will allow prediction of measurement results for circumstances in which the volume of experimental measurement data needed is so large or the experimental conditions so inaccessible, that it is not technically or economically feasible to actually generate measurement data. These models are useful for both extrapolation and interpolation [322].

While predictive methods could be shown as a separate structural element (see fig. 3) in the formal model of the measurement system, they are at this time encompassed as part of the block labelled "science."

### 2.2.6 Fundamental Constants

In all of our fundamental theories there are a certain few parameters which characterize the fundamental particles and interactions that we find in nature. These are the fundamental physical constants [12,39,93,112,205]. The precise determination of the numerical values of these constants has long been and remains one of the principle objectives of experimental science, and one of the greatest driving forces toward increased accuracy and precision in the measurement system. These parameters are the quantitative link between our most basic theories and the physical reality that we wish them to describe. The progress of our understanding of the physical world is therefore very much intertwined with the advance of the art of precision measurement and its application to the determination of the fundamental constants.

There is an essential connection between the fundamental constants and our choice and definition of the base units in our scheme of physical measurement. Moreover, scientific invention and discovery continue to provide us with new opportunities for strengthening these connections.

Ideally, we want our measurement system to be based on aspects of nature that are invariant with time and place and that can be reliably and independently reproduced in different laboratories. We want the measurement system to be independent of reference to artifacts whose continued existence and long-term stability is a matter of fundamental uncertainty. The fundamental constants appear to be the true invariants of nature, and therefore represent the ideal basis for a measurement system.

In fact, both length and time are now defined in terms of atomic transitions, and are therefore conceptually closely connected with the fundamental constants related to these transitions. The volt is now maintained by use of the relationship between voltage phenomena in superconducting tunnel junctions and electromagnetic frequencies, the proportionality factor involving the fundamental constant,  $2e/h$ . The definition of the candela involves the fundamental constant relating temperature and the emission of radiant energy.

The fundamental constants are often used to calculate desired quantities from measurements actually made of some other quantities. This is particularly true in the case of length, where the speed of light is often used to convert time interval measurements into length measurements. Examples include laser ranging of the moon and terrestrial surveying, radar and radionavigation systems.



Similarly, the most precise method of realizing a known force consists of utilizing the action of the terrestrial gravitational field on a known mass. This requires precise knowledge of the local acceleration of gravity, determined in an absolute manner by means of measurements of length and time. The fundamental Newtonian gravitational constant enters into determinations by earth scientists of the mass, mean density, and mass distribution of the earth.

As our measurement capabilities evolve, it is becoming apparent that it may become desirable to define certain fundamental constants as fixed numbers relating what were previously independent units. In particular, it is becoming technically feasible to define the speed of light as an arbitrary number (in the last several decimal places), so that one standard could serve as either the time standard or the length standard, with the relation between time and length being the defined constant  $c$ . Doing so could allow the limitations in convenience, stability, precision, and accuracy of the present Krypton length standard to be avoided, and could eliminate some current aspects of confusion in relating length measurements based on the transit time of light and those based on the wavelength of specific spectroscopic lines.

It is possible to determine certain fundamental constants by basically independent and different measurement paths, involving substantially different combinations of measurement units. Intercomparison of the resulting independent values can provide insight not only into the precision with which the constants themselves are known, but also into the consistency and accuracy of realization of the different measurement units.

Precision determination of the fundamental constants often requires close access to the national measurement reference standards. As a result, the national reference standards laboratories, such as NBS, often can play a unique role in this field of science: as custodians of national measurement standards, they can perform experiments in this field that are not practical in other laboratories, and, indeed, performance of such scientific research is one of the obligations that these laboratories have to the world of science.

The forcing-factor effect of this kind of research often leads to improvements in measurement methods that can then be applied quite widely. A current NBS example involves the improvement of silicon density standards in order to allow a higher precision determination of Avogadro's number. These silicon

density standards appear adequate to meet all foreseeable density standard needs for years to come, and represent a solution to the long-standing inadequacies associated with the use of water for this purpose (inadequacies due in large part to the basic variability in the isotopic composition of water).

The fundamental constants thus play a subtle but key role in the measurement system. They enter into the definition of the basic conceptual system, they are of substantial importance in the realization of measurement capabilities, and as one of the most demanding areas of scientific measurement, they are a driving force for advances in the state of the measurement art. In principle, an additional structural element could be added to figure 3, labelled fundamental constants. For present purposes, however, it seems adequate simply to handle them as part of the central scientific portion of the system.

## 2.2.7 Science and People

The central core of the measurement system consists of knowledge or science and of the people who employ it. In newly developing or simple measurement areas, this element often suffices to hold the system together quite adequately, without the need for any formal technical or institutional infrastructures.

The necessary structural elements of this portion of the system are substantially the same in kind as for any technical field. Publication mechanisms are needed to record and disseminate knowledge. Academic education and training are necessary. Professional societies support these activities. The only structural element that may be somewhat unexpected is the heavy education and training role played by the instrumentation industry in connection with its sales efforts; for many aspects of the measurement system, the primary burden of providing such education and training as does exist, is borne by the instrumentation industry.

Historically, metrology and mathematics (and logic) developed in parallel to meet basic human needs. Civil engineering came into existence for similar reasons, and was inseparably connected with applied mathematics and metrology. Mathematical, metrological, engineering, and craftsmanship capabilities interacted with each other through the ages, each enhancing the others. The rise of experimental science at the end of the Middle Ages drew upon them heavily. The development of experimental science and the new fields of engineering became the driving force for the

evolution of metrology from its ancient weights-and-measures-and-clocks role into a comprehensive ability to characterize quantitatively the physical world around us.

Today, metrology, science, engineering, and technology form a highly interdependent knowledge complex. Advances on the frontiers of science result from or depend upon advances in measurement capabilities. Advances in measurement capabilities result from exploitation of advances in science, engineering, and technology.

Among recent developments in science and technology that are of major importance in metrology are the following:

(1) The development of nuclear transmutation and isotope separation technology during World War II allowed the production of the isotopically pure electrical discharge light sources that have allowed the redefinition of the meter from being based on a physical artifact to being based on a wavelength of light.

(2) The development of microwave technology during World War II led to the development of microwave resonance techniques that have led to the definition of the second in terms of an atomic transition. Furthermore, unlike the case of length measurements for which the absolute atomic definition of the meter is physically realized in only a very few laboratories around the world, atomic clocks and frequency standards are eminently practical devices in wide use.

(3) The development of computer technology based on semiconductor phenomena is allowing man to be replaced as a vital link in the measurement observation and calculation process. It is making possible measurement capabilities that man could never achieve with his unaided observational and calculational powers.

(4) The laser is profoundly changing the physical basis for many measurements. Laser ranging on retroreflectors placed on the moon is allowing experimental determination of the drift of the continents. Laser and computer controlled machine tools are drastically changing the field of precision machining. Capabilities in precision spectroscopy have been increased by orders of magnitude.

(5) The superconducting tunnel junction ("Josephson junction") is providing links between frequency measurements and other basic phenomena, which suggests that some day frequency may be the only basic measurement pa-

rameter. Today, the U.S. national legal voltage standard is based upon the Josephson effect. Temperature can be determined and controlled in a similar manner. Length can already be defined more precisely through the speed of light in terms of the time or frequency standard, than it can be defined directly. There is promise that mass and the mole can be related to length by definition of the kilogram in terms of the number of atoms of silicon contained in a given volume of a highly perfect crystal of semiconductor grade silicon. Luminous intensity is currently based on length and temperature measurements.

Today, every scientific, technical, engineering, or trade society or association has an interest in the quantities, units, and methods of measurement. A number of professional societies and trade associations exist directly as part of and in support of the measurement system; among them are:

- American Society for Quality Control
- American Watchmakers Institute
- American Watch Workers Union
- Gasoline Pump Manufacturers Association
- Instrument Society of America
- Metric Association, Inc.
- National Conference on Weights and Measures
- National Conference of Standards Laboratories
- National Committee on Radiation Protection and Measurement
- Precision Measurements Association
- Scale Manufacturers Association
- Scientific Apparatus Makers Association

The measurement system is critically dependent upon the adequacy of the knowledge possessed by those making the measurements. As a result of this dependence, much negative leverage potential exists in the system; lack of knowledge leads to poor measurements *plus* lack of awareness of their poor quality. The poor measurement data can result in misinformation, erroneous conclusions, and mistaken actions.

The educational system in the field of measurements consists of a widely diffused collection of coincidental efforts plus a very small number of focussed programs. In elementary education, measurement skills are taught as a coincidental adjunct of the teaching of science. Metrology as such, is taught in only a very few formally defined programs in this country.



## 2.3 Realized Measurement Capabilities

The pivotal level in the whole measurement system is that of realized measurement capabilities [19,20,22,24-27,33,36,37,41,51,66,67,72,86,94,119,140]. The capabilities of end users and of the dissemination and enforcement network institutions rest upon, exploit, and apply a specific, achieved, limited, measurement capability. Inversely, the conceptual and technical infrastructural levels have meaning only as they lead to an actual capability to measure, and as one moves from the basic conceptual and technical levels out into the field of making useful measurements, limitations in measurement capabilities steadily increase.

The primary limitations of measurement capabilities can be stated in terms of the ranges over which a parameter can be measured; of precision or repeatability of a measurement; of accuracy of measurement, the degree of agreement with a theoretical "absolute" truth; of environmental sensitivity of all of the above, with special emphasis on adverse conditions; and of cost, of the equipment or measurement, in money and in time.

The vastness of this subject--given the large number of measurement quantities studied and the fact that many discussions of it have been published by NBS and others in the past--renders it unprofitable to attempt any extensive summary of realized measurement capabilities in this report. Table 7 is presented to give an indication of the best that can be done in fields of measurement of interest now. Achieved measurement precisions and accuracies range from a few parts in  $10^{13}$  for time and frequency to approximately one percent in such fields as radiometry and photometry.

## 2.4 Institutional Infrastructure

The institutions (organizations) that currently play a major role in the national measurement system are the documentary standardization institutions and the instrumentation industry in support of the technical infrastructure, the central measurement standards authorities in support of all aspects of the system, the state and local offices of weights and measures in the enforcement of honest weights and measures in commercial transactions, the standards and testing laboratories and services in dissemination of industrial technological measurement capabilities, and the technical regulatory agencies in connection with regulations requiring measurements for their establishment and enforcement.

## 2.4.1 Standardization Institutions

Standardization institutions operate at the international, national, industrial, technical, company, and local governmental levels. With few exceptions, these organizations in the United States are non-governmental, and the standards issued are used voluntarily by industry and government [88, 99,109,121,128,129,291,308].

The main international body in the area of industrial and commercial standards is the (non-treaty) *International Organization for Standardization* (ISO) whose main function is to develop international cooperation in standardization activities. ISO is comprised of national standardization bodies from 69 countries. Its prime objective is to promote the development of world-wide standards with a view of facilitating international exchange of goods and services. From the work of thousands of technical experts around the world emerge the ISO Recommendations, which serve to promote freer international trade by helping to reduce the differences between various national standards. IEC, the *International Electrotechnical Commission*, became affiliated with ISO in 1947 and today has 41 member countries.

There are also regional organizations. The Pan American Standards Commission (COPANT) operates in the Western Hemisphere. The International Commission on Rules for 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.

In the field of metrology, the *General Conference of Weights and Measures* promotes international standardization of the scientific or basic technical aspects of the field, while the *International Organization for Legal Metrology* promotes standardization of the legal aspects of metrology--laws, instruments, procedures (see section 3).

At the national level, the United States has a single standards organization that coordinates the development and publication of industrial and commercial standards, known as the *American National Standards Institute* (ANSI). Its principal function is to act as a clearing-house to coordinate the work of standards development in the private sector, which is currently being carried on by some four hundred different organizations (see Appendix E). Through its procedures, timely development of standards is made possible, duplication and overlap are minimized and a

Table 7. Realized measurement capabilities.

Measurement Quantity	Estimated Accuracy (Parts per unit)	Measurement Quantity	Estimated Accuracy (Parts per unit)
Time and frequency:		Electricity	
NBS-5	$1-2 \times 10^{-13}$	DC voltage, NBS	$1 \times 10^{-7}$
Commercial Cs beam devices	$1 \times 10^{-11}$	RMS voltage, 10 kHz, NBS	$2 \times 10^{-5}$
Length:		Capacitance, NBS	$1 \times 10^{-7}$
Kr-86 lamp, NBS	$1-2 \times 10^{-9}$	Resistance, NBS	$8 \times 10^{-8}$
NBS end-std. calib.: 25 cm	$3 \times 10^{-7}$	Electromagnetics	
1 mm	$3 \times 10^{-3}$	Impedance	$1 \times 10^{-3}$ to $2 \times 10^{-1}$
Geodetic surveying	$1 \times 10^{-6}$	Attenuation	$10^{-2}$
Surface Finish:	2.5 nm	Phase delay	$5-10 \times 10^{-3}$
Mass:		Power	$1-10 \times 10^{-2}$
International comparisons	$2-3 \times 10^{-9}$	Voltage	$10^{-4}$ to $2 \times 10^{-1}$
Class M laboratory weights	$5 \times 10^{-6}$	Noise	$5-300 \times 10^{-2}$
Commercial test weights	$1 \times 10^{-4}$	Field Strength	$3-20 \times 10^{-2}$
Volume: Laboratory use	$5 \times 10^{-4}$	Medical Ultrasonics: power	$5 \times 10^{-2}$
Density: NBS	$5 \times 10^{-6}$	Acoustics:	
Force:		Sound pressure, NBS	$10^{-3}$
NBS deadweight standards,	$2 \times 10^{-5}$	Noise exposure, commercial	$3-30 \times 10^{-2}$
corrected for air buoyancy	$1 \times 10^{-5}$	Radiometry and photometry:	
Working calibration standards	$5 \times 10^{-5}$	NBS	$1-5 \times 10^{-2}$
Vibration: NBS	$1 \times 10^{-2}$	Field workers	$5-10 \times 10^{-2}$
Fluid Flow:		Spectrophotometry:	
Air flow, NBS	$1.5 \times 10^{-3}$	Transmittance, NBS	$3 \times 10^{-4}$
Pipelines, liquid and gas	$1-3 \times 10^{-2}$	Reflectance, NBS	$5 \times 10^{-3}$
Water, open conduits	$5 \times 10^{-2}$	Far ultraviolet radiometry:	
Pressure:		Detectors, NBS	$6-10 \times 10^{-2}$
NBS standards	$3-6 \times 10^{-5}$	Sources, NBS	$5-10 \times 10^{-2}$
Military maintenance stds.	$1 \times 10^{-4}$	Optics:	
Temperature:		Resolution limits	1000 lines per mm
Water triple point	$1 \times 10^{-6}$	Optical density	$5 \times 10^{-3}$
Commonly used sensors	$1 \times 10^{-5}$ to $5 \times 10^{-4}$	Lens diopters, NBS	$10^{-4}$
Humidity:		Lasers:	
NBS	$1 \times 10^{-3}$	Frequencies, NBS	$10^{-10}$ to $10^{-9}$
Commercial humidity meters	$1 \times 10^{-2}$	Power and energy, NBS	$1-7 \times 10^{-2}$
Moisture: In grain	up to $2 \times 10^{-1}$	Physical properties of atoms and molecules:	
Thermodynamic properties	$1 \times 10^{-4}$	Energy levels	$5 \times 10^{-12}$ to $1 \times 10^{-6}$
of fluids:	to $5 \times 10^{-3}$	Atomic hyperfine separation	$1 \times 10^{-13}$
Cryogenics:		Cross sections, electrons	$3-20 \times 10^{-2}$
Pressure transducers-	$5-10 \times 10^{-2}$	Cross sections, atoms/ions	$1-2 \times 10^{-1}$
commercial	$10^{-4}$ to $10^{-2}$	Oscillator strengths	$1-5 \times 10^{-2}$
Temperature--commercial	$10^{-4}$ to $10^{-3}$	Electron drift velocity	$5 \times 10^{-3}$
Flow--NBS research facility	$1 \times 10^{-3}$	Surface composition: 0.1% of an atomic layer	
		0.1 $\mu$ m lateral resolution	
		Ionizing radiation: NBS	$1-5 \times 10^{-2}$

neutral forum is provided to consider and identify the need for standards. Through its recognition by such international and non-treaty standardization bodies as ISO, IEC, and COPANT, as the National Standards body of the USA, ANSI serves as the focal point for organizing USA participation in international standardization.

Standards for materials are the province of American Society for Testing and Materials (ASTM). All ASTM technical committees are directed to submit all standards under their jurisdiction for adoption by the American National Standards Institute as national standards.

A major example of industry standards becoming international standards is found in those of the American Petroleum Institute, API [298]. The principal activities of this Institute are simplification, standardization and improvement of equipment and methods used by the petroleum industry. As a result of the work of API, the American petroleum industry standards have become world-wide standards. As part of this API standardization system, NBS maintains the API Grand Master Gages against which essentially all hardware unique to this industry is ultimately checked, world-wide.

The Federal Government is also a major contributor of standards and specifications. Its specifications for purchasing are only

mandatory for the federal government, but many, such as military specs, are adapted for industrial use.

The Department of Defense's (DOD) "Defense Standardization Program" provides uniform definitions of the technical requirements for parts, equipment, and systems in which the various elements of the DOD have a common interest. The principal product of this program has been the development of nearly 40,000 specifications and standards defining the technical requirements of the DOD. It couples the enormous Defense Department budget, approximately 100 billion dollars, directly to the National Measurement System, since it requires that the length, density, capacity, electrical values, and other physical properties of every item be traceable to the national artifacts at NBS via industry's quality control system.

The General Services Administration [280] issues five types of Federal Standards for items employed by the Federal Government:

- 1) Supply Standards
- 2) Test Method Standards
- 3) Material Standards
- 4) Engineering Standards
- 5) Procedural Standards.

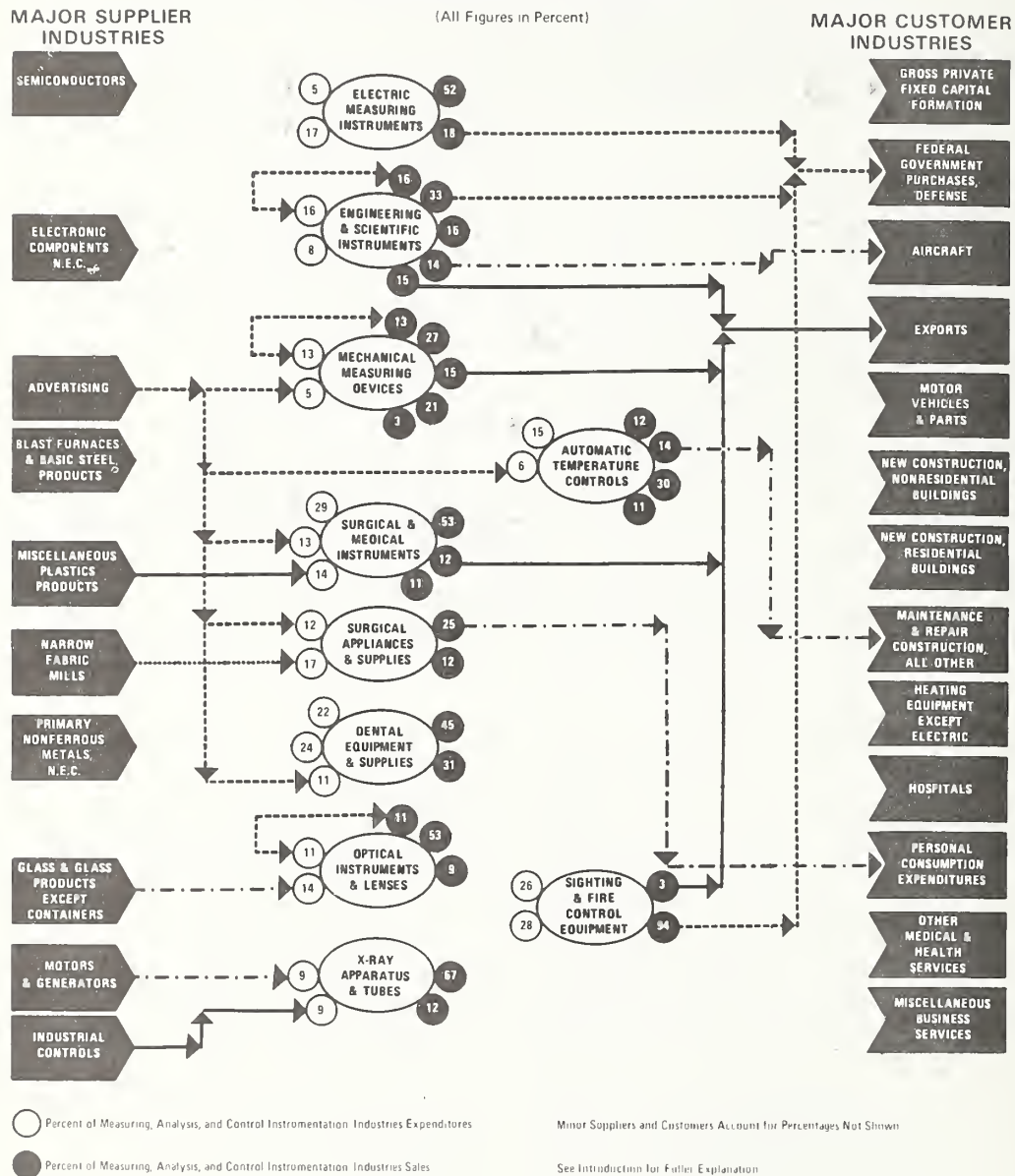
The National Bureau of Standards has long been interested in promoting documentary standardization as well as uniform physical measurements. Its role has been that of a central catalytic agent and monitor of the standardization efforts of the nation.



Figure 16. Location of measurement and control instrumentation companies.



## MEASURING, ANALYSIS AND CONTROL INSTRUMENTATION INDUSTRIES EXPENDITURES AND SALES



U.S. Bureau of Economic Analysis, Bureau of Domestic Commerce

Figure 17. Measuring, analysis and control instrumentation industries expenditures and sales [237].



## 2.4.2 The Instrumentation Industry

The product scope of the instrumentation industry has been discussed in section 2.2.2 and summarized in table 3. The number of companies in this industry is large. Over 4000 companies (or divisions or subsidiaries of large corporations) are known to NBS as sources of measurement instruments. The geographical distribution of these organizations is shown in figure 16.

Most of these companies are small. Some are corporate giants. There appears at least in a preliminary look at the industry to be less economic concentration in it than in any other high technology field. This appears to be due to the wide variety of instruments needed and the multitude of highly specialized economic niches available for small, competent companies. Indeed, some of the leading organizations in precision measurement instrumentation are small businesses by current industrial standards.

A study in some depth of this industry is currently in progress as part of the continuing study by NBS of the national measurement system; this study is the source of table 3 [328]. Data from another Department of Commerce look at this industry [237] are shown in figures 17-18 and tables 8-11.

## 2.4.3 State and Local Offices of Weights and Measures

The legal responsibilities for enforcement of justice in the use of weights and measures in our domestic commercial marketplaces lie with the state and local offices of weights and measures (see figure 19) [13,28,46,119,202-4,212,284]. These agencies

combine a basic technical capability, a regulatory function, and a police investigative and citation authority.

The National Conference of Weights and Measures is the central coordinating body for the operating agencies in this field. Its paid staff and executive secretariat are provided by the NBS Office of Weights and Measures. The mission of this conference is quoted in the box on this page [202]. A prime function of this organization is the promotion of a uniform set of weights and measures laws in this country. The vehicle in which the model code is embodied is NBS Handbook 44 [119] (see table 12). The current working interests of the Conference and its members can be seen by consideration of the conference titles covered during six recent years (table 13).

Historically, weights and measures officials acted as "sealers" who put their seal of approval for accuracy on the length, weight, and volume measures used in commercial transactions. As the evolution of science and technology increased the scope of the substances involved in commercial transactions, such as through the provision of water, gas and electricity by the public utilities, the scope of the weights and measures official also increased.

Weights and measures officials also have historically been involved in matters of taxation. The most obvious point of contact has been in the customhouse at a port of entry for imported goods. Customs duties based on the amount of goods imported require measurement of those goods. Inconsistencies among customhouses and lack of agreement between

### The Mission of The National Conference on Weights and Measures is

- (a) to provide a national forum for the discussion of all questions related to weights and measures administration as carried on by regulatory officers of the States, Commonwealths, Territories, and Possessions of the United States, their political subdivisions, and the District of Columbia;
- (b) to develop a consensus on model weights and measures laws and regulations, specifications, and tolerances for commercially-used weighing and measuring devices, and testing, enforcement, and administrative procedures;
- (c) to encourage and promote uniformity of requirements and methods among weights and measures jurisdictions; and
- (d) to foster cooperation among weights and measures officers themselves and between them and all of the many manufacturing, industrial, business, and consumer interests affected by their official activities.

Table 8. 1974 Profile, instruments for measurement, analysis and control [237]

SIC Codes-----	3811	3821	3822	3825	3832
Value of industry shipments (\$ million)-----	1,391	2,060	880	2,204	800
Number of establishments-----	721	817	129	622	482
Total employment (000)-----	43	72	44	70	25
Exports as a percent of product shipments-----	17	35.5	5.4	21.9	17.2
Imports as a percent of apparent consumption-----	4.4	6.4	n.a.	9.3	21.8
Compound annual average rate of growth 1967-74 (percent):					
Value of product shipments (current dollars)-----	4.8	4.8	6.0	8.1	6.1
Value of exports (current dollars)-----	4.2	12.7	8.1	14.4	22.0
Value of imports (current dollars)-----	12.2	25	n.a.	20.2	19.8
Employment-----	-1.0	1.3	1.4	1.7	0

Table 9. Instruments for measurement, analysis and control: projections 1974-80<sup>1</sup>  
(value of shipments in millions of dollars) [237]

SIC Code	Industry	1974	Percent Increase 1973-74	1980	Percent Increase 1974-80 <sup>2</sup>
3811	Engineering and Scientific Instruments-----	1,391	13	2,500	10.3
3823,24,29	Measuring and Controlling Instruments--	2,060	11	3,400	8.7
3822	Automatic Environmental Controls-----	880	5	1,500	9.3
3825	Instruments to Measure Electricity-----	2,204	20	5,000	14.6
3832	Optical Instruments and Lenses-----	800	23	1,500	11.0

Table 10. Medical and dental instruments and supplies: projections 1974-80<sup>1</sup>  
(value of shipments in millions of dollars) [237]

SIC Code	Industry	1974	Percent Increase 1973-74	1980	Percent Increase 1974-80 <sup>2</sup>
	Value of industry shipments--total-----	3,960	11	6,880	9.6
3693	X-ray apparatus and tubes-----	550	13	1,060	11.6
3841	Surgical and medical instruments-----	1,145	12	2,045	10.0
3842	Surgical appliances and supplies-----	1,760	10	2,840	8.3
3843	Dental equipment and supplies-----	505	12	935	12.8

<sup>1</sup>Estimated by Bureau of Domestic Commerce. <sup>2</sup>Compound annual rate of growth. n.a. = not available

Table 11. 1974 Profile -- X-ray apparatus and tubes [237]

SIC Code -----	3693
Value of industry shipments (\$M) -----	550
Number of establishments -----	98
Total employment (thousands)-----	13
Exports as a percent of product shipments -----	32.3
Imports as a percent of apparent consumption -----	24.6
Compound annual average rate of growth 1967-74 (percent):	
Value of product shipments (current dollars)-----	13.2
Value of exports (current dollars)-----	19.9
Value of imports (current dollars)-----	25.0
Employment-----	6.0
Major producing areas -----	North Central Region

**Instruments show variable trends**

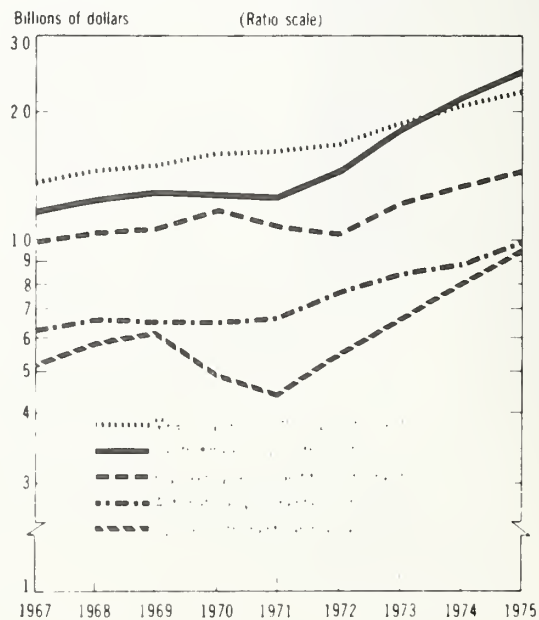


Figure 18. Instruments show variable trends. [237]

merchant and customs officials cause frictions. Indeed, it was such problems that stimulated the earliest systematic look in the United States at the National Measurement System and the first steps to correct the obvious deficiencies [1,2].

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Table 12. Outline of Contents of NBS Handbook 44, U.S. Specifications, Tolerances, and Other Technical Requirements for Commercial Weighing and Measuring Devices [119]

Introduction:

1. Source
2. Purpose
3. Handbook Amendments
4. Replacement Sheets
5. System of Paragraph Designation
6. Classification of Requirements
7. Using the Handbook

Fundamental Considerations:

1. Uniformity of Requirements
2. Tolerances for Commercial Equipment
3. Testing Apparatus
4. Inspection of Commercial Equipment
5. Correction of Commercial Equipment
6. Rejection of Commercial Equipment
7. Tagging of Equipment
8. Records of Equipment
9. Sealing of Equipment
10. Rounding Off Numerical Values

Individual Codes:

- General
- Scales
- Belt-Conveyor Scales
- Weights
- Liquid-Measuring Devices
- Vehicle-Tank Meters
- Liquified Petroleum Gas Liquid-Measuring Devices
- Liquified Petroleum Gas Vapor-Measuring Devices
- Cryogenic Liquid-Measuring Devices
- Liquid Measures
- Vehicle Tanks Used as Measures
- Farm Milk Tanks
- Measure-Containers
- Milk Bottles
- Graduates
- Linear Measures
- Fabric-Measuring Devices
- Wire and Cordage-Measuring Devices
- Taximeters
- Odometers
- Timing Devices
- Dry Measures
- Berry Baskets and Boxes

Appendix:

- General Tables of Weights and Measures

Today, with the prevalence of the sales tax for many commercial transactions, the adequacy of measurements for tax purposes covers many commodities undreamed of two hundred years ago. Equity in taxation, rather than equity in trade, has in some cases been the primary stimulus for expansion of the weights and measures enforcement aspect of the National Measurement System, and has even been a primary driving force for substantial innovations in metrology at the National Bureau of Standards. The story of cryogenic flow-metering of liquid nitrogen is an outstanding example [269].

-----

Table 13. National Conference on Weights and Measures--Titles of non-routine sessions, 1970-75 [96,126,145,211,253,292]

- 1975: New Measurement Partnerships & Opportunities Meeting with Consumers National & International Standards
- 1974: Metric Conversion Metric Plans, Programs and Problems Net Weight--Policy and Procedures
- 1973: Measures for Progress Universal Product Code in the Grocery Industry Digital Designs in Weighing Systems Dynamic Weighing in the Railroad Industry Gasoline Measurement and Marketing Weighting on the Mail Net Quantity--Direction and Determinations Management Assistance for Weights and Measures Progress New Approach in Weights and Measures Operations: Pilot Program and Development of Dallas Department of Consumer Affairs Consumer Protection in Minnesota
- 1972: Forum on Liaison for the Benefit of Clients and Consumers Forum on Managing to Keep Pace with the Consumer Movement Forum on Consumer Concerns in the Marketplace Forum on Technological Developments to Aid Consumers
- 1971: Forum on Management Forum on Merchandising Forum on Measurement
- 1970: Forum on Packaging and Labelling Forum on Weighing Technology Forum on Measuring Technology Forum on Organization and Management



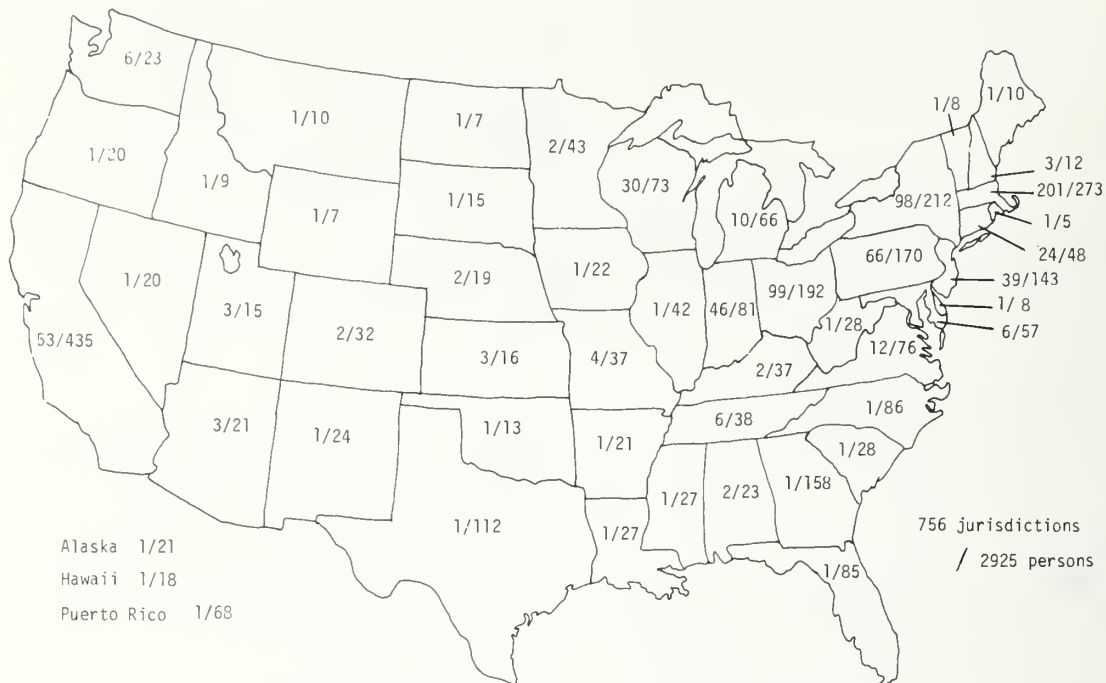


Figure 19. Location of weights and measures governmental jurisdictions and personnel [212,284]

#### WHAT IS NCSL?

NCSL is a continuing, nonprofit laboratory-oriented organization to promote cooperative efforts toward solving the common problems faced by standards laboratories in their organization and operation. It was established in 1961 under the sponsorship of the National Bureau of Standards. Its membership consists of academic, scientific, industrial, commercial, or governmental laboratories concerned with the measurement of physical quantities, the calibration of standards and instruments, and the development of standards of practice. It provides liaison with technical societies, trade associations and educational institutions interested in these activities.

NCSL pursues its goals through joint voluntary action in:

1. Holding conferences, workshops, seminars, and meetings for presentation of papers and discussions pertaining to technical and managerial problems, operating practices, and policies for standards laboratories.
2. Collecting and disseminating information about current practices for the organization, operation, and evaluation of measurement standards and calibration laboratories.
3. Preparing and disseminating source material and recommendations for preferred technical procedures and operating practices.
4. Providing a medium of interchange of information relative to deficiencies or advances in calibration techniques and laboratory instrumentation.
5. Collecting, analyzing, and disseminating pertinent statistical information related to the scope, growth trends, operation, and management of measurement standards and calibration activities.
6. Assisting measurement standards and calibration laboratories in arranging measurement agreement audits.

State weights and measures officials have been expanding their scope in other respects, also. One of these is a simple extension of their historical role, in the field of pre-packaged goods. By providing an *official, legal, accepted* weights and measures quality control function to local manufacturers, as for instance to a local brewer, or to a candy bar manufacturer, these manufacturers can gain nation-wide acceptance of their products as containing true weight or volume, so that their products do not have to undergo weights and measures inspections in every state or every local jurisdiction. The economic benefits to the consumer, to the manufacturer (every sample taken for weights and measures inspection costs him money), and to the taxpayers in all of the states, are obvious.

The most notable example of expansion of scope is into the broad areas of consumer protection. The weights and measures field is one in which governments have always acknowledged their consumer protection responsibilities, at least in theory, although often not too effectively in practice. With the recent surge in governmental activity in consumer protections, weights and measures offices both have expanded their concept of their traditional role, and have formed the nuclei of new departments of consumer protection. Creation of the Dallas Department of Consumer Affairs is a striking example [211]. All parties involved appear to have benefitted (except those merchants perhaps intent upon defrauding the public): the consumer, the honest merchant and manufacturer, the city administration, the consumer protection interests, the weights and measures

staff, weights and measures enforcement *per se*, and the taxpayer, since the case is persuasive that he is getting more for his tax dollar after this expansion in scope than before.

Appendix F contains excerpts from recent annual reports by weights and measures officials, selected to give the flavor of the full scope of their activities today.

#### 2.4.4 Standards and Testing Laboratories and Services

Standards and testing laboratories and services provide physical standardization services to specific portions of the National Measurement System. Standards or calibration laboratories are a specialized type of testing laboratory, which tests measurement equipment and renders reports on its functioning (calibration reports); they may also undertake preventive or restorative maintenance [19, 49,75,140,223-4,277,293,309]. Testing laboratories *per se* are sources of final end-use measurement data on the items that they test. There is a third distinct category of institution here, that can be described as a *standards service* prototypes for this category are the service organizations that keep the clocks at airport terminals showing the right time [177].

The National Conference of Standards Laboratories (NCSL) is the central organization in the standards lab field [277,309]. Its mission is described in the box on page 32. NBS provides the central secretariat for this organization. Figure 20 shows the locations of NCSL members.



Figure 20. Location of members of National Conference of Standards Laboratories.

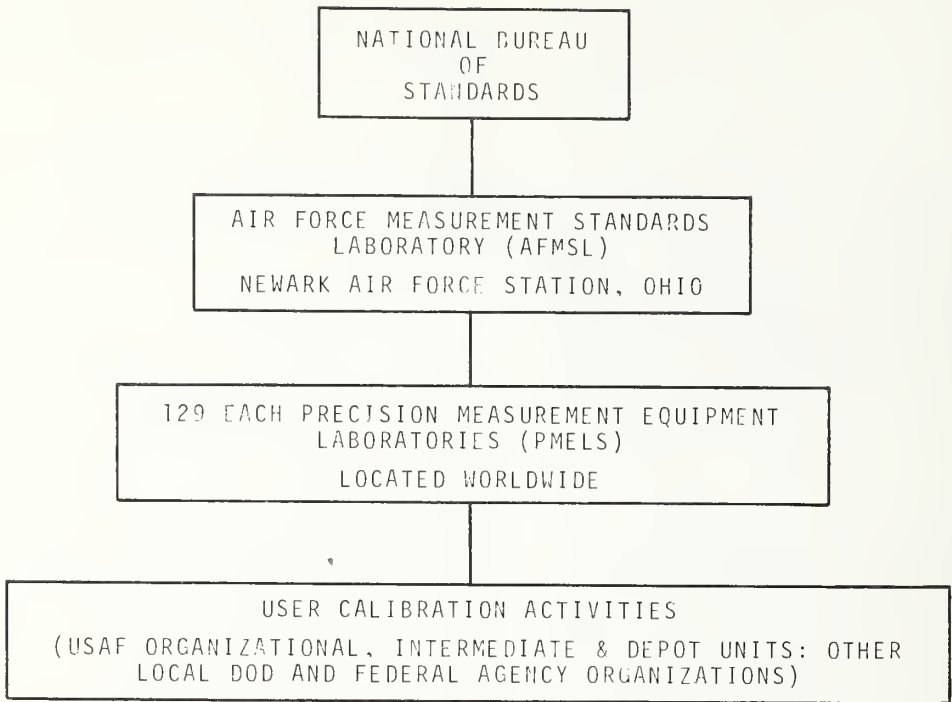


Figure 21. Air Force measurements standards system.

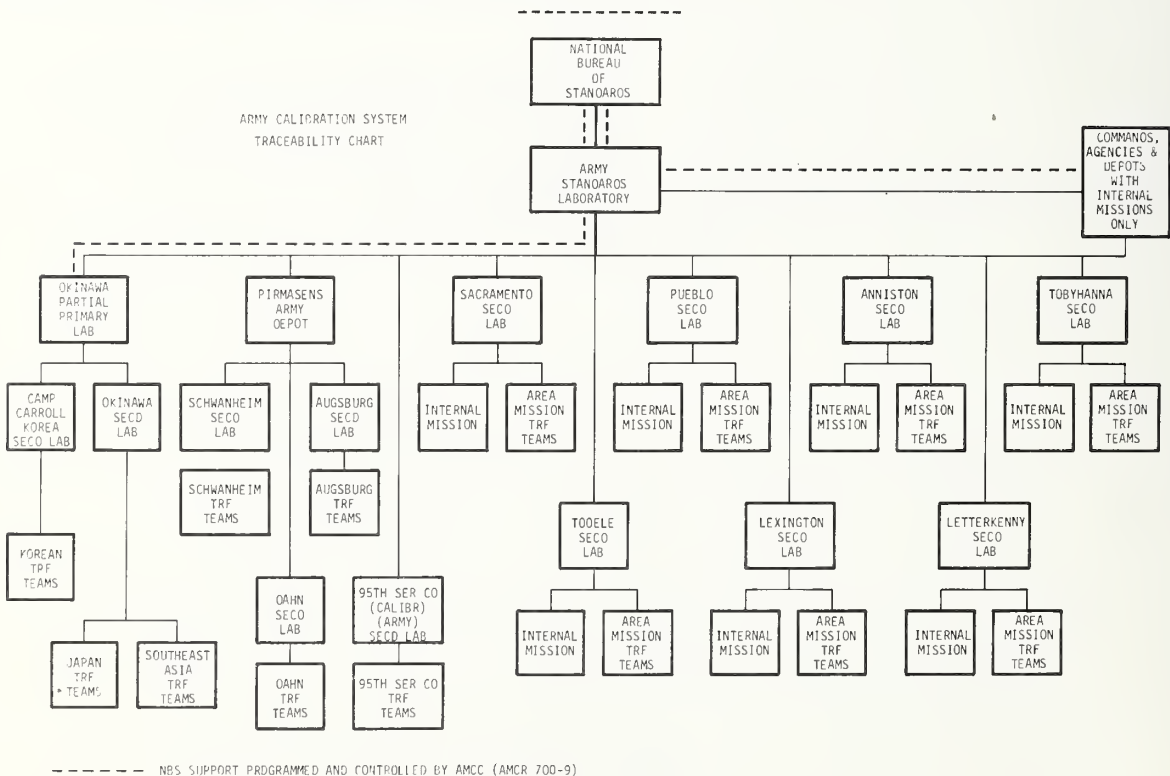


Figure 22. Army calibration system traceability chart.



The most highly developed standards laboratory networks are in the Department of Defense (DOD). These laboratories are arranged in a formal hierarchy, with the National Bureau of Standards being the topmost unit in the DOD hierarchical chain. The structures for the three armed services and the Energy Research and Development Agency (ERDA) are shown in figures 21-24. In the case of ERDA, most or all of the member laboratories are run by private contractors.

The procurement specifications of the Department of Defense require that all comparisons of equipment construction and performance with the specifications be based upon measurements "traceable" to the National Bureau of Standards. As a result, the aerospace and ordnance companies typically have well established standards laboratories that are fully equivalent to those in the military itself. A number of these organizations are of a very high professional caliber, able at least in limited areas, to match NBS fully in applied metrological science.

The major instrumentation companies have highly qualified standards laboratories, as an intrinsic requirement for doing business. A number of independent standards labs also exist, providing service to all comers for a fee. High-technology companies, particularly in communications and electronics, tend to have standards laboratories. However, a significant number of these laboratories are associated with educational institutions and some of the older industrial technologies. Appendix G contains a summary of the known standards laboratories as recognized by NCSL and a check-list description of their capabilities.

Historically, the standards laboratories have operated completely independently of the state and local offices of weights and measures. However, in some states, notably California, recognition is developing of the existence of a state measurement system that includes many governmental interests in addition to those of the traditional weights and measures field, such as in the areas of health and safety associated with nuclear power plants, medicine, and occupational hazards. Recognition is developing that the standards laboratories within the state can play a significant role as part of the *state* measurement systems. Needed talents often already exist, and do not have to be created anew.

Another trend that will increasingly affect the organizations working in this field is that toward establishment of formal laboratory accreditation systems. The Department of

Commerce has recently instituted a National Voluntary Laboratory Accreditation Program, in response to pressures both domestic and international in origin [283,308,310,311]. One manifestation of the domestic pressures has been repeated proposals in Congress of legislation to establish compulsory laboratory accreditation programs. The basic phenomenon at work is the growing feeling that neither our national interests nor those of international trade can tolerate continuation of the current state of affairs in which there is no reliable way to ascertain the degree of reliability of measurement, calibration, or test data generated by calibration and testing laboratories. As discussed below in section 4.2, the increasing complexity and degree of integration of human society, both nationally and internationally, means that confusion is becoming increasingly intolerable regarding the validity of the basic measurement data about the physical universe which is needed to allow our industrial society to function. Some sort of laboratory accreditation system appears to be one unavoidable answer to these concerns.

#### 2.4.5 Regulatory Agencies

With the development of modern technology and the increase in the complexity of society, more and more regulatory roles have been assumed by the formal governmental structure. The Interstate Commerce Commission (established in 1887) represented the first major move in the U.S. to regulate through governmental action a natural monopoly, run by the private sector, based on innovations in technology. The Food and Drug Administration (established in 1907) extended the concept of governmental regulation to include formal protection of the interests of the public and consumers from the pressures of a *caveat emptor* and *laissez faire* marketplace. Actions during the 1960's extended the Federal government regulatory role in areas such as the protection of the environment and of workers from occupational hazards.

Table 14 lists many of the Federal regulatory agencies, aside from those of a purely financial or traditional law-enforcement nature. Some, such as the Food and Drug Administration, the Environmental Protection Agency, and the Nuclear Regulatory Commission, work in highly technical fields and need a particularly high level of both general technical and measurement competence. All of them, from time to time, require significant precision in difficult measurements to do their jobs.

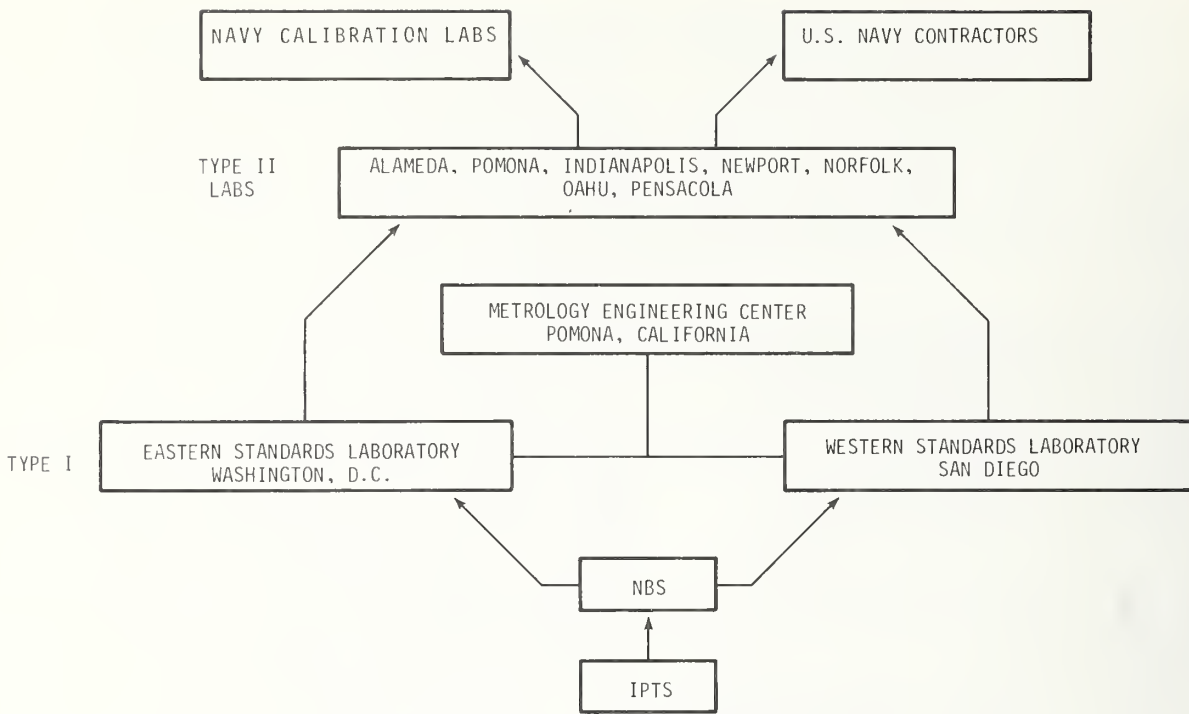


Figure 23. United States Navy temperature calibration chain.

## NATIONAL MEASUREMENT SYSTEM SUBSYSTEM

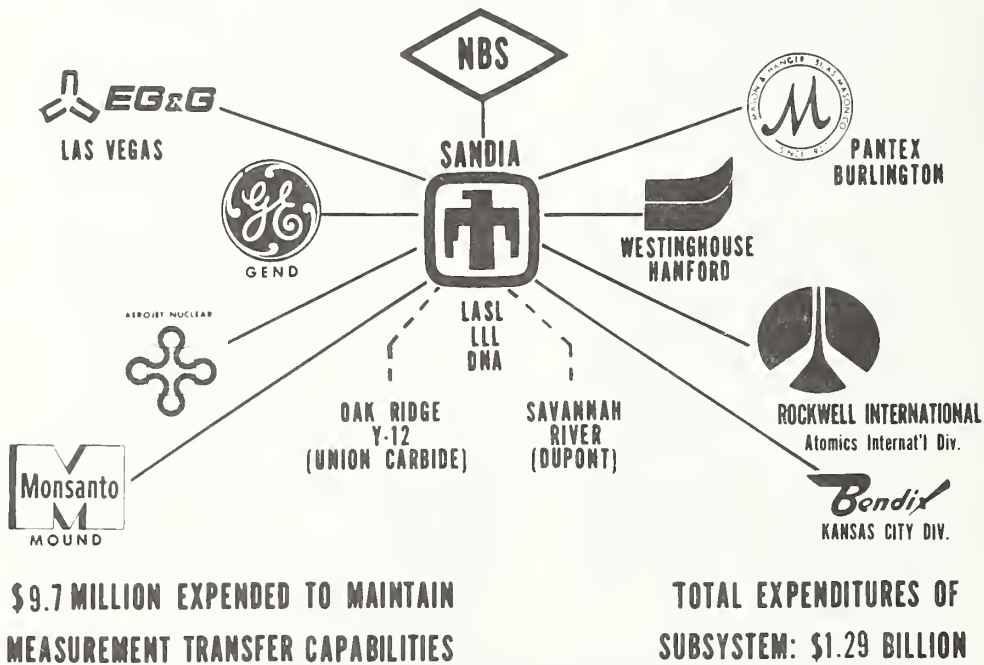


Figure 24. Energy Research and Development Administration National Measurement System Subsystem.

Table 14. Federal regulatory agencies.

Bureau of Alcohol, Tobacco, and Firearms  
Civil Aeronautics Board  
Coast Guard  
Consumer Product Safety Commission  
Environmental Protection Administration  
Federal Aviation Administration  
Federal Communications Commission  
Federal Power Commission  
Federal Trade Commission  
Food and Drug Administration  
Interstate Commerce Commission  
Mining Enforcement and Safety Administration  
National Highway Traffic Safety Admin.  
Nuclear Regulatory Commission  
Occupational Safety and Health Admin.  
Securities and Exchange Commission

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Actions of the regulatory agencies have a major impact on the measurement system, since *promulgation* of regulations requires a measurement capability that allows the necessary knowledge to be obtained and sound decisions to be made in such areas as the feasibility of enforcement; *enforcement* by the regulator requires comparison of actual conditions with the prescriptions of the regulations, and this often requires measurement; *compliance* by the regulatee similarly requires an ability to measure; and *adjudication* requires measurements that will stand up in court.

#### 2.4.6 The National Bureau of Standards

The National Bureau of Standards is the primary authoritative central measurement standards institution in the United States [13,38,46,52,80,81,94,115-6,127,132,217,242,261,273,286,288,289]. However, our ultimate central standards authority, both by treaty and by domestic decision, is a supranational organization, the International Bureau of Weights and Measures (BIPM from the initials of its French name) [250] (see section 4.).

Domestically, only three other organizations today have a significant national measurements standards role in the areas of physical measurement covered by the current study: The U.S. Naval Observatory is responsible for establishing astronomical time of day [294]. The Geological Survey provides a central calibration service for aerial cameras [301]. The Coast Guard is effectively the central measurements standards authority with respect to tankships for liquified natural gas [269].

#### 2.4.6.1 The Present--Scope of NBS Services

The National Bureau of Standards provides:

- (1) The central basis for the U.S. National Measurement System, for physical, material, and technological measurements, and coordination of that system with those existing internationally.
- (2) Standards for Federal use and involvement with computer science and technology.
- (3) Technological innovation in selected fields (e.g., building technology, electronics and cryogenics).
- (4) Direct technical assistance to other agencies, public and private.
- (5) Technical (especially measurement) responsiveness to national needs (e.g., fire safety, general public health and safety, environmental quality, energy, national defense).
- (6) Scientific leadership in mission-related areas.
- (7) Reimbursable measurement services (e.g., calibrations, measurement assurance programs, consulting).
- (8) Technical data, including standard reference data.
- (9) Standard reference materials.
- (10) Coordination of and support to measurement-related or standardization activities at the state and local levels or in the private sectors, or in the developing countries (working with other Federal government agencies).
- (11) Technical information services, including education and general consultation and advice.

Item (1), of course, pervades this whole report. Items (2) and (3) go beyond its scope. Other items need further discussion at this point.

##### A. Measurement Services

The most basic and indispensable services that the National Bureau of Standards provides to the National Measurement System are the calibration and related measurement services that provide to the system access to the national standards of physical measurement. These services are described in a "catalog", NBS Special Publication 250, "Calibration and Test Services of the National Bureau of Standards" [94]. Briefly, they can be summarized here as:

Calibration services  
Measurement Assurance Program  
Consultation and advice  
Other



NBS has established reference standards not only for the SI base units but also for many derived quantities and their multiples and submultiples (see Appendix C). Such reference standards, or equivalent working standards, are used to calibrate laboratory and plant standards for other organizations. Accuracy is maintained by stability checks, by comparison with the standards of other national and international laboratories, and by exploration of alternative techniques as a means of reducing possible systematic error.

Calibrations by NBS in its laboratories for many types of instruments and ranges of physical quantities are described in the itemized service schedules of Special Publication 250 [271] (see Appendix H, NBS Calibration Activity Summary). Upon request, special measurements not listed in SP 250 may be made. These might involve unusual physical quantities, upper or lower extremes of range, higher levels of accuracy, fast response speeds, short durations, broader ranges of associated parameters, or special environmental conditions.

Measurement assurance programs are oriented toward calibration of a client's complete measurement system, not simply the calibration of a particular instrument or standard [130]. Typically, such a program involves provision to the *client* of an "unknown" check standard, which the client then proceeds to calibrate, using *his* equipment and personnel. By analysis of the data generated during such processes, NBS can provide the client information regarding the performance of his total measurement system for the measurement quantity involved.

In a similar program NBS assists in the evaluation of state and local weights and measures laboratories.

In areas of its special competence, NBS offers consulting and advisory services on various problems related to measurement, e.g., details of design and construction, operational aspects, unusual or extreme conditions, methods of statistical control of the measurement process, automated acquisition of laboratory data, and data reduction and analysis by computer. Suggestions will be offered on measurement techniques and on other sources of assistance on calibration or measurement problems when the Bureau's own equipment and personnel are unable to undertake requested work.

Other services include:

(1) Tests of measuring instruments to determine compliance with specifications or claims when the evaluation is critical in

national scientific or technical operations and when suitable facilities are not available elsewhere.

(2) Referee tests in important cases when clients are unable to agree upon the method of measurement, the results of tests, or the interpretation of these results.

(3) Educational courses and seminars. To enhance the competence of standards laboratory personnel, NBS at irregular intervals conducts several group seminars on the precision measurement of specific types of physical quantities. Training is provided for weights and measures personnel in the states.

(4) Standard time and frequency broadcasts.

## B. Technical data

Ready-made, usable measurement results constitute the second most vital channel of support to the physical measurement system, and a vital mode of support for the whole range of science and technology in this country.

The objective of the National Standard Reference Data System is to provide a base of reliable data on physical and chemical properties required in industry, universities, and government R and D institutions [50,84]. The program operates through a series of projects at NBS and elsewhere in which data are retrieved from the world literature, evaluated by experts, reconciled as necessary, and prepared for publication. The primary output consists of tables of evaluated data and critical data reviews published on a regular basis in the Journal of Physical and Chemical Reference Data and other channels. The annual output of evaluated data is typically 1500-2000 pages, representing the distillation of the useful quantitative results from 5000-10,000 individual experimental investigations. Other output includes bibliographies and data indexes, translations of Russian data compilations, and computer programs for handling data in various formats. In addition, data are supplied in response to specific inquiries, both for isolated property values and for more extensive compilations directed at a particular application (see Appendix D) [137,267].

## C. Standard Reference Materials

Most uses of reference materials lie in the areas of chemical and material measurements that are outside of the scope of the physical measurements considered in this report. However, as noted in section 2.2.4, reference materials are an integral and essential part of the national system for physical measurements. The aspects of the

NBS Standard Reference Material program that are of particular importance to the areas of physical measurements of primary interest in this study were adequately discussed in that section .

#### D. Coordination Services

As the central agency in the U.S. National Measurement System, NBS provides a number of services which serve to coordinate that system. The oldest of these, antedating the establishment of NBS, is the Office of Weights and Measures [46].

The role of the NBS Office of Weights and Measures is to provide leadership and those technical resources that will assure accuracy of the quantities and quantity representations in all commercial transactions for all buyers and sellers in the United States, and to promote a uniform national weights and measures system [203]. In fulfilling its mission, the Offices of Weights and Measures engages in a wide range of activities. Foremost is the assistance offered to the States in the following areas:

- Laws and Regulations
- Standards and Laboratories
- Testing Equipment and Procedures
- Measurement Studies
- Packaging Practices
- Technical Training
- Information Dissemination
- Conferences and Meetings

The NBS Office of Measurement Services provides similar support to the standards and calibration laboratories of the nation, and manages the calibration services program of the NBS Institute for Basic Standards [94].

The Standards and Applications Division of the NBS Institute for Applied Technology provides a central focal point for domestic standardization activities, while the Office of International Standards under the Associate Director for Information Programs provides a similar function in the international field [261]. Together, they serve as the focal points for contact and control for NBS participation with national and international standards organizations. They provide access to the Standards Information Center, which is a library of more than 85,000 standards. They publish general and specific indices of engineering and related standards. They handle inquiries from governmental agencies and industry on the availability and source of international, national, foreign national, industry, state, and federal governmental standards. The

Office of International Standards represents the U.S. officially with the International Organization for Legal Metrology.

The Office of International Relations coordinates NBS' international interactions, and serves as a focal point for NBS support to the measurement systems abroad, especially those of the developing nations [121,261].

#### E. Information Services

Technical information is a principle product of the National Bureau of Standards [261]. The basic goal of the technical information services program is to ensure that the results of work at NBS are provided, through appropriate media, to all interested users and to disseminate other information to which NBS has access because of its central role in the national measurement system and its participation in the development of science and technology. The activities which NBS conducts in pursuit of this goal include the following:

- Documentation, reference, and general information services.
- Operation of specialized technical information centers closely associated with laboratories working in specialized fields.
- Organization of, and provision of, facilities for symposia, technical meetings, and specialized training courses.
- Research and development in information sciences.
- Provision of consulting and advisory services by members of the NBS technical staff.

#### 2.4.6.2 Alternate Sources for Services Provided by NBS

Historically, the National Bureau of Standards has served the Nation by performing three primary roles, related respectively to:

- I. Measurements
- II. Standardization
- III. Technological development

These will be discussed in inverse order.

As a rule, many alternative sources exist today for NBS in the field of technological development. Industrial research matured following World War II and today is fully capable of developing virtually all of the technology needed by industry. Industry is enlightened and motivated to do what it needs. Governmental research has also matured since World War II, and similar statements are valid here, also.



The NBS role in technology development became much more sharply focussed with the reorganization of the Bureau following the Baker report in 1953 on the proper role of the National Bureau of Standards. Historically, it is clear that the Bureau's early major involvement in industrial and technological research was necessary for the times (the first 30 years of this century) and for three major wars. With the Baker report and the transfer from NBS of major involvement in military technology in 1953, the issue was effectively settled that, as a general rule, there are satisfactory alternate sources to NBS in fields of technological development[46].

In the field of standardization, the primary actual or potential alternate sources to NBS for the services it renders are the Department of Commerce's Office of Product Standards, the American National Standards Institute and its affiliated organizations, the non-profit research institutes, the universities, and the professional societies. NBS has far from a monopoly in this field. Its role continues, because the subject of standardization has a close functional connection with the field of physical measurements, and the high technology end of the field clearly benefits from being associated with an active, high technology organization that is neutral among the competing technological and commercial interests.

In the field of measurements, as a rule no effective alternative sources exist. If NBS did not exist, it would have to be invented. These points are best made service area by service area:

(a) Calibration services. At the highest level, there is no alternative source, without reinventing one or more National Bureaus of Standards, since only one agency can have custody of *the* national physical reference standard for a given quantity. Any other approach would be equivalent to a decision that we should have two Supreme Courts.

At more routine levels, there are many alternative sources of supply, (see Appendix G), and there could be more, if economic barriers could be overcome. The present trend toward measurement assurance programs, self-calibration techniques, laboratory accreditation, and the like should serve to make alternatives to the Bureau's calibration services more viable. This trend may not lessen the total Bureau work load in the measurement services area, but it will convert it from providing routine services to an active quality control operation, which

will be far more challenging intellectually and far more effective in assuring the nation the measurement system that it needs.

(b) Technical data. The Bureau has two major roles here, generation of technical data and management of the Standard Reference Data Program. The alternative sources of technical data are many, primarily the universities, the non-profit research institutes, the industrial laboratories, and other governmental laboratories. The NBS role in data generation is restricted to the fields of data that cannot be obtained with adequate precision elsewhere and for which the NBS measurement expertise is particularly relevant.

Management of the National Standard Reference Data System was entrusted to NBS only after it had become apparent that private sector agencies could no longer adequately handle the job, and that there was no more effective alternative governmental agency available. In principle, the job could be given back to the National Academy of Sciences/National Research Council, or to the National Science Foundation. Much of the work is, of course, done on contract by organizations independent of NBS. On the other hand, the philosophy of precision that dominates NBS is essential in this program, and it would appear that the program could not benefit by being placed in another agency.

(c) Standard Reference Materials. In principle, private organizations could provide the standard reference materials needed by this country. Some, in fact, are supplied now by commercial vendors and many are prepared commercially and then analyzed and certified by NBS. Often, however, alternative sources for operating this program would suffer from the lack of immediate access to national standards and the large pool of materials measurement expertise that exists in NBS, and from a lack of a tradition of precision.

(d) Coordination Services. It is hard to see alternative sources to NBS except by reinventing NBS. The NBS role historically has been to be a catalytic agent, bringing organizations into existence, and then withdrawing as they become self-perpetuating. The National Council on Radiation Protection and Measurements is an outstanding example of an organization created by NBS that today has only minor ties to it.



(e) Technical information services; direct technical assistance to other agencies, public and private; and technical responsiveness to national needs. When such work is dominantly based upon measurement expertise or other direct mission competence uniquely possessed by NBS, there are, by definition, no reasonable alternative sources. When this work bears no close connection with NBS measurement expertise (or other unique mission competence, in fields outside the scope of this study), then there are usually many potentially satisfactory alternative sources. Similarly, when such work offers a unique opportunity for NBS to become intimately aware of real-life measurement problems, it is of unique value to NBS. When it simply exploits NBS' capabilities and does not regenerate them in any significant sense, it is of little, no, or negative value to NBS.

#### 2.4.6.3 NBS Funding and Staffing

NBS funds come from the following four primary sources:

(1) The working capital fund, which is augmented from time to time by Congressional appropriations.

(2) Congressional appropriations for annual operating budgets.

(3) Funds transferred from other agencies, public or private, to cover non-routine technical services.

(4) Funds that reimburse NBS for the costs of its normal, "advertised", routine technical services.

The NBS working capital fund is used to provide long-term working capital for investment in equipment, standard reference material inventories, and similar purposes. The fund is regenerated by depreciation charges and by the sale of standard reference materials.

The NBS annual operating budgets are funded from three sources: direct appropriation by Congress, reimbursement for routine services, and funds transferred from other agencies, public or private, to cover the costs of special technical services. In FY 75, the approximate percentages from the three sources were 55%, 6%, and 39%. The primary sources of the transferred funds for recent years are shown in figure 25. The FY 75 budget is given in table 15. The NBS staffing pattern is displayed in figure 26 [261].

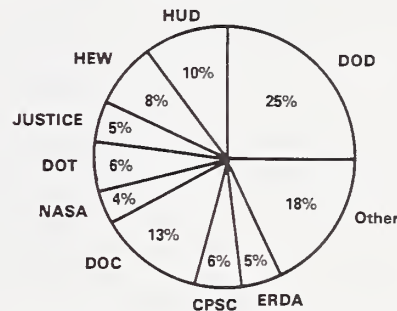


Figure 25. Other agency funding sources.

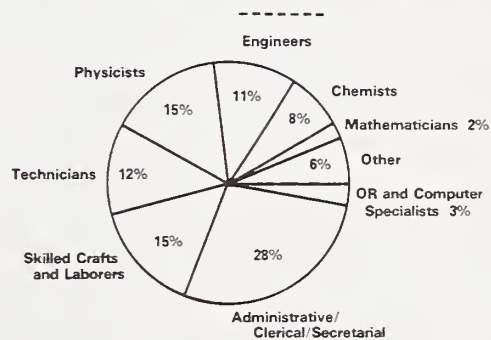


Figure 26. Composition of staff.

Table 15. NBS funding by program (amount in millions) [261].

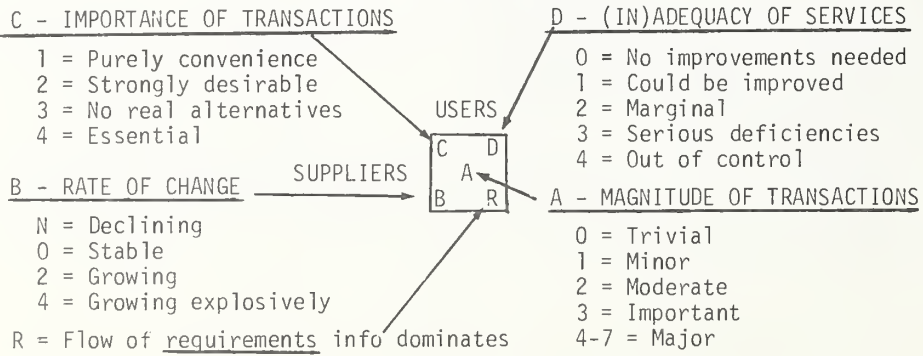
Program Area	Appropriations		Reimbursements		Total	
	\$	%	\$	%	\$	%
Provide a National System for Physical Measurement	24.5	40	11.4	25	35.9	33
Provide Services to Improve Use of Materials	16.0	26	9.6	21	25.6	24
Provide Services to Improve the Application of Technology	10.7	21	19.0 <sup>1</sup>	37	29.7	28
Experimental Technology Incentives Program (ETIP)	2.7	5	--	--	2.7	
Improve the Application of Computer Technology	5.1	8	4.7	10	9.8	9
Supporting Nontechnical Services for Other Agencies	--	--	2.9	7	2.9	
<b>TOTAL, NBS, FY 1975 (Actual)</b>	<b>59.0</b>	<b>100</b>	<b>47.6</b>	<b>100</b>	<b>106.6</b>	<b>100</b>

<sup>1</sup>Includes \$2.1 million transferred to NBS for work supported by the National Fire Prevention and Control Administration, which NBS performs under Section 18 of the Federal Fire Prevention and Control Act of 1974.

Table 16. Direct measurements transactions matrix for IBS Study of National Measurement System.

SUPPLIERS	COMMUNITY (Science, Education, Prof. Soc. & Publ.)	INTERNATIONAL METROLOGICAL ORGANIZATIONS	DOCUMENTARY STANDARDIZATION ORGANIZATIONS	INSTRUMENTATION INDUSTRY (SI, Major Gp 38)	NBS	OTHER U.S. NATIONAL STANDARDS AUTHORITIES	STATE & LOCAL OFFICES OF WEIGHTS & MEASURES (OWM's)	STANDARDS & TESTING LABORATORIES AND SERVICES	REGULATORY AGENCIES (excl. OWM's)	DEPARTMENT OF DEFENSE (excl. Stds. Labs)	CIVILIAN FEDERAL GOV'T AGENCIES (excl. Stds. Labs & Reg. Ag.)	STATE & LOCAL GOVERNMENT AGENCIES (excl. OWM's & Reg. Ag.)	INDUSTRIAL TRADE ASSOCIATIONS	AGRICULTURE, FORESTRY, FISHING, MINING (SIC Div. A & B)	CONSTRUCTION (SIC Div. C)	FOOD/TOB/TEXTILE/APPAREL/LBR/FURN/PAPER/LEATHER (SIC 20-26, 31)	CHEM/PETROL/RUBBER/PLASTICS/STONE/CLAY/GLASS (SIC 28-30, 32)	PRIMARY & FAB. METAL PRODUCTS (SIC 33-34, 39)	MACHINERY, EXCEPT ELECTRICAL (SIC Major Gp 35)	ELECTRIC AND ELECTRONIC EQPMT (SIC Major Gp 36)	TRANSPORTATION EQUIPMENT (SIC Major Gp 37)	TRANSPORTATION & PUBLIC UTILITIES (SIC Div. E)	TRADE/INS/FIN/REAL EST/PERS SVCS/PRINT (SIC F-H, Bal. 1, 27)	HEALTH SERVICES (SIC Major Gp 80)	GENERAL PUBLIC	
																										1
1 KNOWLEDGE COMMUNITY (Science, Education, Prof. Soc. & Publ.)	4	6	1	2	1	3	1	1	1	1	2	2	2	1	3	3	1	2	2	1	1	2	2	2	2	2
2 INTERNATIONAL METROLOGICAL ORGANIZATIONS	2	1	3	1	3	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3 DOCUMENTARY STANDARDIZATION ORGANIZATIONS	3	2	1	3	2	1	1	2	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
4 INSTRUMENTATION INDUSTRY (SI, Major Gp 38)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5 NBS	3	3	3	3	3	3	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6 OTHER U.S. NATIONAL STANDARDS AUTHORITIES	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7 STATE & LOCAL OFFICES OF WEIGHTS & MEASURES (OWM's)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8 STANDARDS & TESTING LABORATORIES AND SERVICES	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
9 REGULATORY AGENCIES (excl. OWM's)	3	1	1	3	1	3	2	3	1	3	2	2	1	3	2	1	1	1	1	1	1	1	1	1	1	1
10 DEPARTMENT OF DEFENSE (excl. Stds. Labs)	3	2	3	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11 CIVILIAN FEDERAL GOV'T AGENCIES (excl. Stds. Labs & Reg. Ag.)	3	1	2	2	1	3	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
12 STATE & LOCAL GOVERNMENT AGENCIES (excl. OWM's & Reg. Ag.)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13 INDUSTRIAL TRADE ASSOCIATIONS	2	1	1	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14 AGRICULTURE, FORESTRY, FISHING, MINING (SIC Div. A & B)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15 CONSTRUCTION (SIC Div. C)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
16 FOOD/TOB/TEXTILE/APPAREL/LBR/FURN/PAPER/LEATHER (SIC 20-26, 31)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17 CHEM/PETROL/RUBBER/PLASTICS/STONE/CLAY/GLASS (SIC 28-30, 32)	2	1	2	1	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
18 PRIMARY & FAB. METAL PRODUCTS (SIC 33-34, 39)	2	1	3	3	2	1	3	2	2	3	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
19 MACHINERY, EXCEPT ELECTRICAL (SIC Major Gp 35)	2	1	3	1	3	2	1	2	1	3	1	1	3	1	3	1	2	2	2	2	2	2	2	2	2	2
20 ELECTRIC AND ELECTRONIC EQPMT (SIC Major Gp 36)	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	2	2	2	2	2	2	2	2	2	2
21 TRANSPORTATION EQUIPMENT (SIC Major Gp 37)	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2
22 TRANSPORTATION & PUBLIC UTILITIES (SIC Div. E)	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	2	2	2	2	2	2	2	2	2
23 TRADE/INS/FIN/REAL EST/PERS SVCS/PRINT (SIC F-H, Bal. 1, 27)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
24 HEALTH SERVICES (SIC Major Gp 80)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
25 GENERAL PUBLIC	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

KEY TO MATRIX ENTRIES





#### 2.4.6.4 Evaluation Panels and Visiting Committee

The National Bureau of Standards has a long-established mechanism for evaluation of its programs, which consists of an array of evaluation panels managed by the National Academy of Sciences. Normally, these panels are continuing institutions, with rotating membership, the normal term being three years, each panel corresponding to an NBS division-level organizational unit. Institute-level panels include the chairmen of all of the Institute's division-level panels.

The evaluation panels have been involved with the National Measurement System Study from its beginning. Panel members have reviewed the reports of this study.

A Visiting Committee was established by the NBS Organic Act, for the purpose of evaluating the work of the Bureau, reporting to the responsible cabinet-level officer. The evaluation panels have no such legal standing, nor any legal connections with the Visiting Committee. Nevertheless, clearly established communication channels exist between the two mechanisms, so that systematic observations by evaluation panels can and do get channeled directly to the Secretary of Commerce.

#### 2.5 The Measurements Market-Place: The Direct Measurements Transactions Matrices

The fifth level in the national measurement system model consists of the "measurements market place" in which the end-use measurement activities occur. The technique that has been chosen for displaying these activities is a measurement transactions matrix, which displays the direct interactions among the various suppliers and users of measurement information, data, goods, and services [302].

The following categories appear to encompass all of the kinds of goods and services that are involved in these transactions:

- A. End-use measurement data
- B. Reference data
- C. Other measurement services (e.g., calibrations or time & frequency broadcasts)
- D. Reference materials
- E. Measurement instrumentation and its associated software
- F. Measurement *how-to* information
- G. Measurement *requirements* specifications (e.g., laws, regulations, documentary standards)
- H. Measurement *needs* information
- I. Money to pay for the above.

Attention was focused on the functional information, goods, and services involved in the transactions. The last item, money, was ignored as a direct entry in these matrices.

All institutional sectors of the system have been included in the transactions matrices, for service.

so that only part of a matrix describes end-use measurements. Every defined sector is entered as both a supplier and a user, so that the flow of measurement needs information from the users to the suppliers of measurement goods and services can be entered. The diagonal elements define the measurement goods and services generated within a given sector that are consumed by that same sector, either within a given organization or by others; these diagonal elements contain the vast bulk of the measurements made in our society.

For simplicity, zeros have been suppressed in the matrices, so that a blank data entry location means zero, with the following exception: When the only data entry is for the central magnitude quantity, the blank entries for all of the other numerically coded quantities mean simply that no estimates have been made for them.

Table 16 is the master supplier-user matrix for the whole system, as seen by this study of the National Measurement System. Table 17 summarizes NBS outputs to the various user sectors in the fields of physical measurement covered by this 1972-75 study of the National Measurement System.

The supplier-user sectors have been adequately identified in table 16. Sectors 1-9 and 13 are primary supplier sectors, and sectors 1,4, and 9-25 are primary users. Sectors 4 and 14-24 are based on Standard Industrial Classification (SIC) Codes [141]. These codes are used in a straightforward fashion, except that: Major group 39 "miscellaneous manufacturing industries" activities are informally associated with those non-miscellaneous groups most nearly similar technically. Standard sector 23 includes only those parts of SIC division I not elsewhere accounted for. SIC 27, printing and publishing, is grouped in sector 23 with the technically similar activities of division I; SIC division J, public administration, is covered in the various governmental sectors. A yes-no summary of the users of NBS services has also been developed (see Appendix J).

There is a rather inevitable bias in the transactions matrices that probably magnifies the apparent importance of the user sectors with which the NBS Institute for Basic Standards is most familiar. All approaches indicate that the Government sectors are of first-rank importance. From here on, the indicators diverge. The high technology industries that are major users of NBS services, and that place major demands on innovation in the measurement system, show up high in these matrices, even though their absolute expenditures on measurements are a minor part of the country's total [173,200,218]. In contrast, such areas as retail and wholesale trade that expend tremendous sums in measurement-related activities, make only modest demands on NBS for service.



Table 17. Direct measurements transactions matrix for outputs of NBS.

\*

MEASUREMENT SECTOR	USERS																								
	KNOWLEDGE COMMUNITY (Science, Education, Prof., Soc. & Publ.)	INTERNATIONAL METROLOGICAL ORGANIZATIONS	DOCUMENTARY STANDARDS ORGANIZATIONS	INDUSTRY (SIC Major gp. 38)	OTHER U.S. NATIONAL STANDARDS AUTHORITIES	STATE & LOCAL OFFICES OF WEIGHTS & MEASURES (DM's)	STANDARDS & TESTING LABORATORIES AND SERVICES	REGULATORY AGENCIES (excl. DM's)	DEPARTMENT OF DEFENSE (excl. Stds. Labs)	CIVILIAN FEDERAL GOV'T AGENCIES (excl. Stds. Labs & Reg. Ag.)	STATE & LOCAL GOV'T AGENCIES (excl. DM's & Reg. Ag.)	INDUSTRIAL ASSOCIATIONS	AGRICULTURE/FORESTRY/FISHING/ MINING (SIC Div. A & B)	CONSTRUCTION (SIC Div. C)	FOOD/TEXTILE/LBR/ PAPER/LEATHER/ETC. (SIC 20-26, 31)	CHEM/BETRL/RUBBER/ STONE/CLAY/GLASS... (SIC 28-30, 32)	PRIMARY & FAB. METAL PRODUCTS (SIC 33-34, 391)	MACHINERY EXCEPT ELECTRICAL (SIC Major gp. 35)	ELECTRIC AND ELECTRONIC EQUIP (SIC Major gp. 36)	TRANSPORTATION EQUIPMENT (SIC Major gp. 37)	TRANSPORTATION & PUBLIC UTILITIES (SIC Div. E)	TRADE/INS/FIN/REAL EST/PERS SVGS/PRINT (SIC F-H, bal. 1, 2)	HEALTH SERVICES (SIC Major gp. 80)	GENERAL PUBLIC	
1 TIME & FREQUENCY	3	3	1	3	3	3	3	3	3	3	3	3	4	4					1	1	3	1	3	2	
2 LENGTH & RELATED DIMENSIONAL MEASUREMENTS	1	1	3	2	3	3	3					3	4	1		3	3	3	3	3	1	3	1	1	
3 VIBRATION & SHOCK	3	2	2	2	2	2	2				2	1	2	1		3	1	2	3	3	2	2	2	3	
4 SURFACE FINISH	2	2	2	3	2	2	3				3	1	2	1		3	2	2	2	2	1	2	2		
5 MASS, VOLUME & DENSITY	4	1	4	2	1	4	2				4	1	2	3		2	2	2	2	1					
6 FORCE	2	3	4	2	3	3	4				1	3	3	3		2	2	2	2	2	2	2	1		
7 FLUID FLOW	2	1		2	3	3	1				3	3	3	3		2	2	2	2	2	2	3	2	1	
8 PRESSURE	3	3	2	3	2	4	3				3	1	2	3	4	3	2	1	1	2	3	4	4	1	
9 TEMPERATURE	3	3	4	2	2	3	3				2	1	2	3	2	3	2	2	2	2	2	2	1	1	
10 HUMIDITY & MOISTURE	2	1		2	3	3	1				3	3	3	1		2	2	3	3	3	2	2	1	1	
11 THERMODYNAMIC PROPERTIES OF FLUIDS	4	2	4	1	4	2	3				3	1	2	2	3	1	2	1	1	2	2	2	2	1	
12 CRYOGENICS	4	1	4	1	4	1	3				2	2	2	1	3	4	2	2	2	2	2	3	1	2	
13 ELECTRICITY	3	2	3	3	4	4	1				1	4	3	3	2	2	3	1	3	3	1	3	1	2	
14 ELECTROMAGNETICS	3	2	3	2	2	3	1				3	2	3	2	1	3	2	2	2	2	2	3	3	1	
15 MEDICAL ULTRASONICS	2	2	2	2	2	3	2				3	1			1				1				3	2	
16 ACOUSTICS	3	2	1	2	1	2	1				2	1	3	3	2	1	2	3	2	3	2	1	2	3	
17 PADIOMETRY & PHOTOMETRY	3	1	3	1	2	2	3				4	1	4	2	2	1	3	1						3	1
18 SPECTROPHOTOMETRY	2	x	2	2	2	2	1				2	2	2	1	1	2	3	1	2	2	2	2	2	2	
19 FAR ULTRAVIOLET RADIOMETRY	2	2	3	2	2	4	2				2	2	2	3	2	2	3						2	2	
20 OPTICS	2	1	2	2	3	1	3				4	3	1	4	3	4	2	1				4	4	1	
21 LASERS	4	3	4	4	4	2	4				2	4	4	4	4	1	3								
22 PHYSICAL PROPERTIES OF ATOMS & MOLECULES	3	4		2	3	4					3	4	3	4								3	4		
23 SURFACE PROPERTIES	4	1	3	1	3	2	3				2	2	3	2	2	3	2					3	3	3	
24 IONIZING RADIATION	2	3	2	3	3	1	4				3	3	3	3	2	4	3	2	2	2	2	3	4	3	
25 AVERAGE	3	3	3	3	3	4	1				2	1	3	2	3	2	3	1	2	1	2	2	2	1	

KEY TO MATRIX ENTRIES

C - IMPORTANCE OF TRANSACTIONS

- 1 = Purely convenience
- 2 = Strongly desirable
- 3 = No real alternatives
- 4 = Essential

D - (IN)ADEQUACY OF SERVICES

- 0 = No improvements needed
- 1 = Could be improved
- 2 = Marginal
- 3 = Serious deficiencies
- 4 = Out of control

B - RATE OF CHANGE

- N = Declining
- 0 = Stable
- 2 = Growing
- 4 = Growing explosively

A - MAGNITUDE OF TRANSACTIONS

- 0 = Trivial
- 1 = Minor
- 2 = Moderate
- 3 = Important
- 4 = Major



R = Flow of requirements info dominates

? = Unknown, X = Not studied, Blank = 0

### 3. THE INTERNATIONAL CONTEXT

The U.S. National Measurement System is part of an international measurement system. The international system exists primarily to carry compatibility in measurements beyond national borders, and also functions as a mechanism for sharing of information and of effort to reduce the burdens borne by individual measurement systems or laboratories.

Figure 27 displays a model of the International Measurement System structure. The model includes

- the national measurement systems ( $N_1, N_2, \dots$ ),
- the supranational sector where everything is common to all nations and national interest is completely suppressed (central circle),
- the "co-national" portion that represents cooperative efforts for their mutual benefit by groups of national measurement systems (intermediate band),
- the "bilateral" portion of the system which represents one-to-one relations between national measurement systems acting in their frank self-interest (outer band).

The supranational portion represents organizations and people (including some international civil servants) that are the source of agreements, definitions, and physical reference standards which are unique, accepted by all, non-political in nature and which act as the central tie point for the achievement of compatibility of all measurement systems. National systems (notably national standards laboratories) contribute their efforts and inputs to this portion by, for example, participation in working groups or submission of draft documents and ideas.

Once internationally accepted definitions and standards related to the SI base quantities are made available, it is possible for a national laboratory to generate independently the derived units of measurement. An example of such a unit is the milliwatt (power) at 10 GHz (a microwave frequency). The same process is followed within other national measurement systems to arrive at *almost* the same units; small errors in fabrication or measurement and variations in techniques employed make inevitable small but often significant differences. One of the main functions of the "*co-national*" portion of the international measurement system is to identify these differences, find their bases, and, where possible, reconcile them. Any number of national measurement systems (usually through their national standards laboratories) can usefully participate in any standards coordination and evaluation effort.

The international dissemination of information concerning measurement techniques and new results in measurement research also

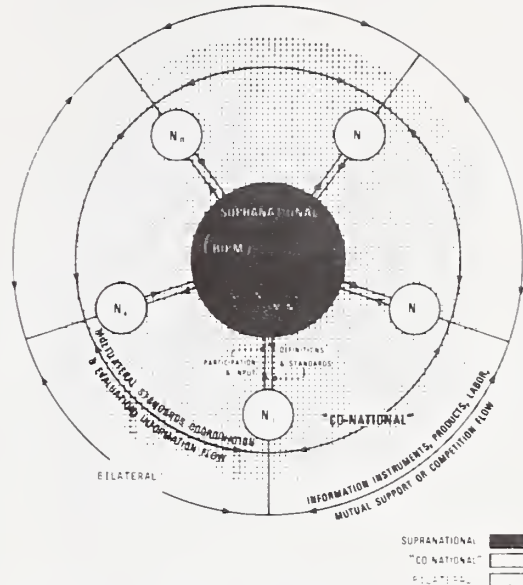


Figure 27. Model of the international measurement system [190].

falls substantially into the "*co-national*" portion of the international measurement system. National laboratories can profit considerably in many areas from each other's experience and outputs because they often have the only efforts within their own countries to reach certain measurement and standards objectives. In this respect a real community of specialized technical interest often lies only in the "*co-national*" area and is virtually absent within any one national measurement system.

The "*bilateral*" portion of the international measurement system probably involves many more different activities than either the supranational or the "*co-national*". Many of these are small or one-time affairs, some are quite substantial. Included are the flow of information between one national system and another, and of measuring instruments and manufactured products with measurement content, and of labor by measurements people. The flows may be unidirectional, often truly bilateral, and sometimes multilateral as the result of a concatenation of bilateral interactions.

The information flow is typically in the form of technical papers, reports, plans, or data. A second important channel is the visitor to or from another system and the guest-worker who comes from one system into the other. Attendance at the national technical meetings in one system by scientists from another is a third channel. Some of these mechanisms are based on formal bilateral agreements, many are entirely *ad hoc* and based on personal contacts.



The export of measuring instruments produced within one system to another is a very important component of the international measurement system. The measurement systems of some smaller nations depend almost completely on this mechanism, but even the technologically advanced nations often use each other's instruments.

Measurements on high technology products manufactured for export also form part of the international measurement system. The point is the question of satisfying the specifications and standards of the importing national measurement system with measurements made in the exporting system.

Mutual support in the "bilateral" area tends to take the form of cooperative measurement research projects in which different nations contribute what they can toward a common objective. Contributions are normally not identical.

Competition in the international measurement system is somewhat harder to document. Still, it exists, especially in the area of international engineering standards where nations vie with each other to have their national standards adopted as international standards. In the field of physical standards, national standards laboratories sometimes compete to produce an output first or best and others seek to catch up or copy. One reason for this is that the reputation and image of a national measurement laboratory are important because they reflect on the technological capability of the nation to produce sophisticated instruments and products that will be internationally sought.

The International Bureau of Weights and Measures was established by the Convention of the Metre, of May 20, 1875. It is located in a tiny international enclave, at Sevres, France, near Paris. The initial essential mission of the international bureau was to construct and preserve the definitive standard meter and kilogram, to compare them with the national standards which were to be furnished to the various countries, and to improve procedures of measuring in order to advance progress in all fields of metrology. In subsequent years, assignments of BIPM extended into other areas such as thermal, electric, photometric and ionizing radiation fields. Today, it functions to advance the most basic parts of the conceptual and technical infrastructures of the international measurement system, and promotes coordination and harmony among the measurement systems of the different nations of the world.

The supreme authority governing the International Bureau of Weights and Measures is the General Conference of Weights and

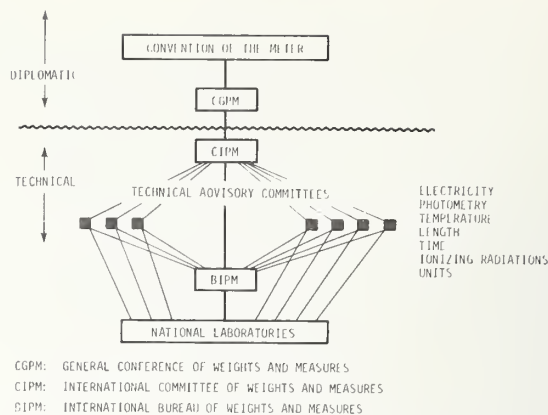


Figure 28. International coordination of measurement standards [71].

Measures (CGPM). It consists of delegates from all of the countries belonging to the Convention of the Metre and meets at least every six years. The International Committee of Weights and Measures, composed of eighteen members, acts for CGPM between conferences to look after scientific and administrative matters. A series of consultative committees have been established under the International Committee, each charged with a particular field of measurement, each drawing on the leading experts in the world in its field (see fig. 28.).

Other supra-national organizations function in specialized parts of the international measurement system. In particular, BIPM shares responsibility in the area of time and frequency with BIH, the International Time Bureau, which is also located near Paris. In the field of legal metrology, the area covered by the offices of weights and measures in this country, the primary international coordinating body is OIML, the International Organization for Legal Metrology.

The International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC), although primarily documentary standardization bodies, also have a significant effect on the international physical measurements system. Other, more specialized bodies have an even more direct role. In particular, the International Commission on Radiation Units and Measurements develops documentary standards that are of major importance in defining the international radiation measurement system. All of the major international technical organizations have substantial effects on the international measurement system: the International Unions of Pure and Applied Physics and Pure and Applied Chemistry, the International Telecommunications Union and its consultative committees; the International Scientific Radio Union (URSI); and others.



#### 4. IMPACT AND TRENDS OF MEASUREMENT SYSTEM

##### 4.1 Impact of Measurements

##### 4.1.1 Functional, Technological, and Scientific Applications

This subject was touched upon in a general fashion in section 1., *Functions of Measurement*. Table 1 presented there is the outline for the present discussion.

The functions of measurements, including those in science and technology, involve all of the uses made by human beings of knowledge of the physical universe. Since science deals with the advancement of knowledge, the uses of measurements in that field set a pattern often followed in other fields. For this reason, it is useful to observe the functions of measurement in scientific activities, as an initial entry into the general subject.

Science consists of the human mechanisms for acquiring knowledge in an organized fashion, and of the organized body of knowledge thus acquired.

The most basic use of measurement by science *is to describe* what is or was. Understanding is built upon these descriptions.

The utility of science, and the ultimate test of any understanding developed by it, depends upon an ability *to predict* what will be. Predictions of the future are based upon measurements of the past and present.

Science originates with the individual. It becomes significant to the race when communicated. Measurements provide a language *to communicate* the knowledge and understanding developed by science.

The development of science does not proceed on a purely random basis. Measurements provide knowledge that allows the scientist *to decide* among alternate courses of action.

Scientists plan courses of action, some of which may be very elaborate. Control of the preplanned process is essential. Measurements are used *to control*.

Science studies the uncontrollable as well as the controllable. When the uncontrolled does occur, the scientist must be prepared to respond, to react. Measurement of what is, allows the scientist *to react*, when the events he is seeking do occur.

The uses of measurements in the world of science are, then:

- to describe,
- to predict,
- to communicate,
- to decide,
- to control,
- to react,

in dealing with what is, was, or will be in the physical universe. This set is believed to be complete.

Of this set of six descriptors, two are most fundamental: To communicate and to decide. In the broadest sense of the words, these can encompass the other four. Nevertheless, it seems useful for most purposes to restrict the meanings of "to communicate" and "to decide" to the narrower meanings implicit in the discussion above, and to use the total set of six infinitives for most purposes when discussing the functions of measurements.

It is now instructive to consider the application of these six infinitives to the areas of personal life, society, and technology.

In the *personal life* of the individual, the infinitive "to describe" can be translated into the noun, *knowledge*: "My automobile weighs a nominal 3630 pounds and gives me 19 miles per gallon at 55 miles per hour".

The individual is also concerned with *prediction of the future*: "Our porch thermometer reads 2 degrees above freezing now, at 6 p.m. The weather is clear and wind-still. It is sure to freeze tonight."

Some of the simplest *communications* between individuals depends upon the availability of a measurement capability: "What time is it?"

Many *decisions* depend upon measurement data: "Should I take time to stop to get gas?"

Our personal *actions* are often determined--*initiated*--by measurements. "The alarm clock just went off."

We use measurements to *warn* us of the occurrence of uncontrolled, unplannable events: "The oil pressure gage just dropped to zero. I'd better stop and find out what's wrong."

Measurement activities also play many roles in contributing to the *efficiency and fairness of our society*.

The "to describe" dimension shows up in the use of measurements to develop *data bases* for social use, such as in all kinds of maps and charts, e.g., those used for navigation in the coastal waterways.

Many aspects of *public planning* and *forecasting* are heavily dependent upon measurement activities. The meteorological data generation system is one of the largest formal measurement subsystems in our society, and it exists to provide a basis for weather prediction.

Communication applications of measurements pervade all of the social applications, by the very definition of the word "social". Perhaps the purest form of communication occurs in the use of measures to define *land ownership* and *political boundaries*.

Just as communication aspects tend to show up everywhere in the social uses of measurements, so do the decision dimensions of measurements. Perhaps the purest occurrence of the decision dimension occurs in the use of measurements in the *judicial process*: "You will pay to this woman the damages prescribed by the jury, because it has concluded that the evidence of the measurements shows that you were indeed driving in a reckless and negligent manner and that you were responsible for the accident in which she was seriously injured."

Closely related are *equity in trade and taxation*, and the *payment of wages* (and the like) on a time basis.

Measurements are used for *policing* and for *regulation* in our society. "Pull over. You were doing 70 miles per hour in a 55 mile per hour zone."

Measurements are used for *hazard warning*: "Take cover! Weather radar has picked up tornado funnels advancing on us at 25 miles per hour!"

The same set of six basic functions of measurement show up in the *implementation of technology*. It is convenient to use a single industry--petroleum--as a source of specific examples.

*To describe* finds its purest embodiment, perhaps, in the area of *resource location*, such as geophysical prospecting for oil.

*To predict* translates into such terms as *engineering design*, as in the design of liquified natural gas tankers.

*To communicate* can translate into *interchangeability*, as in the fact that the threads on oil drilling hardware are interchangeable for equipment originating anywhere in the free world.

*To decide* can be correlated with *quality assurance* function: "Is this lot of gasoline of an acceptable octane rating?"

*To control* translates directly into *process control*, as in refinery operations.

*To respond or react* can be translated into *fault diagnosis*, as in detecting the existence of and locating leaks in pipelines.

The significance of measurements varies among the different fields of science and technology. The descriptive/observational fields of science--such as anatomy and taxonomy in biology historically, at least, have made few demands on the measurement system. Such observational fields as astronomy have made immense demands on the system. Experimental physical science is founded upon a measurement capability. Today, there are very few frontiers in any field of science that are not dependent in a major way on the existence and advancement of precision measurement capabilities. Resolution of detailed problems even in taxonomy, for instance, may today depend upon precision biochemical measurements.

In the field of technology, the older areas such as leather tanning and brick manufacturing make few exacting demands on the measurement system. While one of the oldest of all--metal working--makes some of the most exacting demands, it is the newer physical technologies that usually pose the most difficult measurement requirements--electronics and nucleonics, to name two outstanding examples.

#### 4.1.2 Economic Considerations

The National Measurement System is part of the information sector of our economy [225, 316]. It cuts across all other economic and technological systems in our society. Every sector of our economy owns measuring instruments, employs labor for the purpose of making measurements, and uses the results of measurement activities. Every technology, every means of production, depends upon measurement activities of one sort or another [47,98].

In the broadest sense of the phrase, the national measurement system consists of all of the mechanisms used by our society to obtain the objective, quantitative knowledge needed for its functioning. However, for present purposes, two major categories of quantitative knowledge are excluded: Knowledge of the kind of subjective human phenomena that can be determined quantitatively only by such means as polling or voting, and those quantitative determinations of subjective value that are made by the fiscal pricing system or some analog or substitute for it. Operationally, we are here dealing only with the national system for quantitative *physical* measurements.

The national system for physical measurements plays a pervasive role in our economy. It accounts for perhaps 6 percent of our gross national product [173,200,218]. It is a significant consumer of economic resources. It generates essential economic benefits [307,327].



The system deals with both public and private goods. The private goods aspects include the overwhelming majority of the costs. The cost of a butcher weighing out meat is clearly a private expense between seller and buyer. The cost of measurements made during the production of an automobile engine is clearly a private cost to the auto manufacturer. The cost and benefits of a piece of measurement instrumentation reside with the purchaser who needs, controls, and uses the instrument.

Public goods aspects of the measurement system can be characterized as market enabling, market failure, and public market.

The *market enabling* aspects of the system relate to the fact that it is essential both in enabling our markets and in allowing the production of many of the goods traded in them. Few markets as we know them could exist without the measurement system. And this system does not exist as a matter of spontaneous creation, any more than does our present monetary system. Actions are required to generate and maintain an infrastructure for the system, which actions benefit the whole society in such a manner that there is no feasible way to recover costs other than by taxation, which means governmental action.

*Market failure* aspects can come in from several directions. The classical one is that markets usually fail to provide adequate incentive to the sellers to promote social efficiency and to alleviate social frictions in commercial transactions. The rule of the unregulated market place is *caveat emptor*, "let the buyer beware!" The public goods aspect of fair weights and measures overrides the private goods drive on the part of the sellers to cheat when they think they can get away with it.

Another aspect of market failure stems from the importance of the information part of the national measurement system infrastructure. Since much of this information either usually cannot be retained as the exclusive property of the originator, or has such public goods aspects to it that it should not be so appropriated, the economy will tend to underinvest in the development of such information unless a public subsidy is provided.

The *public market* aspects come from the fact that the national measurement system functions to deliver information needed for many governmental regulatory, decision-making, or operational purposes. The uses of such information may be either coincident-

ally or inherently public. The use by the military of measurement information in the maintenance of its equipment inventory is no different in kind than similar uses in the private sector. On the other hand, measures of the quality of air throughout a metropolitan region inherently have primarily a public goods value, at least at this time.

On any time scale that we wish to consider, a measurement system is a "must" for the functioning of our human society, just as is a monetary or a transportation system. If through some means any of these systems should be seriously disrupted, major social disruptions would result, that would (and do) require prompt corrective action. It is of little usefulness to try to establish in an absolute quantitative sense the value of such "musts."

How much of any of these systems--measurement, monetary, transportation--is optimum, is quite another question, and for such questions the concepts of marginal economics can be applied, albeit not necessarily easily [76]. Economic "externalities" and other complications are often involved. When costs and benefits are not neatly localized and clearly calculable, cost/benefit analyses and decisions become difficult.

Detailed economic discussions are inappropriate here. Such questions are dealt with in other reports in this series [307,327].

## 4.2 Trends of the National Measurement System

The major trends of the system can be described under the following headings:

- Increased complexity
- Increased integration
- Improved quality control
- Improved information resources
- Automation
- Metrication
- Science

### 4.2.1 Increased Complexity of the National Measurement System

The confluence of three major driving forces inevitably dictates that the measurement system will increase in complexity, in all dimensions. Its total scope will widen. Its internal structure will grow. Its meaning for society will expand.

The three major driving forces are (a) the ever-increasing scope of science and technology, (b) the development of the information economy, and (c) the challenge of mastering the ever-growing complexity of our



society as a whole. Implications for the measurement systems of the first factor are discussed frequently in this report and do not need elaboration at this point. The latter two factors, however, require some discussion here.

The Information Economy. Figure 29 summarizes an analysis of the American economy performed by Mr. Mark Porat while at the Institute for Communication Research of Stanford University [225,316]. Briefly, Mr. Porat adopted a not unusual concept, namely that there was a significant component of the American economy that could best be described by the term "Information Sector", and then set out to see just how important this sector was to the economy. He proceeded to look at what people actually do, rather than what their organizations are thought to do. The question was, what is the ultimate significant output from this particular kind of job? Outputs were classified into four categories:

- (1) Provision of data, information, or knowledge, or of physical products whose only real value lies in the data, information, or knowledge that they transmit or allow to be created.
- (2) Provision of physical services, such as restaurant meals, health care, or most transportation.
- (3) Provision of manufactured products whose utility is inherent in the product as a physical object and not in any use of the product to transmit or generate data, information, or knowledge, including products resulting from the extraction of resources from the earth and oceans.
- (4) The provision of food and other products of agriculture and fishing.

The major conclusions that follow from Mr. Porat's analysis of the data is that the much-heralded explosion in recent years of the service sectors of the economy is all concentrated in the information sector except for a small net effect due to the large increase in the health-care sector. Further, approximately half of all American workers are found in the information sector, a fraction so large that a saturation effect appears to be taking place: the economy simply can't afford any more (see figure 29).

The National Measurement System is, of course, inherently part of the information sector of the economy. Since the information sector depends for its operation upon the availability of raw data, and the measurement system is one of the major sources of raw data, the measurement system has probably

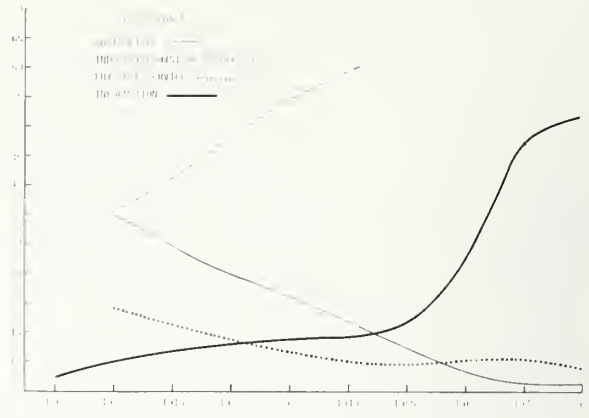


Figure 29. Composition of U.S. labor force, 1860-1980.

shared some of the growth of the information sector during the last 10-15 years. Of more importance are the effects of the interaction of the newer information technologies-- automatic data processing, in particular-- with the measurement system, and of the inevitable pressures toward economy and efficiency and complexity that are implied by "saturation" of the economy with information sector workers. At the very least, such pressures will increase the importance of an ability of the measurement system to deliver exactly the data needed when it is needed, with exactly the required quality, no more, no less. Doing so inevitably increases aspects of complexity of the measurement system.

Social complexity. The need to manage the ever-growing complexity of our society is probably the greatest single driving force affecting the measurement system today. The general factors involved here were discussed by Daniel E. Noble in 1971 during a symposium entitled "The next twenty years--the promise and the challenge." The following is quoted from his paper, "The Challenge of Intelligent Decision-Making [97]:

"I suggest to you that our present permeating sense of alienation, confusion, and frustration should have been expected. There should be no mystery about the exponential growth curve we have been following... or about the stagnation, frustration, and confusion which result when the curve flattens out and we find ourselves in an environmental state of equilibrium brought about by the saturation of the growth-supporting forces. While the saturation includes limitations upon the availability of power and resources, the primary factor is the degradation of the quality of control and decision-making

induced by the saturation of our information processing facilities. The crowding into the cities with the attendant prodigious rise in interdependence and interaction among all of the systems, subsystems and the people, the rise of high speed transportation, high speed printing systems, and high speed communications systems of all kinds, and the information inundation which makes it impossible to select from the flood the relevant information needed for our decision-making processes, all contribute to the saturation of our 'communications' channels.

"In other words, we have created a very high information 'noise level' and the noise level in turn fosters alienation, frustration, confusion, and the stagnation of effective decision-making processes.... We have overloaded the information processing capabilities of our brains and of our filing cabinet-memory systems and procedural structures, so that we are suffering from a very high 'noise level' in all of the social, political, and economic areas of our culture.... We have three choices: 1) we can continue in a state of confusion... down to disaster; 2) we may adjust to a static state of equilibrium...; 3) we can use our brains and marshal all the forces of science and technology to desaturate our culture and, by the introduction of new step-function forces of change, create a fresh new exponential growth curve which will revitalize our total cultural growth over the next fifty years...

"We may characterize the industrial revolution as a major concentration upon the development of muscle power extension systems of all kinds. These muscle power extension developments, which created machinery for heavy work, for intricate work, and for redundant work, also created high speed transportation, communications, printing, and distribution systems of prodigious efficiency. The emphasis was upon orders-of-magnitude increase in man's muscle power, muscle efficiency, and labor productivity. The cultural configurations changed sharply from a farming economy to an industrial economy, and from rural living to urban living....

"Education has been the key to the expansion of the new power of the individual and to the new freedom of choice for the individual but, admittedly, an opposing force has been constantly increasing in its limiting negative effect upon the individual freedom of today. This force

(the real villain of the piece) which, with some poetic license, might be called 'complexity', has been increasing steadily in nearly all areas of our cultural patterning until the organizational structures and procedural systems erected to combat complexity are in danger of becoming self-defeating. They have become so procedurally complex that they control the people who are supposed to be controlling the functioning of the system....

"We are now faced with the increasingly important job of rescuing man from the very complexities he has created. Since the primary cause of the present dilemma is the low speed, low efficiency and poor productivity of man's information processing systems, we must make monumental use of high speed electronic brain extension systems. As man has revolutionized his environmental structures through the application of muscle power extension systems, so in the next fifty-year period, he must revolutionize his total culture (including the social, economic, and political elements) through the application of brain extension systems....

"Without the introduction of radically new techniques for processing information, our modern culture is headed for saturation, stagnation, and collapse; it will perish under the weight of its own rising complexity. As the man/machine symbiotic muscle power relationship has prodigiously extended man's labor efficiency, so the introduction of electronic brain extension systems will extend man's capacity for processing information and enable him to rationalize the flood of information that now confuses our decision-making efforts. A new brain extension culture must supplant the muscle extension culture...."

The implication of Dr. Noble's thesis for the National Measurement System is simply that our culture can no longer afford the complexity introduced by poor, inadequate, or excessive measurements. The measurement system provides the foundation of data about the physical universe that allows the industrial system and society to function. Confusion about these data introduces confusion and complexity at the most fundamental level. The overwhelming social driving force for reduction of social complexity means that confusion in the physical measurements data base will become increasingly intolerable. We must have the data we need, with the reliability we need. We can no longer afford to *guess* about the validity and adequacy of our fundamental data.



#### 4.2.2 Increased Integration of the National Measurement System

Increased integration of the measurement system is essential to improve its ability to provide most economically and effectively the measurement data required by our society. While integration itself implies an increase in complexity, it can on the net reduce complexity if it brings enough order out of chaos in a sufficiently simple manner.

Three primary arenas exist for integration of the measurement system. In the federal government, vast new areas of measurement responsibility have developed during a very few years, in the newer regulatory areas relating to health, safety, and protection of the environment. New needs have arisen in the older economic areas, as a result of the increased pressure of international standardization, a recurring balance of payments deficit, lagging productivity in the economy, and general economic malaise. However, the benefits of pooling measurements needs and of responding in an integrated manner are only casually perceived by the agency managers involved, for the most part. A new initiative similar to the National Conference of Weights and Measures or the National Conference of Standards Laboratories could be in order, perhaps a Federal Council on Measurement Operations. A moderate extension of current NBS efforts could lead to the creation of such a coordinating group.

The second arena exists at the state level, where the state governments are becoming aware of the substantial expansion of state regulatory measurement activities and of the benefits of approaching all of the formal measurement system involvements of the state government in an integrated manner. Historically, state and local governments functioned only at the commercial weights and measures level. Today, they are also functioning in the fields of environmental pollution control and of health and safety, particularly in connection with the regulation of the use of ionizing radiation and in the enforcement of occupational safety and health. Increasing miscellaneous needs also arise, such as the calibration of radar speed measuring instruments for state highway patrol use.

The State of California has taken a lead in moving toward integration of its state measurement system, by the establishment of a Measurements Advisory Committee with the responsibility of looking at and formalizing the existence of a California State Measurement System.<sup>+</sup> This Measurement Advisory Committee includes representatives from industry, the cities, and the state government.

It meets only for action. Some results to date have included moves to allow private standards laboratories to undertake calibrations for the state and local weights and measures operations on a fee basis; the motivation was simply to tap into well established expertise that already existed in the state, with established ties to NBS. Not surprisingly, this committee early uncovered numerous duplications of effort. On the other hand, it early became clear that it was essential to avoid any appearance of having the offices of weights and measures take over the measurement regulatory functions of other departments of the state government. In California the interested departments include agriculture, health, transportation, water resources control, and others. Functions of the Advisory Committee include looking at "exotic" areas, new needs, and identification of problems. It provides a clearing-house for measurement science R and D and for inventorying measurement needs and expertise. It is finding that people from the different agencies and localities can be inspired to work together, and that its own job is immensely satisfying to its members.

Similarly, the explosion in the need for measurements for technological regulation suggests that a "National Conference on Regulatory Metrology" could well be in order. This would involve state, Federal, and local governmental agencies, private industries, and private public interest groups.

#### 4.2.3 Improved Quality Control in the National Measurement System

Improvement of the quality of any operation requires determination of the quality of its output and of feedback of this information to those responsible for the output. Historically, except in the weights and measures enforcement field, few mechanisms existed in the national measurement system to permit quality assurance or control with respect to its functioning. The orientation of NBS was to make it *possible* for good measurements to be made by the end-use levels of the system, but little was done to assure that adequate measurements were in fact made, or even to provide mechanisms to allow anyone to know what quality was in fact being achieved, much less control it.

Today, improvements in the quality of the output of the national measurement system are being pursued along two lines. One is

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<sup>+</sup> Unpublished presentation by W.F. Cowan at a Workshop on Study and Improvement of State Measurements Systems, NBS, Gaithersburg, Md., Jan 14-15, 1975.



the historical orientation of enabling good measurements to be made. Specific programmatic efforts in this area include laboratory accreditation programs; extension of the concept of measurement traceability to NBS; and provision of new calibration services, standard reference materials, and standard reference data. All of these establish a potential for the production of good measurements, but they do not establish that good end-use measurements are in fact made.

The second approach is a true *quality control* approach of determining the quality of the output and feeding it back to the input. It includes the NBS-sponsored Measurement Assurance Programs (MAP's) [130] the measurement audit packages used by the Department of Defense [91], cooperation by state offices of weights and measures with manufacturers of pre-packaged commodities to assure the measurements quality of their products, and shifts in the operating philosophy of the state and local offices of weights and measures.

The Measurement Assurance Program concept originated over ten years ago as a "self-calibration program" in the mass measurement area [52]. The term "self-calibration" meant that a user who has an instrument requiring calibration will arrange to do it himself using a technique provided by the central laboratory. Self-calibration was seen then to have obvious advantages of providing an evaluation of the users' measurement techniques as well as his instruments. In late 1965 it was decided to develop a self-calibration program in the mass measurement area as a pilot study. By 1967, it was evident that a considerable amount of innovation was required, in philosophy as well as in procedural detail. Philosophically, this self-calibration program required NBS to consider the ability of the organization to use its own standards, and to face up to the fact that it might not know what an NBS calibration really meant at the point of end use. It became obvious that lack of attention to the problems of demonstrating measurement consistency independent of location (an automatic by product of self-calibration) was a failure to assume responsibility for the role of standards in our society.

In 1970, the quality assurance aspects of this "self-calibration" program came to the fore, and the term "measurement assurance program" was coined to describe the expanding program in this field. An NBS Measurement Assurance Program provides to its participants standards, techniques, and data analysis services which allow the participants to know how well their measurement processes work under the conditions prevailing during the Measurement

Assurance Program. If the results are inadequate, a participant can effect the changes needed in his measurement system until adequacy is achieved [130].

Measurement audit packages perform functions similar to the measurement assurance programs. These packages are designed to test the measurement abilities of the technicians and laboratories involved. They consist of a collection of hardware whose properties are known to the auditor but not the auditee. The deftness and precision with which the auditee is able to determine the properties measures his measurement competence [91].

The expansion of scope of state and local weights and measures operations into cooperation with manufacturers in assuring the measurement quality of pre-packaged goods has been discussed earlier in section 2.4.3. There has been a parallel shift in philosophy to transfer of the burden of measurement responsibility from the inspecting agency to the measurer. In 1962 a law became effective in the State of Wisconsin which contained a provision that allowed weights and measures officials to test devices as often as necessary to obtain compliance with the law [96]. It removed the mandatory provision for placing seals on approved devices and left such marking or sealing up to the discretion of the weights and measures official. Under this law, a "Selective Testing Program" was implemented to return to the user the responsibility of selecting, maintaining, and using his weighing and measuring equipment correctly. As one part of the program, the weights and measures officials collect statistics for many of the devices tested. These statistics tell which retailers are doing a good job and which ones a poor one in maintaining their equipment. As a result, enforcement efforts can be focused where they will do the most good, and the retailers doing a good job are rewarded by being able to put their resources where they are productive--in maintaining their equipment in good condition --rather than in dealing with the weights and measures officials on a frequent basis.

#### 4.2.4 Improved Information Resources for the National Measurement System

One major internal result of the National Measurement System study has been a broad awareness of the need of more "how-to" measurement information at all levels of the system. In field after field, it became apparent that NBS could increase the system effectiveness more by the generation of such publications than by almost any technical improvements in its own laboratories. Development of such

publications is underway in a number of areas. Notable are the "metrology guides" of the Electromagnetics Division, two of which have so far been issued [214,215], the "self-study manual" [285] being developed in the field of radiometry and photometry, and the "user's manual" published by the Time and Frequency Division [315]. A long range goal of the NBS Institute for Basic Standards is a "National Measurement System" series of books which will contain factual and how-to information about all aspects of the system.

#### 4.2.5 Automation of Measurements

The application of automatic data taking and processing techniques to the field of measurement is having a revolutionary impact. Briefly, the machine is augmenting man's brain power in the field of measurements, along the lines discussed philosophically by Dr. Noble in his essay cited in section 4.2.1. The measurement process is no longer limited by the limitations of man's brain: its ability to get bored, to get confused, to make unpredictable mistakes, its difficulty in dealing with simultaneous complexity--many different things or too much all at once. The most significant impact of automation occurs when it augments man or goes beyond his limitations.

Among the obvious benefits of automation of the measurement process are speed (simply doing what a person has previously done or could reasonably do, only faster) and cost (often a direct result of speed). Somewhat less obvious are reliability (the machine can be inherently more reliable than man, and it can be inherently easier to reliably monitor that reliability), and the machine's ability to master complexity in memory processes and computation: The machine can remember complex correction conditions and complex data reduction instructions and apply these reliably, rapidly, at low cost, in a manner that a human being finds impractically difficult. Further, then is the machine's adaptive capability: it can determine in real time the appropriate corrections and computational processes for the measurement being made. In addition the machine is able to make inherently better measurements than a man can ever make, simply because it can do so many things so fast, that *drift* effects that have long plagued precision measurements either simply vanish or can be determined and corrected out.

In a similar vein, the computation can follow the transients of the measurement process and extrapolate to a steady state, without having to wait for the steady state to exist. Implicit in all of this latter discussion is the fact that the machine can *control* the measurement process in real time, to optimize

that process and its results. The machine controls the measurement process, senses the raw measurement data, computes meaningful data output, and feeds back the results into the control function to optimize the ultimate product.

The ultimate revolutionary impact of automation on the measurement system is due to the synergistic or compounding effect of all of the advantages that the "brain-machines" offer. Any one by itself may be of relatively minor importance, but the net effect of the whole array is truly astounding. Another approach to the same point can be gotten by following the logic that says that a man can do anything that a computer can do, it just normally takes a little longer, and he is more likely to make (obscure) mistakes, and he has to spend some time correcting his mistakes. This is true, but ultimately, the argument breaks down ("a man can do anything a computer can") because it takes so much time and energy to correct the mistakes made in correcting the mistakes made in correcting the mistakes...made in the original computation, that no man or group of men can work long enough to get the job done in the massive, complex calculations that computers make in minutes today. When this phenomenon is tied in with the problems of drift in the measurement process, it becomes clear that machines can in fact make measurements that an unaided man can never do.

Often, automation (computers) has been employed in the measurement process as simply a replacement for man, and only a few of the ultimate benefits have been achieved. However, major exceptions exist:

A. In the mid-1960's, computer controlled X-ray crystallography machines became available that could do in hours and days the work that previously took weeks and months.

B. Automated radio-frequency and microwave measurement techniques are allowing measurements to be made that were previously impossible. The machines can make measurements so rapidly at a given frequency, and apply all necessary correction factors, that it is now possible to obtain measurement results as a function of frequency with the data points spaced closely enough to reveal many new features of equipment performance, with each datum point possessing an accuracy equal to the best of the old, laborious, manual single-frequency measurements. Another way to state this point is to note that it is now possible to obtain the equivalent of "swept" measurements (data taken while the frequency is being continuously changed) without any sacrifice of precision



or accuracy relative to fixed frequency measurements. On the purely economic side, these machines are allowing far more information to be obtained about devices being calibrated than with the previous manual techniques, far more rapidly, at a lower total cost.

C. The NBS automated noise-factor measurement techniques developed a few years ago illustrate another major benefit of automation: Because measurements could now be made in hours and days that formerly took weeks and months, the creativity of the scientists working in this area was unleashed. Ideas that were formerly dismissed without experimentation--because it would simply take too long to try them out and cost too much--can now be tested in hours or days--and they *are* tested. Thus automation is not a depressant to creativity, it is a powerful stimulant.

D. Numerically controlled machine tools and automated factories using them provide another example. Because dimensional instructions can be developed by computer and fed to the machines by computer, the whole production process can be (and has been in some cases) revolutionized. Limitation of the number of different varieties of product produced is no longer essential to productivity. Every job can be a custom job, with very little or no increase in cost. The measuring equipment automatically measures the dimensions appropriate for the job, and the product gets made.

E. On a "trivial" or primitive scale, automation has been with us in the measurement field for decades, in the form of control instrumentation that senses the environment, compares the result with a control setting, and then automatically takes the action that it has been set to do.

#### 4.2.6 Metrication

As the U.S. Metric Study [98,99-110,113] and developments since 1971 clearly show [226,231, 234,238,245,248,281,290], a major trend in the U.S. measurement system is toward substantially increased use of the metric system. In the words of the report of that study [98]:

"Many times in the last two centuries, the Congress considered the merits of adopting the metric system as America's primary language of measurement. Each time, action was postponed, often because the metric system was not then in use by our major trading partners abroad. Now, with every other major nation converted to metric or committed to conversion, this obstacle has been removed."

"The U.S. Metric Study concludes that eventually the United States will join the rest of the world in the use of the metric system as the predominant common language of measurement. Rather than drifting to metric with no national plan to help the sectors of our society and guide our relationships abroad, a carefully planned transition in which all sectors participate voluntarily is preferable."

"The basis for the conclusion that the U.S. will eventually be metric lies in the findings of the Study that America is already metric in some respects; that we are becoming more so; and that the great majority of businessmen, educators and other informed participants in the Study reported that increased use of the metric system is in the best interests of America. They also believe that it is better for the nation to move to metric by plan rather than by no plan at all."

"On the basis of all the factors that were considered, the Study concludes that it would be best for the nation to change to metric under a coordinated program that provides for flexibility and encourages the various sectors of society to deal with their particular problems voluntarily. Within this framework, these sectors would work out their own timetables and programs, dovetailing them with those of other sectors."

In his letter of transmittal to the Congress, the Secretary of Commerce recommended [98]:

- That the United States change to the International Metric System deliberately and carefully;
- That this be done through a coordinated national program;
- That the Congress assign the responsibility for guiding the change, and anticipating the kinds of special problems described in the report, to a central coordinating body responsive to all sectors of our society;
- That within this guiding framework, detailed plans and timetables be worked out by these sectors themselves;
- That early priority be given to educating every American schoolchild and the public at large to think in metric terms;
- That immediate steps be taken by the Congress to foster U.S. participation in international standards activities;
- That in order to encourage efficiency and minimize the overall costs to society, the general rule should be that any changeover costs shall "lie where they fall";
- That the Congress, after deciding on a plan for the nation, establish a target



date ten years ahead, by which time the U.S. will have become predominantly, though not exclusively, metric;  
-That there be a firm government commitment to this goal."

Congress responded to these recommendations by passing two pieces of legislation [281 290]. The Education Amendments of 1974, P.L. 93-380 authorized a Metric Education Program to be managed by the U.S. Office of Education. The Metric Conversion Act of 1975, P.L. 94-168, declared "a national policy of coordinating the increasing use of the metric system in the United States," and established "a United States Metric Board to coordinate the voluntary conversion to the metric system."

Aside from the fundamental fact of metric conversion itself, the main impacts on the measurement system of metrication appear to be the following:

A. A substantial emphasis on metrology and metrication in education, primarily at the elementary, vocational, and continuing adult educational levels. As a result of the focus on *metrication*, there will also be a renewed emphasis on *metrology per se*. Today, metrology is dominantly a step-child in the educational system of arithmetic, the vocational arts and the sciences. If the leaders in metrological education can have a significant influence on the general educators and publishers as they respond to the needs of education for metrication, then the whole educational basis of the measurement system could be profoundly strengthened.

B. Publicity about metrication can also be highly supportive of the essential role of the measurement system. The national awareness of the important role of measurements can be substantially increased. The awareness at the measurement-related worker level almost inevitably will be increased.

C. Housecleaning: As a result of metrication, many obsolete tools, instruments, practices, and procedures will be swept away and replaced, where appropriate, with a metric version.

D. Instrumentation: A minor but significant increase in the sales volume of the instrumentation industry should occur, as any inherently essential new metric instrumentation is bought and as marginally obsolete "customary unit" equipment is retired somewhat earlier than would otherwise have happened. However, the major impact would appear to be in the repair,

maintenance, and recalibration service industry in the instrumentation field, where it appears that the work force may need to expand substantially in order to handle the task of converting useful existing equipment from reading in customary units to reading in metric units. A side benefit of this expanded service effort is that the total array of instrumentation in the field is likely to be in better working order at the end of any formal changeover period than it is at the beginning, simply because more of it will have received much more thorough attention during this process.

It is important to note that the only measurement units affected directly by metrication are length, mass, temperature, and their derivatives. Time, electrical, photo-metric, and chemical units are not directly affected. Therefore, not all parts of the instrumentation industry will be affected by metrication.

Costs and benefits are hard to assess quantitatively. Clearly, the conversion will not be made without some costs, at least the mental effort of planning the conversion. Clearly, also, the measurement system will be stronger after the conversion.

#### 4.2.7 Science

As discussed in sections 2.2.6 and 2.2.7, scientific developments during the past 35 years have put us in a position to nearly realize the dream of the founders of the metric system, of a universal system for physical measurements founded on natural law, fundamental constants, and a single material constant of nature. The single material constant would be a microwave transition of the cesium atom. The key developments include:

Microwave technology, essential for the cesium frequency standard.

Nuclear science and technology, and the ability to create monoisotopic chemical species.

The laser.

Superconductivity, especially the superconducting tunnel junction (Josephson junction).

Semiconductor science and technology, with special emphasis on high purity silicon.

Computer and "brain-power extension" technologies.

It appears that all of the essential scientific components for a "new metrology" are in hand, and that the next quarter century will be devoted to completing and solidifying the revolution that began over a quarter of a century ago.

## 5. SUMMARY

Measurement is essential for obtaining objective knowledge about the physical universe. We use this knowledge for communication and control in many aspects of our lives: on the personal level, in science and technology, in industry and commerce, in governmental regulation. The measurement data used by our society are generated by the National Measurement System, which comprises the totality of the activities and mechanisms employed for this purpose. These activities and mechanisms can be usefully discussed as either technical or institutional: It takes both tools and people working in an organized fashion to get the job done. The technical tools include the basic conceptual system of measurement quantities, units and standards; physical standards, instrumentation and operating instructions; reference data and reference materials; documentary agreements concerning all of the above; and a basic core of knowledge or science. The institutional mechanisms in this country include the National Bureau of Standards, state and local offices of weights and measures, standards and testing laboratories and services, governmental regulatory agencies, documentary standardization institutions, and the instrumentation industry. All of these depend upon a central core of competent, educated people. The major trends of the system are toward increased complexity, increased integration, improved quality control, improved information resources, automation, metrication, and consolidation of a major metrological revolution based on the scientific developments of the past 35 years.





APPENDIX A. MEASUREMENT SYSTEM INTERACTION DIAGRAMS

These charts are a simplified picture of how NBS actions affect users' problems in physical measurements, through various agencies and institutions. Each series for one technical area is typically composed of four charts:

(1) FIELD PROBLEMS -- in square boxes -- measurement problems as users see them -- and USERS -- in ovals -- identified user groups with an economic or safety stake in the solution of the problems.

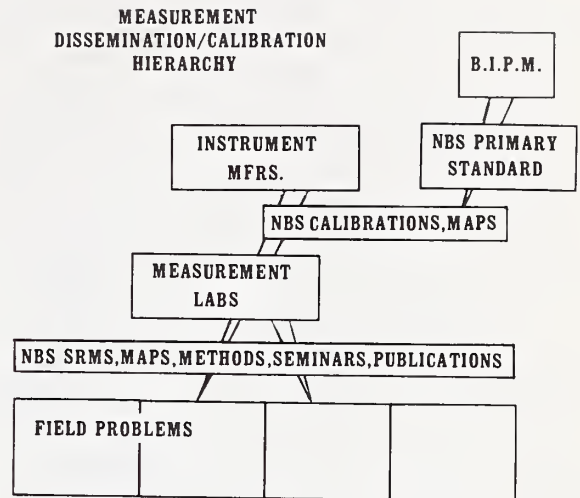
(2) MEASUREMENT DISSEMINATION/CALIBRATION HIERARCHY. Arrows proceeding downward indicate the flow of instruments and services, from instrument manufacturers to measurement laboratories, to their use on the problems. Crossing these arrows are boxes which illustrate NBS impacts such as calibration services, measurement assurance programs (MAP's), standard reference materials (SRM's), and maintenance of base standards.

(3) VOLUNTARY/DOCUMENTARY STANDARDS SYSTEM. Arrows proceeding upward from user groups depict the flow of aspirations and technical expertise through industrial and professional associations, to the standards-writing groups. The output of these (larger arrows) flows to international bodies, or into adoption by regulatory agencies. Key NBS memberships and leverage points are indicated in boxes.

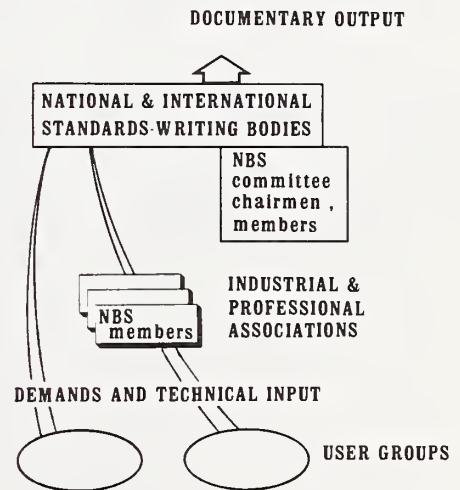
(4) REGULATORY/MANDATORY CONTROL SYSTEM. Downward arrows go from regulatory agencies to the problems which they regulate, or from mandatory control groups to the area in which work is impermissible without their sanction. Important NBS functions, needed for implementation or compliance, are highlighted in boxes.

The total NBS impact for any technical area is the sum of all the "NBS-impact" boxes for the last three kinds of charts. In most cases, this impact is too detailed to present well in a single chart.

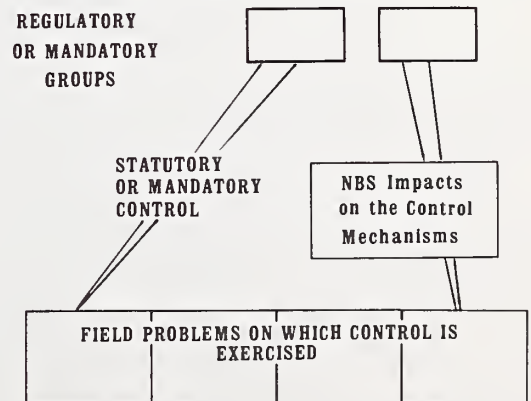
For present purposes, charts have been selected from the total set available [314] to depict the interactions for the six SI base quantities whose units are maintained by the NBS Institute for Basic Standards, plus ionizing radiation. These charts are a result of the first pass by this Institute at using these concepts to describe its program, and are expected to evolve into more definitive forms with future iterations.



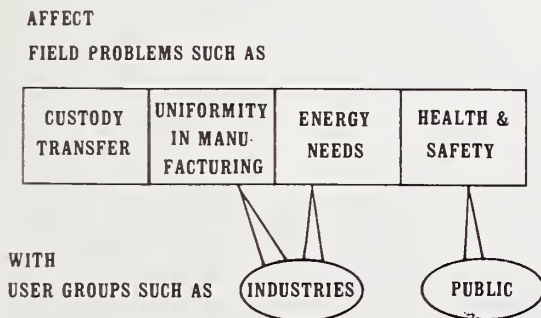
VOLUNTARY/DOCUMENTARY STANDARDS SYSTEM



REGULATORY/MANDATORY CONTROL SYSTEM



NBS TECHNICAL PROGRAMS



The major field problems are shown in the central block of the "measurement dissemination" diagram. *Time of day* is of concern to almost everyone. Telephone companies receive some 5 billion calls per year for the time, and NBS some 2 million. *Celestial navigation* can be a life-and-death matter for approximately 5000 U.S. ships and boats depending upon it as a primary means of navigation, and many more use it for backup. *Precision frequency* demands are steadily growing, in such areas as control of the electric power distribution system and the functioning of sophisticated telecommunications systems. Military demands are the prime driving force for improved *position-location systems*. System design goals of 10 foot accuracy translate into 10 nanosecond time measurements. Loran and Omega systems are currently operational, and initial phases of the multi-billion dollar Global Positioning System are underway.

Major user groups are shown in the ovals at the bottom of the measurement dissemination diagram. The *general public* uses coarse time-of-day information for setting household clocks and personal watches. Most of these clocks maintain their accuracy because the electric power companies watch their frequency rather closely. The *electric power companies* need accurate time and frequency information themselves to control power flow in their systems. As a result of the boom in the solid-state watch business, jewelers now need to check and service watches with rate accuracies of better than a part per million--for this they need NBS services, and many do use WWV. *Telecommunications*, historically a primary demand area for accurate frequency, is still one for commercial broadcasters, ham radio operators, and some of the newest areas of telephony. *Transportation* uses this technology for navigation and position location, and for scheduling. Both commercial airliner and FAA control center station clocks are set with reference to WWV, as often as each eight-hour shift. Private aircraft are beginning to use electronic navigation systems, and the boat owner is a continuing user. The *military* has always been a key figure in time and frequency measurement systems, with needs in such areas as accurate position location and precisely synchronized "time-ordered communication systems." *Astronomy*, the original supplier of precise time data, is not often a user.

Other parts of *science and technology* are also key users; for instance, seismologists use WWVB signals to date events in remotely located strong-motion sensors, and the NASA space program depends heavily on accurate time and frequency.

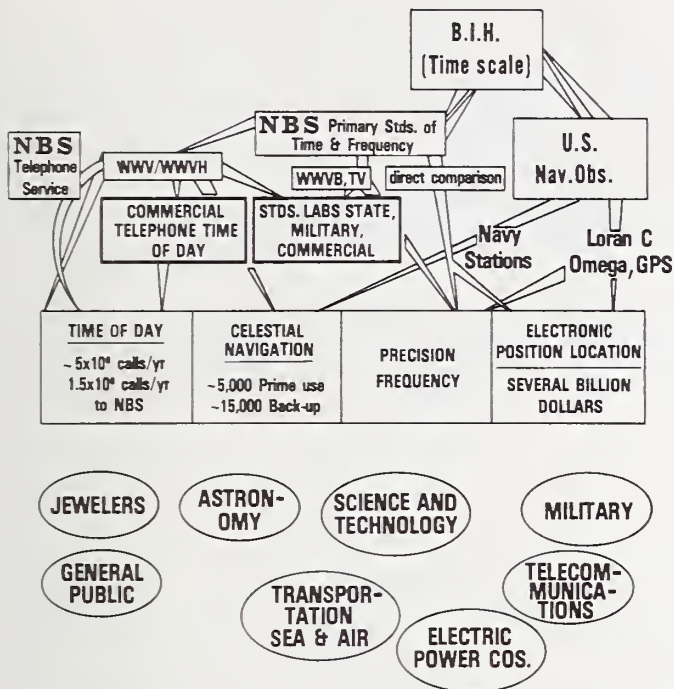
Measurement Hierarchy: The final authority in the world for time is the *International Time Bureau (BIH)*, which uses input from atomic clocks and frequency standards operating in various labs all over the world. NBS uses an ensemble of commercial atomic clocks and two primary frequency standards to maintain time scales which both support BIH and also serve as references for NBS dissemination services. Of these services, the most well-known are the radio stations WWV and WWVB in Colorado and WWVH in Hawaii. These radio stations serve a very large number of users directly, and an even greater number indirectly, through commercial telephone time-of-day services or through standards laboratories which, for example, calibrate TV broadcast frequencies. NBS also

calibrates routinely the TV network color subcarrier, and commercial equipment to use this calibrated signal is readily available. The NBS telephone service has been previously mentioned. The *U.S. Naval Observatory* has a large bank of atomic clocks, used to provide input to BIH and dissemination services to the military; it steers the phase of certain military and navigation broadcasts and provides time-of-day announcements on certain Navy stations. Because of the close coordination and cooperation between NBS and USNO, the NBS services are totally acceptable within the military and are endorsed by USNO as important to the DoD in efficiently meeting military time and frequency requirements.

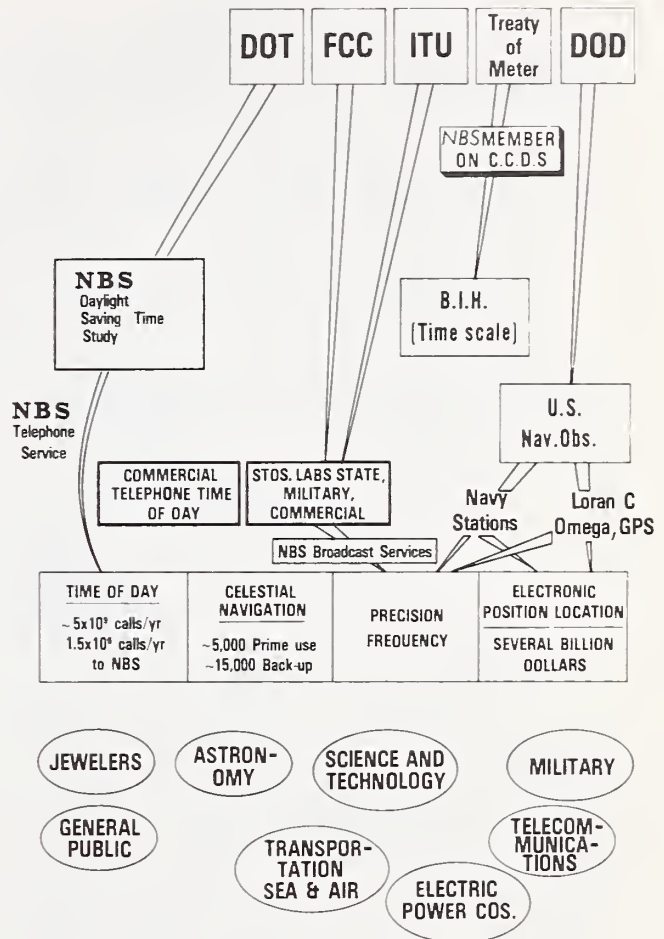
Voluntary Standards Structure. The center of control is the CCIR (*International Radio Consultative Committee*). The CCIR is formally only advisory to the International Telecommunications Union (ITU) under the U.N. In practice, the CCIR resolutions have virtually the force of international law in that no country goes counter to these resolutions. Thus, this system, while formally voluntary, is operating so powerfully as to be almost not "voluntary". This situation reflects the fact that time and frequency are so important internationally that close coordination and cooperation are in everyone's best interest. NBS is well represented on the CCIR.

Mandatory Standards. The *Department of Transportation* is the enforcing authority of the Uniform Time Act. The FCC regulates most of the telecommunications system, and depends upon NBS for accurate frequency information. The internationally accepted definitions of time, time interval, and frequency are handled by the organizations of the *treaty of the meter*. NBS participates on the Consultative Committee for the Definition of the Second (CCDS). Within the DoD, the *U.S. Naval Observatory* is the central authority for precise time and frequency matters.

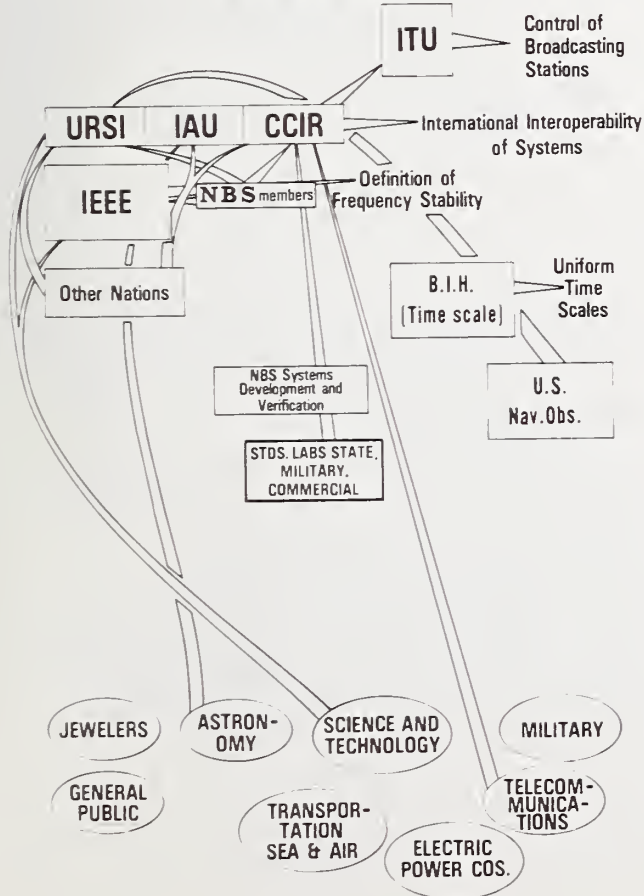
## TIME & FREQUENCY MEASUREMENT DISSEMINATION



## TIME & FREQUENCY MANDATORY SYSTEM



## TIME & FREQUENCY VOLUNTARY STANDARDS SYSTEM

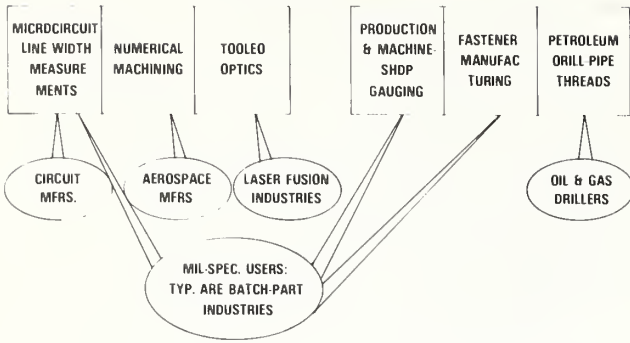


## TIME AND FREQUENCY GLOSSARY

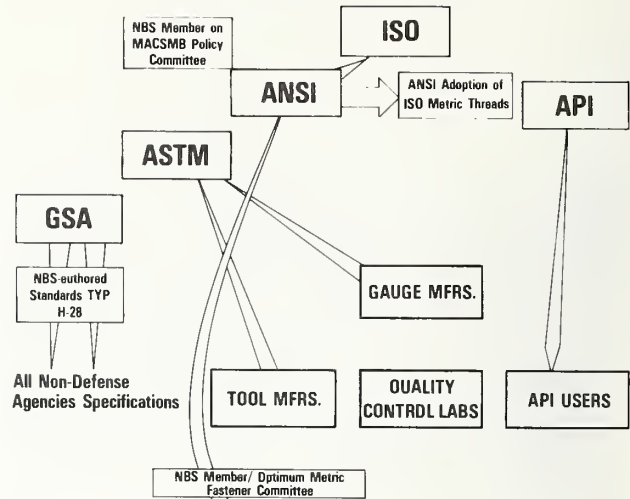
- B. I. H. - Bureau International de l'Heure
- WWV, WWVH, WWVB - NBS broadcast stations
- TV - NBS precision monitoring of TV network color carrier frequencies
- U. S. Nav. Obs. - U. S. Naval Observatory, Washington, D. C.
- Lorán C - low frequency navigation system
- Omega - world-wide long-range navigation system
- GPS - proposed global positioning system, using satellites
- ITU - International Telecommunications Union
- URSI - International Radio Scientific Union
- IAU - International Astronomical Union
- CCIR - International Radio Consultative Committee
- IEEE - Institute of Electrical and Electronic Engineers
- DOT - Department of Transportation
- FCC - Federal Communications Commission
- DOD - Department of Defense
- CCDS - Comité Consultatif pour la Définition de Seconde (technical committee supportive of B. I. H.)



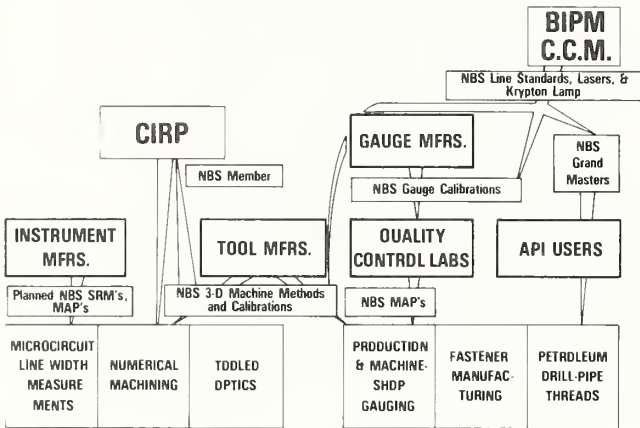
**LENGTH AND DIMENSIONAL MEASUREMENTS  
FIELD PROBLEMS AND USERS**



**LENGTH AND DIMENSIONAL MEASUREMENTS  
DOCUMENTARY STANDARDS**



**LENGTH AND DIMENSIONAL MEASUREMENTS  
MEASUREMENT DISSEMINATION**



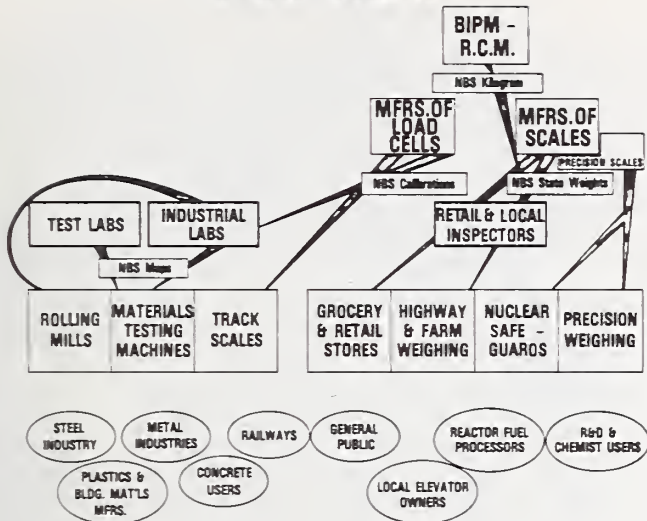
Production \$2 B  
Measurements: 920 M

Value Added \$485 B  
Measurements: 99 B  
Gauge Shipments: \$1.2 B

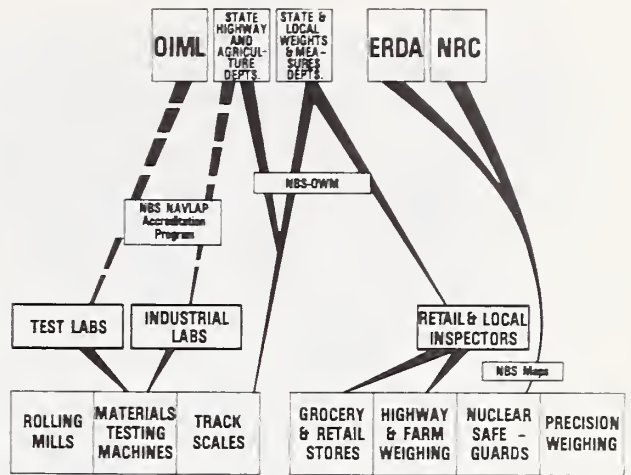
**LENGTH AND DIMENSIONAL MEASUREMENTS GLOSSARY**

- CIRP - International Institute for Production Engineering Research
- BIPM - Bureau International des Poids et Mesures
- C.C.M. - Comite Consultatif du Metre (advisory to BIPM)
- SRM - Standard Reference Material
- MAP - Measurement Assurance Program
- API - American Petroleum Institute
- GSA - General Services Administration
- ASTM - American Society for Testing and Materials
- ANSI - American National Standards Institute
- ISO - International Standards Organization
- MACSMB - a senior policy committee of ANSI

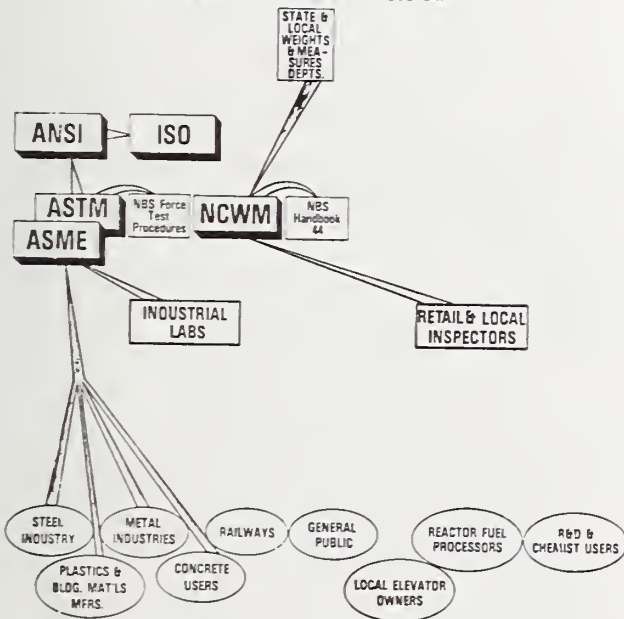
**MASS & FORCE  
MEASUREMENT DISSEMINATION**



**MASS & FORCE  
REGULATORY-MANDATORY SYSTEM**



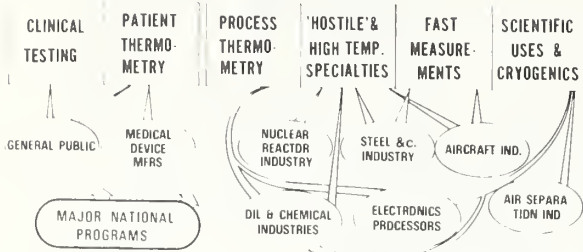
**MASS & FORCE  
VOLUNTARY-DOCUMENTARY SYSTEM**



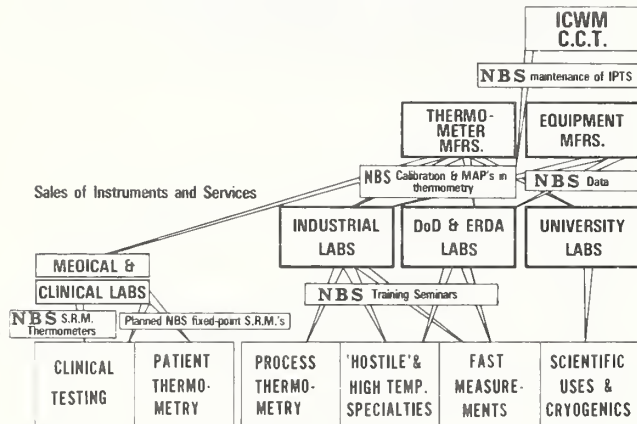
**MASS AND FORCE GLOSSARY**

- ASTM - American Society for Testing and Materials
- ANSI - American National Standards Institute
- ISO - International Standards Organization
- ASME - American Society of Mechanical Engineers
- NCWM - National Conference of Weights and Measures
- OIML - International Organization of Legal Metrology
- NAVLAP - National Voluntary Laboratory Accreditation Program
- OWM - Office of Weights and Measures
- ERDA - Energy Research and Development Administration
- NRC - Nuclear Regulatory Commission

**TEMPERATURE  
FIELD MEASUREMENT PROBLEMS  
AND USERS**



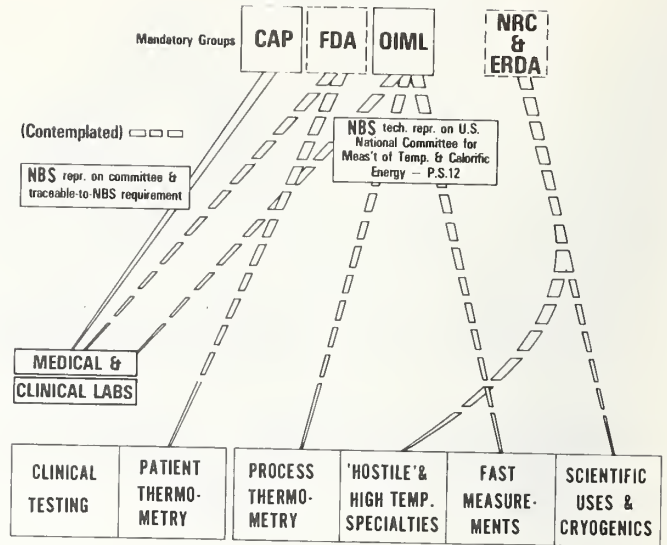
**TEMPERATURE  
MEASUREMENTS CALIBRATION HIERARCHY**



12,000 U.S. Hospitals  
2 Billion Clinical Tests per Year  
Affected by Thermometer Accuracy  
50 percent may be out of control.

ANNUAL VOLUME  
190 M in Thermometers  
1427 M in Equipment

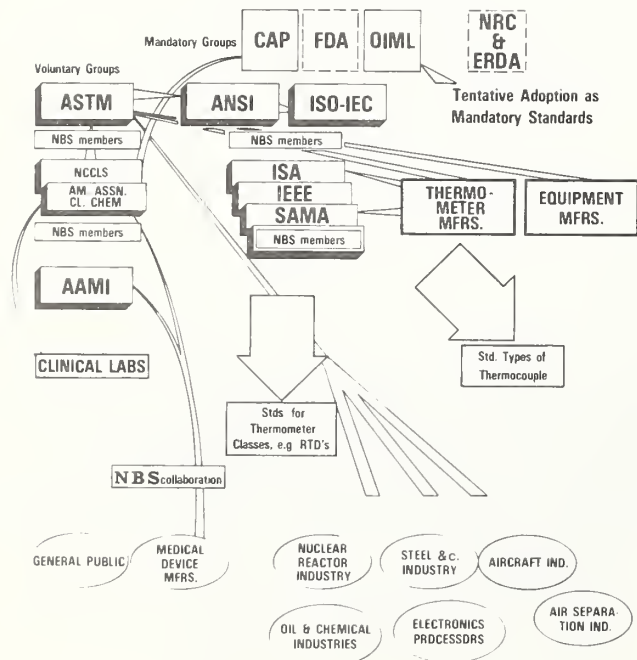
**TEMPERATURE  
MANDATORY STANDARDS**



**TEMPERATURE GLOSSARY**

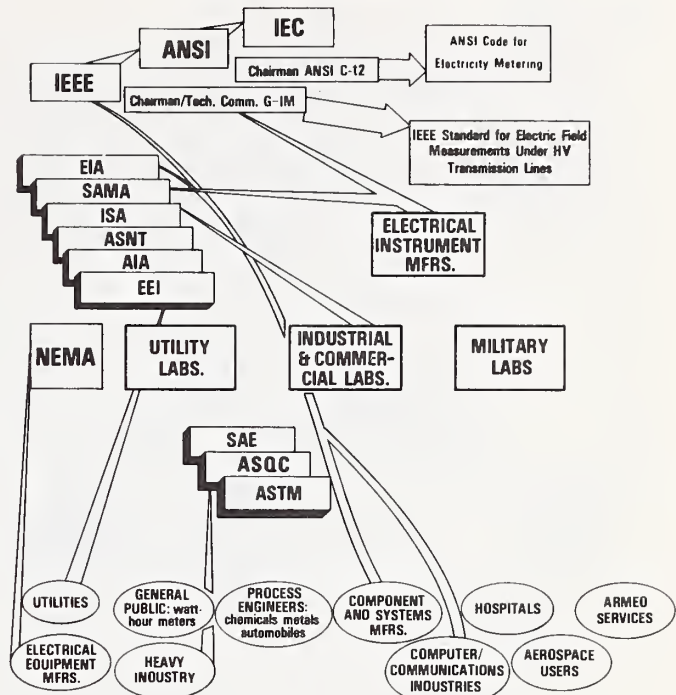
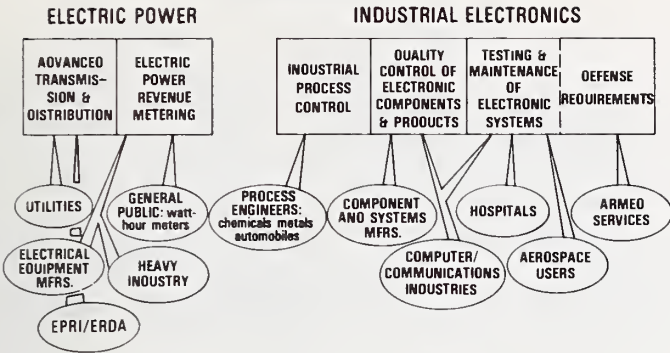
- ICWM - International Committee of Weights and Measures (supervisory to BIPM)
- CCT - Comite Consultatif de Thermometrie - (advisory to ICWM)
- IPTS - International Practical Temperature Scale
- MAP - Measurement Assurance Program
- SRM - Standard Reference Material
- CAP - College of American Pathologists
- FDA - Food and Drug Administration
- OIML - International Organization of Legal Metrology
- NRC - Nuclear Regulatory Committee
- ERDA - Energy Research and Development Administration
- ASTM - American Society for Testing and Materials
- ANSI - American National Standards Institute
- ISO-IEC - International Standards Organization-International Electrotechnical Commission
- NCCLS - National Committee for Clinical Laboratory Standards
- Am. Assn. Cl. Chem. - American Association for Clinical Chemistry
- AAMI - American Association for Medical Instrumentation
- ISA - Instrument Society of America
- IEEE - Institute of Electrical and Electronic Engineers
- SAMA - Scientific Apparatus Makers Association
- RTD - Resistance Thermometer Device
- P.S. - Pilot Secretariat

**TEMPERATURE  
VOLUNTARY STANDARDS SYSTEM**



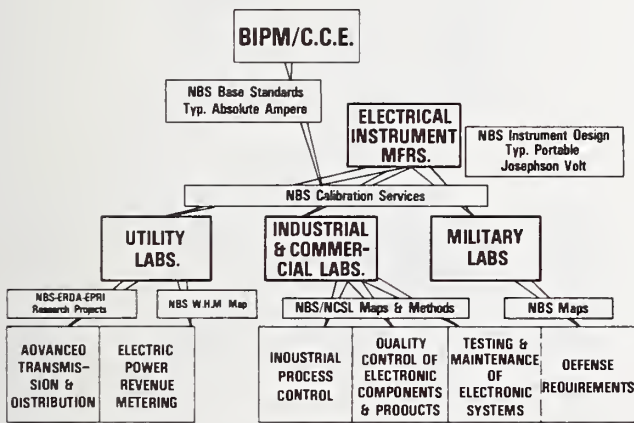


VOLUNTARY-DOCUMENTARY SYSTEM



ELECTRICAL QUANTITIES

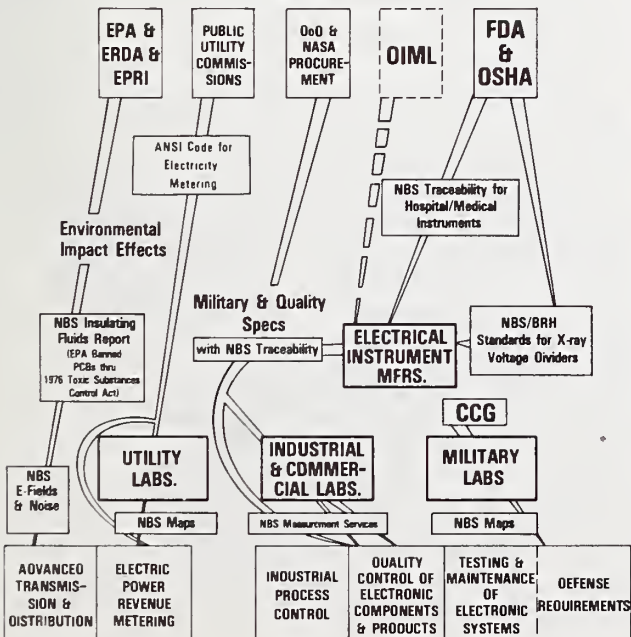
MEASUREMENT DISSEMINATION



Capital Spending = \$7B/yr (ERDA & EPRI T&D Budgets = \$85M/yr.)  
 Power Consumed = \$60B/yr.  
 \$26B of Industrial Electronics in 1976  
 Test Equipment Market = \$1.1B  
 DoD Spends \$85M/yr. to Calibrate \$1.8B of Test Equipment

ELECTRICAL QUANTITIES

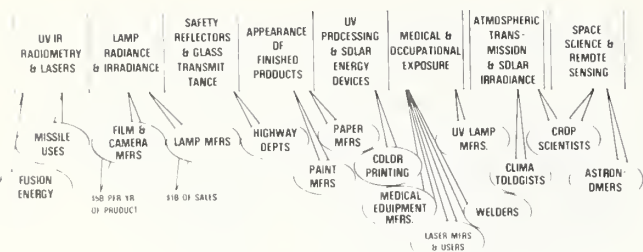
REGULATORY CONTROL



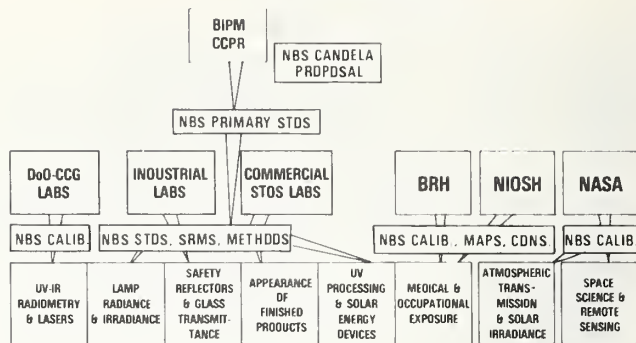
ELECTRICAL QUANTITIES GLOSSARY

- EPRI - Electric Power Research Institute
- ERDA - Energy Research and Development Administration
- BIPM - Bureau International des Poids et Mesures
- C.C.E. - Comite Consultatif d'Electricite (adv. BIPM)
- W.H.M. - Watthour Meter
- MAP - Measurement Assurance Program
- NCSL - National Conference of Standards Laboratories
- DOD - Department of Defense
- IEEE - Institute of Electrical and Electronic Engineers
- ANSI - American National Standards Institute
- IEC - International Electrotechnical Commission
- Tech. Comm. A-IM - Technical Committee of the IEEE Group in Instrumentation and Measurement
- EIA - Electronics Industry Association
- SAMA - Scientific Apparatus Makers' Association
- ISA - Instrument Society of America
- ASNT - American Society for Non-Destructive Testing
- AIA - Aerospace Industries Association
- EEI - Edison Electrical Institute
- NEMA - National Electrical Manufacturers' Association
- EPA - Environmental Protection Administration
- NASA - National Aeronautics and Space Administration
- OIML - International Organization of Legal Metrology
- FDA - Food and Drug Administration
- OSHA - Occupational Safety and Health Administration
- PCB - Polychlorobiphenyl (insulating fluid)
- BRH - Bureau of Radiological Health
- CCG - Department of Defense Calibration Coordination Group

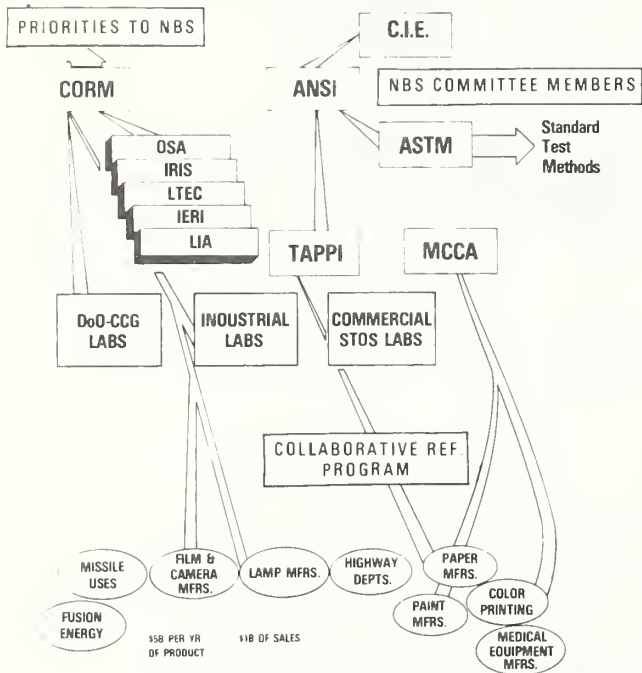
**RADIOIMETRY  
FIELD PROBLEMS PLUS USERS**



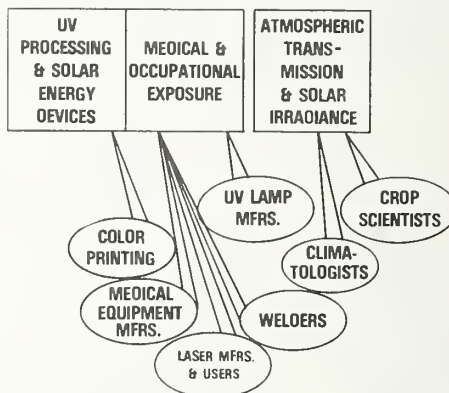
**RADIOIMETRY  
MEASUREMENT DISSEMINATION**



**RADIOIMETRY  
VOLUNTARY STANDARDS SYSTEM**



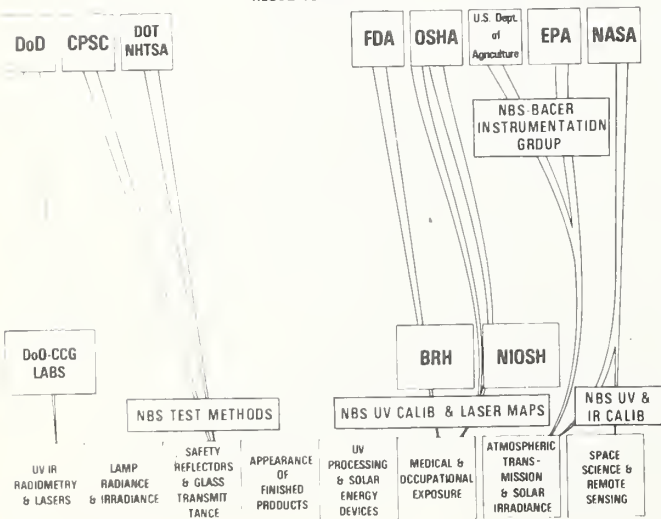
**RADIOIMETRY  
LASER AND ULTRAVIOLET EXPOSURE**



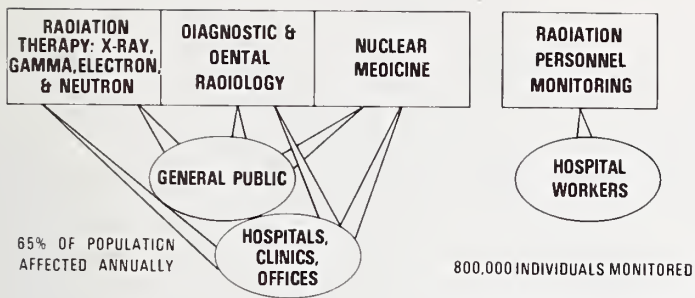
**RADIOIMETRY GLOSSARY**

- UV - Ultraviolet
- IR - Infrared
- BIPM - International Bureau of Weights and Measures
- CCPR - Comite Consultatif de Photometrie et Radiometrie (consultative to BIPM)
- DOD-CCG - Department of Defense Calibration Coordination Group
- BRH - Bureau of Radiological Health
- NIOSH - National Institute of Occupational Safety and Health
- NASA - National Aeronautics and Space Administration
- SRM's - Standard Reference Materials
- CORM - Council for Optical Radiation Measurements
- C.I.E. - International Commission on Illumination
- ANSI - American National Standards Institute
- ASTM - American Society for Testing and Materials
- TAPPI - Trade Association of the Pulp and Paper Industry
- MCCA - Manufacturers Council on Color and Appearance
- OSA - Optical Society of America
- IRIS - Infrared Information Symposium
- LTEC - Lamp Testing Engineers' Conference
- IERI - Illumination Engineering Research Institute
- LIA - Laser Institute of America
- CPSC - Consumer Product Safety Commission
- DOT/NHTSA - Department of Transportation/National Highway Safety Administration
- OSHA - Occupational Safety and Health Administration
- EPA - Environmental Protection Administration
- BACER - Biological and Climatic Effects Research Program

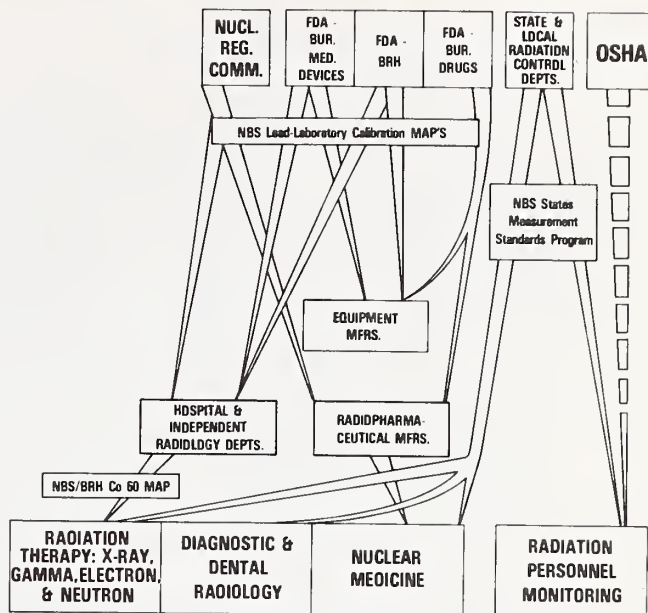
**RADIOIMETRY  
REGULATORY SYSTEM**



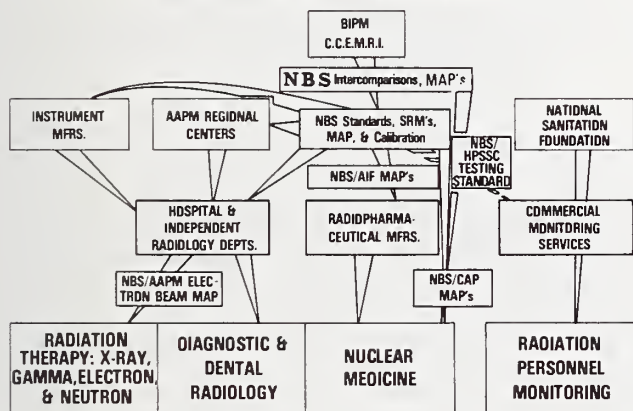
**MEDICAL RADIATION USERS**



**MEDICAL RADIATION: REGULATORY SYSTEM**



**MEDICAL RADIATION MEASUREMENT CALIBRATION**



**MEDICAL RADIATION GLOSSARY**

- BIPM - International Bureau of Weights and Measures
- C.C.E.M.R.I. - Comite Consultatif pour les Etalons de Mesure des Rayonnements Ionizants (advisory to BIPM)
- MAP's - Measurement Assurance Programs
- AAPM - American Association of Physicists in Medicine
- SRM - Standard Reference Material
- AIF - Atomic Industrial Forum
- HPSC - Health Physics Society Standards Committee
- CAP - College of American Pathologists
- ISO - International Standards Organization
- IEC - International Electrotechnical Commission
- ANSI - American National Standards Institute
- ICRU - International Commission on Radiation Units and Measurements
- ICRP - International Commission on Radiological Protection
- NCRP - National Council on Radiation Protection and Units
- ACR - American College of Radiology
- ASTR - American Society of Therapeutic Radiologists
- RSNA - Radiological Society of North America
- OIML - International Organization for Legal Metrology
- EPA - Environmental Protection Administration
- ADA - American Dental Association
- SNM - Society for Nuclear Medicine
- RRS - Radiation Research Society
- HPS - Health Physics Society
- Nucl. Reg. Comm. - Nuclear Regulatory Commission
- FDA - Food and Drug Administration
- Bur. Med. Devices - Bureau of Medical Devices
- BRH - Bureau of Radiological Health
- Bur. Drugs - Bureau of Drugs
- OSHA - Occupational Safety and Health Administration (Department of Labor)
- MAP's - Measurement Assurance Programs
- Co60 - Cobalt 60 (gamma-ray Radiotherapy Source)

**MEDICAL RADIATION: DOCUMENTARY STANDARDS SYSTEM**

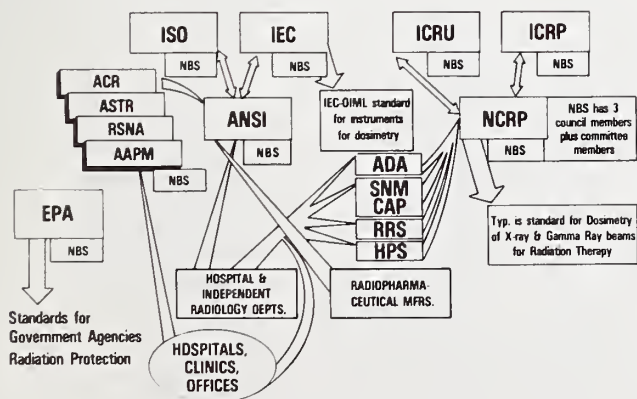




Table B-1. SI base units

Quantity	Name	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

Table B-2. SI supplementary units

Quantity	Name	Symbol
plane angle	radian	rad
solid angle	steradian	sr

Table B-3. SI prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
$10^{12}$	tera	T	$10^{-1}$	deci	d
$10^9$	giga	G	$10^{-2}$	centi	c
$10^6$	mega	M	$10^{-3}$	milli	m
$10^3$	kilo	k	$10^{-6}$	micro	$\mu$
$10^2$	hecto	h	$10^{-9}$	nano	n
$10^1$	deka	da	$10^{-12}$	pico	p
			$10^{-15}$	femto	f
			$10^{-18}$	atto	a

Table B-4. Examples of SI derived units expressed in terms of base units

Quantity	Name	Symbol
area	square metre	$m^2$
volume	cubic metre	$m^3$
speed, velocity	metre per second	m/s
acceleration	metre per second squared	$m/s^2$
wave number	1 per metre	$m^{-1}$
density, mass density	kilogram per cubic metre	$kg/m^3$
concentration (of amount of substance)	mole per cubic metre	$mol/m^3$
activity (radioactive)	1 per second	$s^{-1}$
specific volume	cubic metre per kilogram	$m^3/kg$
luminance	candela per square metre	$cd/m^2$

Table B-5. Examples of SI derived units formed by using supplementary units

Quantity	Name	Symbol
angular velocity	radian per second	rad/s
angular acceleration	radian per second squared	$rad/s^2$
radiant intensity	watt per steradian	W/sr
radiance	watt per square metre steradian	$W \cdot m^{-2} \cdot sr^{-1}$

Table B-6. SI derived units with special names

Quantity	Name	Symbol	Expression in terms of other units	Expression in terms of SI base units
frequency	hertz	Hz		$s^{-1}$
force	newton	N		$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	$N/m^2$	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	$J/s$	$m^2 \cdot kg \cdot s^{-3}$
quantity of electricity, electric charge	coulomb	C	$A \cdot s$	$s \cdot A$
electric potential, potential difference, electromotive force	volt	V	$W/A$	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	$C/V$	$m^2 \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	$\Omega$	$V/A$	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
conductance	siemens	S	$A/V$	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	$Wb/m^2$	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	$Wb/A$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
luminous flux	lumen	lm		$cd \cdot sr$ (a)
illuminance	lux	lx		$m^{-2} \cdot cd \cdot sr$ (a)

(a) In this expression the steradian (sr) is treated as a base unit.

Table B-7. Units used with International System

Name	Symbol	Value in SI unit
minute	min	1 min = 60 s
hour	h	1 h = 60 min = 3 600 s
day	d	1 d = 24 h = 86 400 s
degree	°	1° = (π/180) rad
minute	'	1' = (1/60)° = (π/10 800) rad
second	"	1" = (1/60)' = (π/648 000) rad
litre	l	1 l = 1 dm <sup>3</sup> = 10 <sup>-3</sup> m <sup>3</sup>
tonne	t	1 t = 10 <sup>3</sup> kg

Table B-8. Units used with International System whose values in SI units are found experimentally

Name	Symbol
electronvolt	eV
unified atomic mass unit	u
astronomical unit	(see def'n c)
parsec	pc

Definitions:

- (a) 1 electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 volt in vacuum; 1 eV = 1.602 19 X 10<sup>-19</sup> J approximately.
- (b) The unified atomic mass unit is equal to the fraction 1/12 of the mass of an atom of nuclide <sup>12</sup>C; 1 u = 1.660 53 X 10<sup>-27</sup> kg approximately.
- (c) This unit does not have an international symbol; abbreviations are used, for example AU in English. The astronomical unit is the length of the radius of the unperturbed circular orbit of a body with negligible mass moving round the Sun with sidereal angular velocity of 0.017 202 098 950 radian per day of 86 400 ephemeris seconds. In the system of astronomical constants of the International Astronomical Union the value adopted for it is: 1 AU = 149 600 X 10<sup>6</sup> m.
- (d) 1 parsec is the distance at which 1 astronomical unit subtends an angle of 1 second of arc; we thus have approximately, 1 pc = 206 265 AU = 30 857 X 10<sup>12</sup> m.

Table B-9. Units to be used with International System for a limited time

Name	Symbol	Value in SI units
nautical mile <sup>1</sup>		1 nautical mile = 1 852 m
knot		1 nautical mile per hour = (1852/3600) m/s
ångstrom	Å	1 Å = 0.1 nm = 10 <sup>-10</sup> m
are	a	1 a = 1 dam <sup>2</sup> = 10 <sup>2</sup> m <sup>2</sup>
hectare	ha	1 ha = 1 hm <sup>2</sup> = 10 <sup>4</sup> m <sup>2</sup>
barn <sup>2</sup>	b	1 b = 100 fm <sup>2</sup> = 10 <sup>-28</sup> m <sup>2</sup>
bar	bar	1 bar = 0.1 MPa = 10 <sup>5</sup> Pa
standard atmosphere	atm	1 atm = 101 325 Pa
gal <sup>3</sup>	Gal	1 Gal = 1 cm/s <sup>2</sup> = 10 <sup>-2</sup> m/s <sup>2</sup>
curie <sup>4</sup>	Ci	1 Ci = 3.7 x 10 <sup>10</sup> s <sup>-1</sup>
röntgen <sup>5</sup>	R	1 R = 2.58 x 10 <sup>-4</sup> C/kg
rad <sup>6</sup>	rad	1 rad = 10 <sup>-2</sup> J/kg

- <sup>1</sup>The nautical mile is a special unit employed in marine and aerial navigation to express distances.
- <sup>2</sup>The barn is a special unit employed in nuclear physics to express effective cross sections.
- <sup>3</sup>The gal is a special unit employed in geodesy & geophysics to express acceleration due to gravity.
- <sup>4</sup>The curie is a special unit employed in nuclear physics to express activity of radionuclides.
- <sup>5</sup>The röntgen is a special unit employed to express exposure of X or γ radiations.
- <sup>6</sup>The rad is a special unit employed to express absorbed dose of ionizing radiations. When there is risk of confusion with the symbol for radian, rd may be used as symbol for rad.

Figure B-1. Metric conversion card [228].

U.S. DEPARTMENT OF COMMERCE  
National Bureau of Standards NBS Special Publication 365  
Washington, D. C. 20234 Revised November 1972

**METRIC CONVERSION CARD**

Approximate Conversions  
to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
	acres	0.4	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons	0.9	tonnes	t
	(2000 lb)			
<b>VOLUME</b>				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D. C. 20402 (Order by SD Catalog No. C13.10: 365/2). Price 10¢.

\*1 in = 2.54 cm (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10: 286.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1972 O-488-480

## APPENDIX C. NBS NATIONAL MEASUREMENT REFERENCE STANDARD ARTIFACTS, INSTRUMENTS & FACILITIES<sup>†</sup>

### C.1. Time and Frequency

Frequency standards: NBS-4 and NBS-6.  
Time standard: NBS clock ensemble.  
Standards services:  
Television calibration  
Telephone  
Radio station broadcasts: WWV, WWVB,  
WWVH, WWVL (experimental)  
Services available:  
Time of day - voice, BCD code  
One-second ticks  
Standard frequencies  
Carrier: 2.5, 5, 10, 15, 20,  
25 MHz  
Audio: 100, 440, 500, 600 Hz  
UT1 corrections

### C.2. Length & Related Dimensional Measurements

#### C.2.1 Absolute standards

Helium lamps (3)  
Cadmium lamps (2)  
Mercury lamps (2)  
Lamb-dip stabilized He-Ne lasers (4)  
Iodine-stabilized He-Ne laser (1)  
Zeeman split stabilized He-Ne lasers (5)

#### C.2.2 Multidimensional comparator: Moore 5Z

#### C.2.3 End standards

Steel gage blocks:

4 8-piece sets, 5-20 inches  
1 8-piece set, 125-500 mm  
2 120/121-piece sets, 0.01-4 inches  
2 121/122-piece sets, 0.5-100 mm  
1 28-piece set, 0.01-0.09 inch  
1 18-piece set, 0.0101-0.019 inch  
1 18-piece set, 0.0501-0.059 inch  
1 4-piece set, 1-4 inches  
1 10-piece set, 0.20001-0.2001 inch  
2 88-piece sets, 0.05-4 inches

Chrome carbide gage blocks:

1 18-piece set, 0.0501-0.059 inch  
1 4-piece set, 1-4 inches

Tungsten carbide gage blocks:

1 82-piece set, 0.05-4 inches

Cermet gage blocks:

2 81-piece sets, 0.05-4 inches

Step blocks: 1

<sup>†</sup>In Spring 1976

#### C.2.4 Line standards

Prototype meter bar  
60 m bench standard, for steel tapes

#### C.2.5 American Petroleum Institute thread gages

Cable drilling connections: 14  
Rotary connection gages: 38  
Extreme line casing plugs: 9

#### C.2.6 Angle standards

Angle blocks: Set NBS-25 (16)  
Set NBS-7 (16)  
Polygons: 1 12-sided  
Indexing tables: 2 7-inch  
Angle generator: 1, range 1000 seconds  
Pentaprisms: 2

#### C.2.7 Other dimensional standards

60° Thread wires: 2 sets of 51  
60° Metric thread wires: 2 sets of 29  
29° Acme best wires: 2 sets of 22  
29° Acme flush: 1 set of 22  
29° Acme worm flush: 1 set of 22  
Gear wires: 1.44 series, set of 13  
1.68 series, set of 23  
1.728 series, set of 22  
1.92 series, 2 sets of 26  
Ball plates: 2  
Plug gages: 2 sets of 16, 0.05 or 1/16  
to 1 inch.  
Ring gages: 5 masters, 0.125-1 inch  
Optical flats: 9 masters, 3-16 inches  
Balls (spheres): 2 sets of 31, 1/16-1 inch  
1 set of 25, 1-25 mm

### C.3. Surface Finish

Computerized surface roughness measuring instrument (re ANSI B46.1).

### C.4. Mass

Prototype kilograms  $K_4$  and  $K_{20}$   
Nichrome kilograms  $N_1$  and  $N_2$   
10,000, 20,000, and 30,000 lb stainless  
steel disc weights

### C.5. Volume

1, 5, 30, 50, and 100 gallon provers

### C.6. Density

Silicon single crystals (4)  
Master hydrometers (about 250)



### C.7. Force

7 deadweight machines for applied forces from 44.5 N to 4.45 MN  
Load cells, 4.45 (3) and 13.3 (4) MN capacity, extend force standards range to 53.4 MN

### C.8. Vibration

Vibration exciters, 2 Hz to 10 KHz (3)  
Interferometer (1)

### C.9. Shock

Shock accelerometer comparator, 50-5000 g peak, 0.5-40 ms half sine

### C.10. Fluid Flow

#### C.10.1 Air flow facilities, velocity

Dual test section wind tunnel, 82 m/s max, 45.7 m/s max. with adjustable pressure gradient

Low velocity wind tunnel, 0.05-15 m/s  
Unsteady flow wind tunnel, 27.4 m/s, fluctuations 0.1-25 Hz at max. amplitude of 50% mean flow

#### C.10.2 Air flow facilities, volume flow-rate

Constant volume collection tank, 1400 l/s max. at 100 kPa and 20°C  
Bell type prover, 0.1-25 l/s at 100 kPa at 20°C  
Mercury sealed piston prover, 1-250 ml/s at 100 kPa and 20°C

#### C.10.3 Water flow facilities, velocity

Open-circuit water tunnel, 2.5 m/s max.

#### C.10.4 Water flow facilities, volume and mass flowrates

Tilting open channel, 280 l/s max.  
Collection in weight tank, 630 kg/s max.

#### C.10.5 Liquid hydrocarbon flow facilities, mass flowrate

Collection in weight tanks, 12.5 and 100 kg/s max.

#### C.10.6 Cryogenic fluid flow metering facilities

Atmospheric gases - liquid N<sub>2</sub> and Ar:  
0.00126-0.0126 m<sup>3</sup>/s, at 0.0125-1.9 MPa, 64-114 K.  
Liquified Natural Gas: 0.00126-0.0126 m<sup>3</sup>/s, at 100 kPa-1.38 MPa, 80-150 K

### C.11. Pressure

Controlled clearance piston gages:  
7x10<sup>8</sup> - 3x10<sup>9</sup> Pa, 0.2% F.S. accuracy  
3x10<sup>8</sup> - 4x10<sup>8</sup> Pa, 0.01%  
3x10<sup>6</sup> - 3x10<sup>8</sup> Pa, 0.006%  
1x10<sup>5</sup> - 4x10<sup>6</sup> Pa, 0.003%  
2x10<sup>8</sup> - 1x10<sup>9</sup> Pa, 0.02% (under construction)

Piston and die: 1x10<sup>9</sup> - 5x10<sup>9</sup>, 1%  
Hg melting line: 1x10<sup>5</sup> - 7x10<sup>8</sup>, 0.04%  
Hg U-tube manometer: 1x10<sup>4</sup> - 2x10<sup>5</sup>, 0.003%

Vacuum-backed piston gage: 2x10<sup>3</sup> - 1x10<sup>5</sup>, 0.003%

Ultrasonic Hg manometer: 1x10<sup>-1</sup> - 1x10<sup>4</sup>, 0.05% (tent.)

Ultrasonic oil manometer: 1x10<sup>-3</sup> - 1x10<sup>2</sup>, 0.1% (tent.)

IR laser interferometric manometer: 1x10<sup>4</sup> - 3x10<sup>5</sup>, 0.0005% (under construction)

### C.12. Temperature

Triple point of water cells (12)  
Platinum resistance thermometers (12)  
Platinum-rhodium thermocouple thermometers (6)  
Freezing point cells: gold, silver, zinc, tin (3 each)  
Superconducting fixed point devices (2)

### C.13. Humidity

Primary standard: gravimetric hygrometer  
Precision generators: Two-pressure; two-temperature (low frost-point)

### C.14. Electricity

#### C.14.1 Resistance

Thomas (NBS) one-ohm standard resistors (5)  
At 10<sup>-5</sup> ohm: Commercial high current standards--1 Wolfe, 1 Reichsanstalt  
At 10<sup>-4</sup> ohm: 1 Wolfe, 1 Reichsanstalt  
At 10<sup>-3</sup> ohm: 1 Wolfe, 1 Reichsanstalt  
At 10<sup>-2</sup> ohm: 3 Reichsanstalt  
At 10<sup>-1</sup> ohm: 3 Reichsanstalt  
At 10<sup>0</sup> ohm: 2 Reichsanstalt, 1 Thomas (NBS) standard resistor

#### C.14.2 Precision apparatus

2 Universal ratio sets, commercial, NBS-specified  
1 Dunfee-Dziuba (NBS) volt ratio standard  
Two-stage (NBS) inductive voltage divider  
One-stage (commercial) inductive voltage divider

- C.14.3 Impedance  
Cutkosky (NBS) calculable capacitor
- C.14.4 Voltage  
Denenstein-Finnegan (NBS) AC Josephson effect apparatus
- C.14.5 AC-DC transfer standards  
12 single-junction Evanohm thermoelements, commercial, NBS specified  
2 multi-junction Evanohm thermoelements, commercial, NBS specified
- C.14.6 Transformers  
Voltage: Petersons (NBS) high voltage current comparator bridge  
Current: 2 Souders (NBS) two-stage transformers
- C.14.7 High voltage and energy  
3 Park (NBS) D.C. high voltage dividers  
Hillhouse (NBS) high voltage capacitor
- C.15. Electromagnetics  
Impedance: 21 precision coaxial air transmission lines  
Reflection coefficient: 8 precision waveguide sections (4-40, 55-65 GHz)  
30 MHz attenuator  
30 MHz phase shift reference standard  
Set of 6 microcalorimeters for power, 10 MHz - 75 GHz  
Sampling oscilloscope (20 ps transition time), for pulse generator and 2-port network transition times, and impulse generator spectrum amplitude  
Pulse delay: precision, adjustable, coaxial air transmission line  
Waveform of voltage and current: reference waveform generator (100 ps transition time)  
Thermal noise sources:  
Coaxial: 3 MHz at 77 K  
3 MHz at 373 K  
30-60 MHz at 77 K  
30-60 MHz at 373 K  
1 GHz tunable at 77 K  
1 GHz tunable at 373 K  
10 MHz - 12 GHz at 77 K  
Waveguide: 8-13 GHz at 1200 K  
12-18 GHz at 1200 K  
50-75 GHz at 1200 K  
2.6-4 GHz at 692 K  
Electric field strength: 2 dipole antennas, 30-400 & 300-1000 MHz  
Magnetic field strength: 10 cm loop antenna, 30 Hz-30 MHz
- Material properties, 1 MHz - 10 GHz:  
2 quartz test rods  
1 quartz test disk  
1 glass test rod  
1 glass test disk  
Antenna measurement facilities:  
15 and 60 m extrapolation ranges, for gain and polarization, 0.5-75 GHz  
Near field scanning range, for radiation pattern, polarization, and gain, 1-75 GHz  
Automatic network analyzer facility, for power, attenuation, and complex impedance, 100 MHz - 18 GHz
- C.16. Medical Ultrasonics  
Total beam power calorimeter  
Set of 5 standard transducers
- C.17. Acoustics  
2 WE type 640 AA microphones  
Acoustic anechoic chamber  
Acoustic reverberation chamber
- C.18. Radiometry and Photometry  
Gold point blackbody (3)  
Variable temperature blackbodies (1 each, 100-600°C and -50 to 100°C)  
Facility for International Practical Temperature measurements above 1064°C  
Facility for automated spectral calibrations (FASCAL, spectral radiance and spectral irradiance measurements)  
Cryogenic blackbody calibration facility  
Luminous intensity standard lamps (NBS 839 group - 8 lamps)  
Luminous flux standard lamps (NBS 526 group - 5 lamps)  
Photodetector characterization facility  
Electrically-based radiant power measuring instrument
- C.19. Spectrophotometry  
Reference transmittance spectrometer  
Directional incidence, hemispherical collector  
Retroreflectance reference instrument  
Gloss measurement instrument
- C.20. Far Ultraviolet Radiometry  
Standard sources:  
Synchrotron radiation (SURF)  
Plasma blackbody  
Hydrogen wall-stabilized arc  
Deuterium lamps (4)  
Standard detectors:  
Windowless photodiodes (5)  
Windowed diodes (8)  
Ion chamber

C.21. Optics

Inverse square bar  
Transmission transfer densitometers (2)  
Reflection densitometer  
Wavefront shearing interferometer  
Scanning microdensitometers (4)

C.22. Lasers

C series calorimeter  
K1 series calorimeter  
K2 series calorimeter  
Q series calorimeter  
BB series calorimeter

C.23. Ionizing Radiation

Free air (3) and cavity (set of 8)  
ionization chambers for x-rays and  
 $^{137}\text{Cs}$ ,  $^{60}\text{Co}$   
Graphite calorimeters (2) for high  
energy electrons  
Thin-film calorimeter for intense  
photon fields  
Radium-beryllium photo-neutron source  
Californium-252 spontaneous fission  
neutron source  
Thermal neutron flux density standard  
P-2 ionization chamber for high energy  
photon fluence  
Faraday cage for high energy electron  
beam current measurement  
Monoenergetic neutron beam facility  
Cobalt-60 irradiation facility  
Cesium-137 irradiation facility  
Intermediate-energy standard neutron  
field (ISNF)  
Uranium-235 fission neutron spectrum  
standard field  
Response-energy calibrated ionization  
chambers and solid state detectors  
for radioactivity (12)

SUMMATION:

Approximately 2200 items  
of 170 different types,  
for about 90 different quantities.



APPENDIX D. NATIONAL STANDARD REFERENCE DATA SYSTEM PUBLICATIONS.

A key-word-in-context technique has been employed in generating the list below, to provide rapid, illustrative access to the substantive content of the publications of the National Standard Reference Data System available in the spring of 1976. To avoid excess length, this list has been abridged from a comprehensive list, by choosing only one entry for each bibliographic item.

The sources of the publications, of use in identifying them on the formal publication lists, are shown in abbreviated form in parenthesis following the permuted title listings. The key to the abbreviations is this:

ASM: American Society for Metals	JR: JILA Report
COM: A translation from the Russian	LBL: Berkeley Particle Data Group, Lawrence Berkeley Laboratory
ICRA: International Copper Research Association	NBSIR: NBS Internal Report
JCPDS: Joint Committee on Powder Diffraction Standards	NBSM: NBS Monograph
JPCRD: Journal of Physical & Chemical Reference Data	NBSTN: NBS Technical Note
JPCRD-S: Supplement to the Journal of Physical & Chemical Reference Data	NSRDS-NBS: NSRDS-NBS Series

Activity Coefficients of Strong Electrolytes in Aqueous Solutions from 0 to 100°C. Theoretical Mean (NSRDS-NBS 24)	Atomic Spectra, Atomic Energy Levels and Multiplet Tables, N I, N II, N III. Selected Tables of (NSRDS-NBS 3, Sec. 5)
Activity Coefficients of Univalent Electrolytes in Water at 25°C. Osmotic Coefficients and Mean (JPCRD 15)	Atomic Spectra, Atomic Energy Levels and Multiplet Tables, H I, D, T. Selected Tables of (NSRDS-NBS 3, Sec. 6)
Air and Air Components. Thermophysical Properties of (TT70-50095)	Atomic Spectra in the Range 15 Å to 25000 Å. Reference Wavelengths from (JPCRD 56)
Air and Its Components. Thermophysical Properties of Liquid (TT69-55092)	Band Gaps in Elemental and Binary Compound Semiconductors and Insulators. Compilation of Energy (JPCRD 22)
Alcohols. Physical and Thermodynamic Properties of Aliphatic (JPCRD-S1)	Bimolecular Gas Reactions. Tables of (NSRDS-NBS 9)
Ammonia as an Ideal Gas. Thermodynamic Properties of (NSRDS-NBS 19)	Binding Energies in Atomic Negative Ions. (JPCRD 68)
Argon from the Triple Point to 300 K at Pressures to 1000 Atmospheres. Thermodynamic Properties of (NSRDS-NBS 27)	Bond Dissociation Energies in Simple Molecules. (NSRDS-NBS 31)
Astrophysical Interest. Partial Grotrian Diagrams of (NSRDS-NBS 23)	Calcium, A Critical Data Compilation. Atomic Transition Probabilities, Vol. II. Sodium Through (NSRDS-NBS 22)
Atmospheric Chemistry. Chemical Kinetic and Photochemical Data for Modelling (NBSTN 866)	Carbon Monoxide between 1060 and 1900 Å. Atlas of the Observed Absorption Spectrum of (JPCRD 4)
Atmospheric Chemistry. Survey of photochemical and Rate Data for Twenty-Eight Reactions of Interest in (JPCRD 27)	Carbon Monoxide. The Band Spectrum of (NSRDS-NBS 5)
Atomic Spectra, Atomic Energy Levels and Multiplet Tables Si II, Si III, Si IV. Selected Tables of (NSRDS-NBS 3, Sec. 1)	Carbonates. High Temperature Properties and Decomposition of Inorganic Salts, Part 2 (NSRDS-NBS 30)
Atomic Spectra, Atomic Energy Levels and Multiplet Tables, Si I. Selected Tables of (NSRDS-NBS 3, Sec. 2)	Charge Exchange. Theory of (Wiley)
Atomic Spectra, Atomic Energy Levels and Multiplet Tables C I, C II, C III, C IV, C V, C VI. Selected Tables of (NSRDS-NBS 3, Sec. 3)	Collision Cross Sections at Low Energies - A Critical Review. Total Electron-Atom (RMP)
Atomic Spectra, Atomic Energy Levels and Multiplet Tables, N IV, N V, N VI, N VII. Selected Tables of (NSRDS-NBS 3, Sec. 4)	Collision Integrals and Second Virial Coefficients for the (m,6,8) Intermolecular Potential Function. Tables of (NSRDS-NBS 47)
	Combustion Products, Vol. 1, Computation Methods. Thermodynamic and Thermophysical Properties of (TT74-50019)

- Combustion Products, Vol. II, Oxygen-Based Propellants. Thermodynamic and Thermophysical Properties of (TT74-50032)
- Combustion Products, Vol. III, Oxygen- and Air-Based Propellants. Thermodynamic and Thermophysical Properties of (TT75-50007)
- Copper and Copper Alloys, Part I. Volume and Surface Self-Diffusion in Copper. Diffusion in (JPCRD 36)
- Copper and Copper Alloys, Part II. Copper-Silver and Copper-Gold Systems. Diffusion in (JPCRD 52)
- Copper and Copper Alloys, Part III. Diffusion in Systems Involving Elements of the Groups IA, IIA, IIIB, IVB, VB, VIB, and VIIB. Diffusion in (JPCRD 61)
- Copper and Some of Its Binary Alloys. Selected Thermodynamic Values and Phase Diagrams for (ICRA)
- Copper and Its Inorganic Compounds. Thermodynamic Properties of (ICRA)
- Copper. Elastic Properties of Metals and Alloys, II (JPCRD 57)
- Critical Points. An Analysis of Coexistence Curve Data for Several Binary Liquid Mixtures Near Their (JPCRD 31)
- Critical Region of Magnetic Solids. Analysis of Specific Heat Data in the (JPCRD 18)
- Cross Section Data, Part I. Compilation of Low Energy Electron Collision (JR-6)
- Cross Section Data, Part II. Compilation of Low Energy Electron Collision (JR-7)
- Cross Section Data, Part III: Total Scattering; Differential Elastic Scattering, Low Energy Electron-Collision (AD)
- Cross Section Data for Atoms, Atomic Ions, and Diatomic Molecules: I. Experimental Data. Electron Impact Ionization (RMP)
- Cross Section Data for Modeling Gas Discharge Lasers. Compilation of Electron Collision (JR-13)
- Cross Sections at Low Energies - A Critical Review. Total Electron-Atom Collision (RMP)
- Cross Sections. Atomic Form Factors, Incoherent Scattering Functions, and Photon Scattering (JPCRD 67)
- Cross Sections, Attenuation Coefficients, and Energy Absorption Coefficients from 10 keV to 100 GeV. Photon (NSRDS-NBS 29)
- Cross Sections for Molecules of Astrophysical and Aeronomic Interest. Critical Review of Ultraviolet Photoabsorption (NSRDS-NBS 38)
- Crystal Data, Determinative Tables, Third Edition, Volume 1. Organic Compounds. (NBS/JCPDS)
- Crystal Data, Determinative Tables, Third Edition, Volume 2. Inorganic Compounds. (NBS/JCPDS)
- Crystal Structure Transformations in Binary Halides. (NSRDS-NBS 41)
- Crystal Structure Transformations in Inorganic Nitrites, Nitrates and Carbonates. (NSRDS-NBS 53)
- Crystal Structure Transformations in Inorganic Sulfates, Phosphates, Perchlorates, and Chromates (NSRDS-NBS 56)
- Dielectric Constant of Inorganic Solids. Compilation of the Static (JPCRD 28)
- Diffusion Coefficients. Gaseous (JPCRD 1)
- Dipole Moments for Molecules in the Gas Phase. Selected Values of Electric (NSRDS-NBS 10)
- Elastic Properties of Metals and Alloys. I. Iron, Nickel, and Iron-Nickel Alloys. (JPCRD 34)
- Electric Conductivity of Ferroelectrics. (TT70-50180)
- Electrolytic Conductance and Conductances of the Halogen Acids in Water (NSRDS-NBS 33)
- Electron Impact on Atoms and Diatomic Molecules. Resonances in (NSRDS-NBS 50)
- Electron in Alcohols. Selected Specific Rates of Reactions of the Solvated (NSRDS-NBS 42)
- Electron. Selected Specific Rates of Reactions of Transients from Water in Aqueous Solution, I. Hydrated (NSRDS-NBS 43)
- Electron, Supplemental Data. Selected Specific Rates of Reactions of Transients from Water in Aqueous Solution. Hydrated (NSRDS-NBS 43, Supplement)
- Electron Swarm Data. A Survey of (JPCRD 69)
- Electrons in Dielectric Liquids. Drift Mobilities and Conduction Band Energies of Excess (NSRDS-NBS 58)
- Energy Levels as Derived from the Analyses of Optical Spectra, Vol. I.  $^1\text{H}$  to  $^{23}\text{Y}$ ; Vol. II.  $^{24}\text{Cr}$  to  $^{41}\text{Nb}$ ; Vol. III.  $^{42}\text{Mo}$  to  $^{57}\text{La}$ ,  $^{72}\text{Hf}$  to  $^{89}\text{Ac}$ . Atomic (NSRDS-NBS 35)
- Ethylene on Metallic Catalysts. Hydrogenation of (NSRDS-NBS 13)
- Evaporation and Condensation Coefficients of Simple Substances. Selected Values of (JPCRD 3)
- Ferroelectrics. Electric Conductivity of (TT70-50180)
- Freon-22. Thermophysical Properties of (TT70-50178)
- Fundamental Constants. The 1973 Least-Squares Adjustment of the (JPCRD 37)
- Hardness Data. Handbook of (TT70-50177)
- Heats of Combustion and Heats of Formation of Organic Compounds Containing the Elements C, H, N, O, P, and S. Selected Values of (JPCRD 6)
- Heavy Particle Collisions. Dissociation in (Wiley)
- Heavy Particle Collisions. Excitation in (Wiley)
- Heavy Water, Thermophysical Properties. (TT70-50094)
- Helium ( $^4\text{He}$  I). Energy Levels of Neutral (JPCRD 26)
- Helium 4 from 2 to 1500 K at Pressures to  $10^8$  Pa. Thermodynamic Properties of (JPCRD 40)
- Helium. Thermodynamic and Thermophysical Properties of (TT70-50096)

- High-Pressure Calibration: A Critical Review (JPCRD 55)
- High Pressures. Behavior of the Elements at (JPCRD 55)
- High Temperature Properties and Decomposition of Inorganic Salts, Part 1. Sulfates (NSRDS-NBS 7)
- High Temperature Properties and Decomposition of Inorganic Salts, Part 2. Carbonates (NSRDS-NBS 30)
- High Temperature Properties and Decomposition of Inorganic Salts, Part 3. Nitrates and Nitrites (JPCRD 11)
- High Temperature Properties and Decomposition of Inorganic Salts, Part 4. Oxy-Salts of the Halogens (JPCRD 51)
- Hydrogen Atom. Selected Specific Rates of Reactions of Transients from Water in Aqueous Solution, II (NSRDS-NBS 51)
- H-Atom Transfer in the Liquid Phases: Chlorine Atom, Alkyl, Trichloromethyl, Alkoxy, and Alkylperoxy Radicals. A Critical Review of (JPCRD 58)
- Hydrogen. Properties of Liquid and Solid (TT70-50179)
- Hydroxyl Radical. A Critical Review of the Gas-Phase Reaction Kinetics of the (JPCRD-6)
- Hydroxyl Radical in Aqueous Solutions. Reactivity of the (NSRDS-NBS 46)
- Impact Excitation of Atoms. Electron (NSRDS-NBS 25)
- Impact Ionization Cross-Section Data for Atoms, Atomic Ions, and Diatomic Molecules: I. Experimental Data. Electron (RMP)
- Impact. Theory of the Ionization of Atoms by Electron (RMP)
- Index to NSRDS Data Compilations. Property (NSRDS-NBS 55)
- Infrared Reference Spectra. Coblentz Society Evaluated; Vol. 6, 1000 Spectra; Vol. 7, 1000 Spectra; Vol. 8, 1000 Spectra; Vol. 9, 1000 Spectra; Vol. 10, 1000 Spectra; Vol. 11, 1000 Spectra; Cumulative Coblentz Indices
- Ion-Molecule Reactions (Wiley)
- Ionization of Atoms by Electron Impact. Theory of the (RMP)
- Ionization Potentials and Ionization Limits Derived from the Analyses of Optical Spectra. (NSRDS-NBS 34)
- Ionization Potentials, Appearance Potentials and Heats of Formation of Gaseous Positive Ions. (NSRDS-NBS 26)
- Ionization Potentials for Lanthanide and Actinide Atoms and Ions. Ground Levels and (JPCRD 54)
- Ions. Ionization Potentials, Appearance Potentials and Heats of Formation of Gaseous Positive (NSRDS-NBS 26)
- Iron, Fe I through Fe XXVI. Energy Levels of (JPCRD 64)
- K<sub>α</sub>N Interactions - A compilation. (LBL-55)
- Methane. Thermophysical Properties of Gaseous and Liquid (TT70-50097)
- Microwave Spectra of Molecules of Astrophysical Interest, I. Formaldehyde, Formamide, and Thioformaldehyde. (JPCRD 14)
- Microwave Spectra of Molecules of Astrophysical Interest, II. Methylenimine. (JPCRD 17)
- Microwave Spectra of Molecules of Astrophysical Interest, III. Methanol. (JPCRD 23)
- Microwave Spectra of Molecules of Astrophysical Interest, IV. Hydrogen Sulfide. (JPCRD 24)
- Microwave Spectra of Molecules of Astrophysical Interest, V. Water Vapor. (JPCRD 45)
- Microwave Spectra of Molecules of Astrophysical Interest, VI. Carbonyl Sulfide and Hydrogen Cyanide. (JPCRD 46)
- Microwave Spectra of Molecules of Astrophysical Interest, VII. Carbon Monoxide, Carbon Monosulfide, and Silicon Monoxide. (JPCRD 47)
- Microwave Spectra of Molecules of Astrophysical Interest, VIII. Sulfur Monoxide. (JPCRD 48)
- Microwave Spectral Tables, Diatomic Molecules. (NBSM70-I)
- Microwave Spectral Tables, Line Strengths of Asymmetric Rotors. (NBSM70-II)
- Microwave Spectral Tables, Polyatomic Molecules with Internal Rotation. (NBSM70-III)
- Microwave Spectral Tables, Polyatomic Molecules without Internal Rotation. (NBSM70-III)
- Microwave Spectral Tables, Spectral Line Listing (NBSM70-V)
- Microwave Spectral Tables I. Diatomic Molecules. (JPCRD 53)
- Molecular Energies and Properties. Compendium of ab-initio Calculations of (NBSTN 438)
- Molten Salts: Vol. 1. Electrical Conductance, Density, and Viscosity Data. (NSRDS-NBS 15)
- Molten Salts: Vol. 2, Section 1. Electrochemistry of Molten Salts: Gibbs Free Energies and Excess Free Energies from Equilibrium-Type Cells. (NSRDS-NBS 28)
- Molten Salts: Vol. 2, Section 2. Surface Tension Data. (NSRDS-NBS 28)
- Molten Salts: Volume 3, Nitrates, Nitrites, and Mixtures, Electrical Conductance, Density, Viscosity, and Surface Tension Data. (JPCRD 10)
- Molten Salts: Volume 4, Part 1. Fluorides and Mixtures, Electrical Conductance, Density, Viscosity, and Surface Tension Data. (JPCRD 41)
- Molten Salts: Volume 4, Part 2. Chlorides and Mixtures, Electrical Conductance, Density, Viscosity, and Surface Tension Data. (JPCRD 71)
- Multiplet Table of Astrophysical Interest, Revised Edition, Part I. Table of Multiplets; Part II. Finding List of All Lines in the Table of Multiplets. A (NSRDS-NBS 40)



- Multiplet Tables, C I, C II, C III, C IV, C V, C VI. Selected Tables of Atomic Spectra, Atomic Energy Levels and (NSRDS-NBS 3, Sec. 3)
- Multiplet Tables, H I, D, T. Selected Tables of Atomic Spectra, Atomic Energy Levels and (NSRDS-NBS 3, Sec. 6)
- Multiplet Tables, N I, N II, N III. Selected Tables of Atomic Spectra, Atomic Energy Levels and (NSRDS-NBS 3, Sec. 5)
- Multiplet Tables, N IV, N V, N VI, N VII. Selected Tables of Atomic Spectra, Atomic Energy Levels and (NSRDS-NBS 3, Sec. 4)
- Multiplet Tables, Si I. Selected Tables of Atomic Spectra, Atomic Energy Levels and (NSRDS-NBS 3, Sec. 2)
- Multiplet Tables, Si II, Si III, Si IV. Selected Tables of Atomic Spectra, Atomic Energy Levels and (NSRDS-NBS 3, Sec. 1)
- National Standard Reference Data System Plan of Operation (NSRDS-NBS 1)
- Neon, Argon, and Xenon 136 in the 1.2-4.0  $\mu\text{m}$  Region. First Spectra of (JPCRD 33)
- Nitrogen Including Liquid and Vapor Phases from 63K to 2000K with Pressures to 10,000 Bar. Thermodynamic Properties of (JPCRD 39)
- NN and ND Interaction - A Compilation. (LBL-58)
- NN and ND Interactions (above 0.5 GeV/c) - A Compilation. (UCRL-20000/NN)
- Nucleation of Liquids from the Vapor. Selected Values of Critical Supersaturation for (JPCRD 2)
- Osmotic Coefficients and Mean Activity Coefficients of Uniunivalent Electrolytes in Water at 25°C. (JPCRD 15)
- Oxygen ( $\text{O}^3\text{P}$ ) with Organic Compounds in the Gas Phase. Rate Constants for the Reactions of Atomic (JPCRD 32)
- Oxygen Species. Gas Phase Reaction Kinetics of Neutral (NSRDS-NBS 20)
- Oxygen. The Spectrum of Molecular (JPCRD 8)
- Parahydrogen from the Triple Point to 100 K at Pressures to 340 Atmospheres. Thermodynamic and Related Properties of (NBSM-94)
- Particle Properties. Review of (LBL-100)
- n-Pentane and Methane-n-Pentane. Phase Behavior in Binary and Multicomponent Systems at Elevated Pressures: (NSRDS-NBS 32)
- $\pi\text{N}$  Partial-Wave Amplitudes. (UCRL-20030/ $\pi\text{N}$ )
- $\pi\text{N}$  Two-Body Scattering Data I. A User's Guide to the Lovelace-Almeid Data Tape. (LBL-63)
- $\pi^+\text{p}$ ,  $\pi^+\text{n}$ , and  $\pi^+\text{d}$  Interactions - A Compilation; Parts I and II. (LBL-53)
- Radiation Chemistry of Ethanol: A Review of Data on Yields, Reaction Rate Parameters, and Spectral Properties of Transients. (NSRDS-NBS 48)
- Radiation Chemistry of Gaseous Ammonia. The (NSRDS-NBS 44)
- Radiation Chemistry of Nitrous Oxide Gas. Primary Processes, Elementary Reactions, and Yields. (NSRDS-NBS 45)
- Radiation. Yields of Free Ions Formed in Liquids by (NSRDS-NBS 57)
- Radiolysis of Methanol: Product Yields, Rate Constants and Spectroscopic Parameters of Intermediates. (NSRDS-NBS 54)
- Rate Constants for the Reactions of Atomic Oxygen ( $\text{O}^3\text{P}$ ) with Organic Compounds in the Gas Phase. (JPCRD 32)
- Rate Constants for Various Gas Phase Reactions. Evaluated Chemical Kinetic (JPCRD 19)
- Rate Constants of Gas Phase Reactions, Reference Book. (COM 72-10014)
- Re-entry Flow Fields in the Atmosphere. A Review of Rate Constants of Selected Reactions of Interest in (NBSTN 484)
- Rotational Energy Levels and Rotational Line Intensities in Diatomic Molecules. The Calculation of (NBSM-115)
- Rotor: Transformation Coefficients from Symmetric to Asymmetric Bases and Expectation Values of  $P_z^2$ ,  $P_z^4$ ,  $P_z^6$ . Tables for the Rigid Asymmetric  $Z'$ ,  $Z''$ ,  $Z'''$ . (NSRDS-NBS 12)
- Silicate Systems, Vol. I. Binary Systems, Second Revised Edition. Handbook of Phase Diagrams of (TT71-50040)
- Silicate Systems, Vol. II. Metal-Oxygen Compounds in Silicate Systems, Second Revised. Handbook of Phase Diagrams of (TT71-50041)
- Space Groups and Lattice Complexes (NBSM-134)
- Spectra of Neon, Argon, and Xenon 136 in the 1.2-4.0  $\mu\text{m}$  Region. First (JPCRD 33)
- Superconductive Materials. Properties of Selected (NBSTN 724)
- Superconductive Materials - 1974 Supplement. Properties of Selected (NBSTN 825)
- Surface Ionization. (TT70-50148)
- Surface Tension of Pure Liquid Compounds. The (JPCRD 13)
- Surfactant Systems. Critical Micelle Concentrations of Aqueous (NSRDS-NBS 36)
- Thermal Conductivity of Selected Materials. (NSRDS-NBS 8)
- Thermal Conductivity of Selected Materials, Part 2. (NSRDS-NBS 16)
- Thermal Conductivity of the Elements. (JPCRD 7)
- Thermal Conductivity of the Elements: A Comprehensive Review. (JPCRD-S2)
- Thermal Properties of Aqueous Uniunivalent Electrolytes. (NSRDS-NBS 2)
- Thermochemical Tables, Second Edition. JANAF (NSRDS-NBS 37)
- Thermochemical Tables, 1974 Supplement. JANAF (JPCRD 50)
- Thermochemical Tables, 1975 Supplement. JANAF (JPCRD 60)
- Thermodynamic and Transport Properties of Ethylene and Propylene. (NBSIR75-763)
- Thermodynamic Properties and Isomerization of n-Butane and Isobutane. Ideal Gas (JPCRD 70)
- Thermodynamic Properties of Binary Alloys. Selected Values of the (ASM)

Thermodynamic Properties of Copper, Silver, and Gold from 0 to 300K. Critical Analysis of the Heat-Capacity Data of the Literature and Evaluation of (NSRDS-NBS 18)

Thermodynamic Properties of Eight Chloro- and Fluoromethanes. Ideal Gas (JPCRD 42)

Thermodynamic Properties of Ethane and Propane. Ideal Gas (JPCRD 30)

Thermodynamic Properties of Ethylene and Propylene. Ideal Gas (JPCRD 62)

Thermodynamic Properties of Geological Substances. Handbook of (TT73-53051)

Thermodynamic Properties of Ruthenium, Rhodium, Palladium, Iridium, and Platinum from 0 to 300K. A Survey of the Literature Data on Osmium. Critical Analysis of Heat-Capacity Data and Evaluation of (JPCRD 44)

Thermodynamic Properties of Six Chloroethanes. Ideal Gas (JPCRD 43)

Thermodynamic Properties of Six Fluoroethanes. Ideal Gas (JPCRD 65)

Thermodynamic Properties of the Eight Bromo- and Iodomethanes. Ideal Gas (JPCRD 66)

Thermodynamic Properties of the Elements. Selected Values of the (ASM)

Thermodynamic Properties, Table for the First Thirty-four Elements in the Standard Order of Arrangement. Selected Values of Chemical (NBSTN 270-3)

Thermodynamic Properties, Tables for Elements 35 through 53 in the Standard Order of Arrangement. Selected Values of Chemical (NBSTN 270-4)

Thermodynamic Properties, Tables for Elements 54 through 61 in the Standard Order of Arrangement. Selected Values of Chemical (NBSTN 270-5)

Thermodynamic Properties, Tables for the Lanthanide (Rare Earth) Elements (Elements 62 through 76 in the Standard Order of Arrangement.) Selected Values of Chemical (NBSTN 270-7)

Thermodynamic Properties, Tables for the Alkaline Earth Elements (Elements 92 through 97 in the Standard Order of Arrangement). Selected Values of Chemical (NBSTN 270-6)

Thermophysical Properties of Gases and Liquids, No. 1 (TT69-55091)

Thermophysical Properties of Matter and Substances, Volume 2. (TT72-52001)

Thermophysical Properties of Matter and Substances, Volume 3. (TT73-52009)

Thermophysical Properties of Matter and Substances, Volume 4. (TT73-52029)

Transition Metal Oxides, Crystal Chemistry, Phase Transition, and Related Aspects. (NSRDS-NBS 49)

Transition Probabilities for Ba I and II. Critically Evaluated (NBSTN 474)

Transition Probabilities for Forbidden Lines of the Iron Group Elements. (A Critical Data Compilation for Selected Lines.) Atomic (JPCRD 20)

Transition Probabilities for Scandium and Titanium (A Critical Data Compilation of Allowed Lines). Atomic (JPCRD 63)

Transition Probabilities, Vol. I, Hydrogen Through Neon. Atomic (NSRDS-NBS 4)

Transition Probabilities, Vol. II, Sodium Through Calcium, A Critical Data Compilation. Atomic (NSRDS-NBS 22)

Unimolecular Reactions. Kinetic Data on Gas Phase (NSRDS-NBS 21)

Vibrational Data of Atomic and Molecular Ions Doped in Alkali Halide Crystals. Electronic Absorption and Internal and External (NSRDS-NBS 52)

Vibrational Frequencies, Consolidated Volume I. Tables of Molecular (NSRDS-NBS 39)

Vibrational Frequencies, Part 5. Tables of Molecular (JPCRD 5)

Vibrational Frequencies, Part 6. Tables of Molecular (JPCRD 21)

Vibrational Frequencies, Part 7. Tables of Molecular (JPCRD 25)

Vibrational Frequencies, Part 8. Tables of Molecular (JPCRD 49)

Viscosity and Thermal Conductivity Coefficients for Dense Gaseous and Liquid Argon, Krypton, Xenon, Nitrogen and Oxygen. The (JPCRD 59)

Viscosity and Thermal Conductivity Coefficients of Dilute Argon, Krypton, and Xenon. The (JPCRD 35)

Viscosity and Thermal Conductivity Coefficients of Dilute Nitrogen and Oxygen. The (JPCRD 38)

Viscosity and Thermal Conductivity Coefficients of Gaseous and Liquid Fluorine. The (JPCRD 16)

X-Ray Emission Spectra of Metallic Solids: Critical Review of Selected Systems. Soft (JPCRD 29)

X-Ray Wavelengths and X-Ray Atomic Energy Levels (NSRDS-NBS 14)

YN Reactions. A Compilation of (UCRL-20000/YN)

APPENDIX E. U.S. PRIVATE ORGANIZATIONS REPRESENTED IN NBS REFERENCE COLLECTION OF STANDARDS [291].

Acoustical & Board Products Association	American Insurance Association
Acoustical Society of America	American Iron & Steel Institute
Adhesive & Sealant Council	American Ladder Institute
Air-Conditioning & Refrigeration Institute	American Leather Chemists Association
Air Diffusion Council	American Library Association
Air Moving & Conditioning Association, Inc.	American National Standards Institute, Inc.
Air Pollution Control Association	American Nuclear Society
Air Transport Association of America	American Oil Chemists' Society
Alumina Ceramic Manufacturers Association	American Paper Institute
The Aluminum Association	American Petroleum Institute
American Alliance for Health, Physical Education & Recreation	American Pharmaceutical Association
American Academy of Pediatrics	American Plywood Association
American Association of Advertising Agencies	American Public Health Association, Inc.
American Association of Cereal Chemists	American Public Works Association
American Association of Hides, Skins and Leather Merchants	American Railway Engineering Association
American Association of Medical Milk Commissions, Inc.	American Society for Nondestructive Testing
American Association of Petroleum Geologists	American Society for Quality Control
American Association of Poison Control Centers	American Society for Testing & Materials
American Association of State Highway and Transportation Officials	American Society of Agricultural Engineers
American Association of Textile Chemists and Colorists	American Society of Brewing Chemists
American Bankers Association	American Society of Cinematographers
American Bleached Shellac Manufacturers Association	American Society of Electroplated Plastics
American Boat & Yacht Council, Inc.	American Society of Enologists
American Boiler Manufacturers Association	American Society of Heating, Refrigeration & Airconditioning Engineers
American Bottled Water Association	American Society of Lubrication Engineers
American Bureau of Shipping	American Society of Mechanical Engineers
American Chemical Society	American Society of Photogrammetry
American Concrete Institute	American Society of Safety Engineers
American Concrete Paving Association	American Society of Sanitary Engineering
American Conference of Governmental Industrial Hygienists	American Sod Producers Association
American Congress on Surveying and Mapping	American Speech & Hearing Association
American Crystallographic Association	American Spice Trade Association
American Dehydrators Association	American Stone Importers Association
American Dental Association	American Textile Machinery Association
American Die Casting Institute, Inc.	American Textile Manufacturers Institute, Inc.
American Dry Milk Institute, Inc.	American Trucking Associations, Inc.
American Feed Manufacturers Association, Inc.	American Vacuum Society, Inc.
American Fishing Tackle Manufacturers Association	American Water Works Association, Inc.
American Foundrymen's Society, Inc.	American Wax Importers and Refiners Association, Inc.
American Gas Association	American Welding Society, Inc.
American Gear Manufacturers Association	American Wood-Preservers' Association
American Gem Society	American Wood Preservers Bureau
American Gum Importers Laboratories, Inc.	Anti-Friction Bearing Manufacturers Association, Inc.
American Home Lighting Institute	Archery Manufacturers Organization
American Industrial Hygiene Association	Architectural Aluminum Manufacturers Association
American Institute of Architects	Architectural Woodwork Institute
American Institute of Baking	Asbestos Textile Institute
American Institute of Chemical Engineers	Asphalt Emulsion Manufacturers Association
American Institute of Steel Construction, Inc.	Asphalt Roofing Manufacturers Association
American Institute of Timber Construction	Associated Air Balance Council
	Associated Cooperage Industries of America, Inc.
	Associated General Contractors of America
	Associated Locksmiths of America, Inc.



Associated Master Barbers and Beauticians  
 of America  
 Association for the Advancement of Medical  
 Instrumentation  
 Association of American Feed Control  
 Officials, Inc.  
 Association of American Railroads  
 Association of Bedding and Furniture Law  
 Officials  
 Association of Edison Illuminating Companies  
 Association of Home Appliance Manufacturers  
 Association of Iron & Steel Engineers  
 Association of Official Analytical Chemists  
 Association of Official Seed Analysts  
 Association of Petroleum Re-Refiners  
 Audio Engineering Society, Inc.  
 Baking Industry Sanitation Stds. Committee  
 Barley and Malt Institute  
 Barre Granite Association  
 Battery Council International  
 Bicycle Manufacturers Association of America  
 Billiard Congress of America  
 Biological Stain Commission  
 Book Manufacturers' Institute  
 Brass and Bronze Ingot Institute  
 Brick Institute of America  
 Builders Hardware Manufacturers Association  
 Building Officials & Code Administrators, Inc.  
 Building Owners & Managers Association  
 International  
 California Redwood Association  
 Can Manufacturers Institute  
 Canvas Products Association, International  
 Cast Bronze Bearing Institute  
 Cast Iron Soil Pipe Institute  
 Caster & Floor Truck Manufacturers  
 Association  
 Ceilings & Interior Systems Contractors  
 Association  
 Cemented Carbide Producers Association  
 Chain Link Fence Manufacturers Institute  
 Chemical Specialties Manufacturers  
 Association  
 Chlorine Institute, Inc.  
 Coffee Brewing Center  
 Commercial Refrigerator Manufacturers  
 Association  
 Composite Can & Tube Institute  
 Compressed Air & Gas Institute  
 Compressed Gas Association, Inc.  
 Concrete Reinforcing Steel Institute  
 Construction Industry Manufacturers  
 Association  
 Construction Specifications Institute  
 Contractors Pump Bureau  
 Conveyor Equipment Manufacturers Association  
 Cooling Tower Institute  
 Cooper Development Association  
 Cordage Institute  
 Corn Refiners Association  
 Cosmetic, Toiletry & Fragrance Association,  
 Inc.  
 Crane Manufacturers Assoc. of America, Inc.

Cultured Marble Institute  
 Dairy & Food Industries Supply Association,  
 Inc.  
 Diamond Core Drill Manufacturers Association  
 Diaper Service Accreditation Council  
 Diesel Engine Manufacturers Association  
 Door & Hardware Institute  
 Door Operator & Remote Control Manufacturers  
 Association  
 Dry Color Manufacturers Association  
 Edison Electric Institute  
 Electrical Apparatus Service Association, Inc.  
 Electronic Industries Association  
 Entomological Society of America  
 Essential Oil Association of the USA, Inc.  
 Expanded Shale, Clay, & Slate Institute  
 Expansion Anchor Manufacturers Institute  
 Expansion Joint Manufacturers Association  
 Facing Tile Institute  
 Factory Mutual System  
 The Fertilizer Institute  
 Fibre Box Association  
 Fir and Hemlock Door Association  
 Flat Glass Marketing Association  
 Flax Development Committee  
 Floor & Vacuum Machinery Manufacturers  
 Association  
 Fluid Controls Institute, Inc.  
 Forging Industry Association  
 Gas Processors Association  
 General Aviation Manufacturers Association  
 Glass Tempering Association  
 Gravure Technical Association, Inc.  
 Grocery Manufacturers of America, Inc.  
 Gunned Industries Association  
 Gypsum Association  
 Gypsum Roof Deck Foundation  
 Hardwood Dimension Manufacturers Association  
 Hardwood Plywood Manufacturers Association  
 Hearing Aid Industry Conference, Inc.  
 Heat Exchange Institute  
 Helical Washer Institute  
 Hoist Manufacturers Institute  
 Home Ventilating Institute  
 Hydraulic Institute  
 Hydronics Institute  
 Illuminating Engineering Society  
 Indiana Limestone Institute of America, Inc.  
 Industrial Fasteners Institute  
 Industrial Silencer Manufacturers Association  
 Industrial Gas Cleaning Institute, Inc.  
 Industrial Perforators Association  
 Industrial Truck Association  
 Institute of Electrical and Electronics  
 Engineers, Inc.  
 Institute of Environmental Sciences  
 Institute of High Fidelity, Inc.  
 Institute of Makers of Explosives  
 Institute of Printed Circuits  
 Institute of Scrap Iron & Steel, Inc.  
 Institute of Traffic Engineers  
 Instrument Society of America  
 Insulated Power Cable Engineers Association

International Air Transport Association  
 International Association of Plumbing and  
     Mechanical Officials  
 International Association of Wall and  
     Ceiling Contractors  
 International Commission on Radiation Units  
     and Measurements  
 International Conference of Building Officials  
 International Fabricare Institute  
 International Mobile Air Conditioning  
     Association, Inc.  
 International Municipal Signal Association  
 International Nonwovens and Disposables  
     Association  
 International Society for Terrain-Vehicle  
     Systems, Inc.  
 Investment Casting Institute  
 Joint Industrial Council  
 Juvenile Products Manufacturers Assoc., Inc.  
 Laundry & Cleaners Allied Trade Association  
 Lead Industries Association  
 Library Binding Institute  
 Linen Supply Association of America  
 Magnetic Materials Producers Association  
 Manufactured Housing Institute  
 Manufacturers Standardization Society of the  
     Valve & Fittings Industry  
 Manufacturing Chemists' Association  
 Maple Flooring Manufacturers Association  
 Marking Device Association  
 Material Handling Institute  
 Mechanical Power Transmission Association  
 Metal Building Manufacturers Association  
 Metal Cookware Manufacturers Association  
 Metal Ladder Manufacturers Association  
 Metal Lath Association  
 Metal Powder Industries Federation  
 Metal Tube Packaging Council of North America  
 Mill Mutual Fire Prevention Bureau  
 Monorail Manufacturers Association  
 Mo-Sai Institute  
 MTM Association for Standards & Research  
 Narrow Fabrics Institute  
 National Accreditation Council for Agencies  
     Serving the Blind & Visually Handicapped  
 National Agricultural Chemicals Association  
 National Association of Architectural  
     Metal Manufacturers  
 National Association of Broadcasters  
 National Association of Chain Manufacturers  
 National Association of Corrosion Engineers  
 National Association of Food Chains  
 National Association of Furniture  
     Manufacturers, Inc.  
 National Association of Glue Mfrs., Inc.  
 National Association of Hosiery Manufacturers  
 National Association of Insect Electrocuter  
     Manufacturers  
 National Association of Metal Name Plate  
     Manufacturers  
 National Association of Pattern Manufacturers  
 National Association of Pipe Coating  
     Applicators  
 National Association of Plastic Fabricators  
 National Association of Plumbing-Heating-  
     Cooling Contractors  
 National Association of Recycling Industries,  
     Inc.  
 National Association of Relay Manufacturers  
 National Association of Rocketry  
 National Association of Store Fixture Mfrs.  
 National Association of Wiping Cloth Mfrs.  
 National Audio-Visual Association  
 National Automatic Merchandising Association  
 National Barrel and Drum Association  
 National Board of Boiler & Pressure Vessel  
     Inspectors  
 National Building Granite Quarries  
     Association, Inc.  
 National Cable Television Association  
 National Cargo Bureau, Inc.  
 National Clay Pipe Institute  
 National Coil Coaters Association  
 National Committee for Clinical Laboratory  
     Standards  
 National Concrete Masonry Association  
 National Cottonseed Products Association  
 National Council on Radiation Protection &  
     Measurements  
 National Crushed Stone Association  
 National Education Association  
 National Electrical Contractors Assoc., Inc.  
 National Electrical Manufacturers Association  
 National Elevator Industry  
 National Environmental Systems Contractors  
     Association  
 National Fertilizer Solutions Association  
 National Fire Protection Association  
 National Flexible Packaging Association  
 National Fluid Power Association  
 National Forest Products Association  
 National Hardwood Lumber Association  
 National Industrial Leather Association  
 National Institute of Oilseed Products  
 National Knitted Outerwear Association  
 National Lime Association  
 National Lubricating Grease Institute  
 National Machine Tool Builders Association  
 National Micrographics Association  
 National Model Railroad Association, Inc.  
 National Oak Flooring Mfrs. Association, Inc.  
 National Operating Committee for Standards  
     in Athletic Equipment  
 National Paper Box Association  
 National Particleboard Association  
 National Pest Control Association  
 National Printing Ink Research Institute  
 National Ready Mixed Concrete Association  
 National Retail Merchants Association  
 National Rifle Association of America  
 National Roofing Contractors Association  
 National Sanitation Foundation  
 National School Supply & Equipment Association  
 National Silo Association  
 National Soft Drink Association  
 National Solid Wastes Management Association

National Soybean Processors Association  
 National Standards Association  
 National Swimming Pool Institute  
 National Terrazzo & Mosaic Association, Inc.  
 National Wholesale Hardware Association  
 National Pallet & Container Association  
 National Woodwork Manufacturers Association  
 Northeastern Lumber Manufacturers Assn., Inc.  
 Northern Hardwood & Pine Mfrs. Assn., Inc.  
 Northern Textile Association  
 Optical Manufacturers Association, Inc.  
 Packaging Institute, Inc.  
 Paper Converters Association  
 Paperboard Packaging Council  
 Perlite Institute, Inc.  
 Photographic Society of America  
 Pipe Fabrication Institute  
 Plastics Pipe Institute  
 Plumbing & Drainage Institute  
 Porcelain Enamel Institute, Inc.  
 Portland Cement Association  
 Power Saw Manufacturers Association  
 Pressure Sensitive Tape Council  
 Prestressed Concrete Institute  
 Pulverized Limestone Association  
 Rack Manufacturers' Institute  
 Radio Technical Commission for Aeronautics  
 Railway Tie Association  
 Recording Industry Association of America, Inc.  
 Red Cedar Shingle & Handsplit Shake Bureau  
 Redwood Inspection Service  
 The Refractories Institute  
 Resilient Floor Covering Institute  
 Resistance Welder Manufacturers' Association  
 Rubber Manufacturers Association  
 Rubber Reclaimers Association, Inc.  
 Salt Institute  
 Scaffolding & Shoring Institute  
 Scale Manufacturers Association  
 Scientific Apparatus Makers Association  
 Screen Manufacturers Association  
 Sealed Insulating Glass Manufacturers Assn.  
 Sheet Metal & Air Conditioning Contractors  
     National Association, Inc.  
 Snowmobile Safety & Certification Committee  
 Society for Technical Communication  
 Society of Automotive Engineers, Inc.  
 Society of Die Casting Engineers, Inc.  
 Society of Motion Pictures & Television  
     Engineers  
 Society of Naval Architects & Marine  
     Engineers  
 Society of the Plastics Industry, Inc.  
 Southern Building Code Congress International  
 Southern Cypress Manufacturers Association  
 Southern Forest Products Association  
 Southern Pine Inspection Bureau  
 Speciality Equipment Manufacturers Assoc.  
 Specialty Wire Association  
 Spring Manufacturers Institute  
 Sprinkler Irrigation Association  
 Stained Glass Association of America  
 Steel Bar Mills Association  
 Steel Deck Institute  
 Steel Door Institute  
 Steel Founders' Society of America  
 Steel Joist Institute  
 Steel Structures Painting Council  
 Steel Tank Institute  
 Steel Window Institute  
 Stucco Manufacturers Association  
 Sump Pump Manufacturers Association  
 Technical Association of the Pulp & Paper  
     Industry  
 Test Boring Association, Inc.  
 Tile Council of America  
 Tire & Rim Association, Inc.  
 Tire Retreading Institute  
 Truck Body & Equipment Association  
 Truck Trailer Manufacturers Association  
 Truss Plate Institute, Inc.  
 Tubular Exchanger Manufacturers Assn., Inc.  
 Ultrasonic Industry Association, Inc.  
 Underwriters' Laboratories, Inc.  
 U. S. Department of Commerce  
 U. S. Golf Association  
 United States Pharmacopeial Convention, Inc.  
 U. S. Tennis Court & Track Builders Assn.  
 Vacuum Cleaner Manufacturers Association  
 Vacuum Wood Preservers Institute  
 Variable Resistive Components Insitute  
 Vehicle Equipment Safety Commission  
 Water Pollution Control Federation  
 Water Quality Association  
 Water Systems Council  
 Welded Steel Tube Institute  
 West Coast Lumber Inspection Bureau  
 Western Wood Moulding & Millwork Producers  
 Western Wood Products Association  
 Wire Reinforcement Institute  
 Wood & Synthetic Flooring Institute of America  
 Wooden Box Institute  
 Woodworking Machinery Manufacturers of America  
 Writing Instrument Manufacturers Assn., Inc.  
 Zinc Institute



APPENDIX F. STATE AND LOCAL WEIGHTS AND MEASURES ACTIVITY SUMMARY (EXCERPTS), 1974-1975  
[256]

Arkansas.

A two-month study program was conducted with moisture meters at public grain elevators beginning November 1, 1974. After extensive field work the following conditions were found: outdated charts, poor environmental conditions, inaccurate weighing devices (approximately 90 percent were adjusted), and failure to use temperature corrections. All of the preceding are detrimental to correct and accurate moisture determination. Therefore, in addition to moisture meters, charts, operating procedures, and scales are checked. Scales were adjusted when official testing began January 3, 1975.

Colorado.

We initiated and implemented testing of tuning forks used with the Doppler radar gun for traffic speed control. Mr. David Allan, Time and Frequency Division, NBS-Boulder, Colorado, gave us expert advice in procedure testing. The basic principle of operation of these guns is that the radar signal reflected from a moving vehicle is shifted in frequency by an amount directly proportional to the speed of the vehicle relative to the radar gun. We have tested all of the Colorado Highway Patrol equipment and equipment in several of our larger cities.

NBS-Boulder recommended an equipment configuration that would be relatively easy to set up, operate, and reassemble (also inexpensive at \$400 to \$500); yet, with sufficient accuracy, it is traceable to the primary frequency referenced and operated by NBS-Boulder. You may readily see assistance in court cases when tuning forks are certified

Florida.

This has been a big year for our computerized nonfood package inspection program. Selective testing of these types of packages has revealed some rather large scale shortages in certain areas. Our inspections indicated over one-half million pounds of charcoal had been shipped into Florida that was short weight, much of it by more than 10 percent. We also found large quantities of anti-freeze/engine coolant to be short measure. These products were withheld from sale and required to be returned to the packagers. They were then replaced by the packagers on a one-for-one basis with packages inspected

at our metrology laboratory in Tallahassee before distribution. This operation turned out to be very costly for the packagers and very time consuming for our Bureau of Weights and Measures personnel. Our packages inspection program always receives good coverage in the press; and because of the amounts involved, more than usual prominence was given to stories about these two items in all news media.

Our taximeter testing program, which we started several years ago, has proven very effective. The majority of taxi companies now maintain their meters in reasonably good condition, and we find few serious violations. We now have accurately laid out test courses for checking these meters in all major cities of Florida which have taxi fleets. Our testing of odometers on rental cars and trucks is also quite effective, although we occasionally find a new model whose odometer is grossly out of tolerance, apparently because of being equipped with improper gears. We have recently had to reject more than 80 percent of two models tested of a popular brand of rental car for overregistration....

As chairman of the National Conference on Weights and Measures this year, over one hundred presentations on the metric system were made in Florida, as well as other states. These include appearances before professional and technical societies, civic clubs, women's organizations, school groups, as well as newspaper interviews, television shows and discussions with members of Congress. It is our sincere hope that the 94th Congress will enact metric legislation committing this country to planned voluntary conversion programs. Weights and measures officials will have a large responsibility in providing an orderly transition in the marketplace from the customary system of measurement to the metric system. We can play a major part in helping to educate the consuming public to understand this system and appreciate the value of making the conversion.

Georgia.

A heavy count of non-consumer goods has been getting "stop sale" flags and the commodities have been returned to the processors--particularly because of short weight or short fill. Items include salt blocks, feeds, fertilizers, seeds, pesti-

cides, detergents for sprays, and packaged nails. Some items involved package counts of several thousand bags or boxes. A review of packaging systems has been instituted on these and other items of commerce to help keep packaging problems to a minimum.

#### Indiana.

We are pleased also with the success of our Moisture Testing Device Program. Approximately 1,600 devices have been inspected this past year. Of this number, approximately 10 percent have been condemned.

During the past summer, a special project of testing gasoline pump meters was initiated with the employment of three college students. This program was found to be very significant due to the number of pumps that had not been tested for several years and were found to be in a deplorable state. The special project has begun again this spring with the use of four CETA employees the Division has employed to continue the testing of gasoline pump meters.

#### Kansas.

In public relations activities, our anhydrous ammonia safety program took on new aspects. Stress was put on an educational program for dealers, farmers, and transport trucking industries in regard to the two hazardous products of propane and anhydrous ammonia. The anhydrous ammonia program which we inherited in 1968 now takes over half of the office time of the Division along with the increased night educational programs and daily inspections and complaints.

The Division has had more court cases involving weights and measures personnel and the laboratory this past year. Short weight packaging cases were won on the ability of the inspectors to prove equipment and test weights and measures were accurate. Field men had to prove their ability and background in training for the work. A presentation of certificates, as provided by the Office of Weights and Measures, National Bureau of Standards, showing proof of training was necessary. Traceability was the major factor in completing one of the highway overload cases in McPherson County, Kansas.

#### Massachusetts.

Current legislation being considered will give the Division of Standards and municipal weights and measures officials the authority to examine and test the operation of automated electronic retail checkout systems.

Such authority will extend to systems whether there is a scale involved or not. Legislative concern was directed to the fact that there should be a monitoring agency to make inspections from time to time to determine whether the advertised or posted price was in agreement with that programmed in the computerized checkout system. This legislation will provide the necessary authority for weights and measures officials to make such inspections.

The Division of Standards is in the process of acquiring a new combination motor-method and research-method octane machine to be utilized in the enforcement of statutes relating to the Motor Fuel Sales Act. This new unit will replace a research-method unit which has been used for many years and must necessarily be retired.

#### Missouri.

New program emphasis has been given to the bait-and-switch operation. Legal action has been taken against six operations, resulting in four being closed. Fine cooperation has existed between the Weights and Measures Division and the Attorney General's Office.

An additional change in program emphasis is taking place on a joint effort basis between the Division of Water Safety and the Weights and Measures Division. All marinas on our lakes are being inspected on accuracy of the petroleum dispensers and inspection of petroleum in storage tanks. We will completely inspect some 572 marinas during May, June, July, August, and September 1975.

#### Nebraska.

There are two problems that stand out as challenges for the Division. One is the problem of high-shrink packaged products. A great deal of time is being spent on research of these various products with cooperation from the industries involved. The second challenge is in the area of uniformity between our neighboring states. The more involved a state becomes in the weights and measures field, the more obvious it is that we must work together to eliminate a problem existing in our State which may also be existing in a neighboring state or any other state in the nation. This is a difficult task due to the different laws and regulations in each state.

## New Jersey.

Investigations of complaints involving faulty water meters disclosed that thousands of utility-type water and electric meters are under our weights and measures jurisdiction. Data is being compiled as to the total number of meters, types, and sizes so that a test program can be formulated.

Initial type approval tests conducted on four manufacturers' parking meters have not yet been completed, pending manufacturing changes and the possibility of code changes to be considered at the 60th National Conference on Weights and Measures.

The investigation of one complaint uncovered large scale short measure deliveries of gasoline to schools, municipal garages, and police departments. This was accomplished by the drivers riding with the tickets in the meters and charging for the last drop for the total deliveries. Two men are facing criminal action in addition to 31 weights and measures violations.

The lumber enforcement section has uncovered a scheme where at least four lumber dealers were substituting southern yellow pine for other designated species, resulting in overcharges of at least 10 percent. There is nothing inherently wrong with yellow pine; however, it is a much cheaper product.

There are at least three current investigations being conducted with federal and state investigative agencies involving short measure deliveries on contracts of federally-funded programs, one of which is a school lunch program.

## New Mexico.

A concerted effort was made this past winter to test all construction material hopper scales in the State. As with all new programs, there was some resistance; but most of the ready-mix concrete, sand, and gravel dealers welcomed our inspection. Rejections ran as high as 50 percent on first inspection in some areas of the State. Major problems involved maintenance of equipment. Most objections raised were on the supposedly restrictive tolerances applied to sand and gravel scales.

Jewelers' scales represent another area of increased activity. These scales, at trading posts as well as jewelry stores, are used to buy and sell turquoise, silver, gold, and other materials used to make handmade jewelry. Rejection rates were very low for these

balances and scales compared to other types of weighing devices.

Package checking activities were extended to two new areas: large packages, such as pet foods, livestock feed, and garden supplies; and petroleum products, especially motor oil. The initial round on large packages uncovered many violations in short fill and labeling. Subsequent inspections found many of these problems corrected. Short fill on motor oil was often found, but not consistently. In other words, quantity control seems to be an area of managerial concern in some firms but not in others.

## Virginia.

OUTSTANDING COURT CASES: Top management of a tobacco warehouse in southwest Virginia was found guilty of improper record keeping and for taking more tobacco than represented. Each party was fined \$113.75 and ordered to pay six farmers for the 145 lbs of tobacco they were shortweighted. Similar charges against the weigher are still pending, but cannot be heard since the defendant is in jail in another state.

A court case against a Richmond beef company was terminated in Virginia's favor when the judge ordered forfeiture of the \$300 bond and issued an attachment for the manager's arrest.

Top management of a large supermarket chain was convicted and fined \$1,000 plus \$6.25 court costs on one charge and was fined \$1,000 for each of six additional charges. However, the charges were suspended for one year, providing no further violations are found.

A warrant was issued against a service station manager for pouring water into antifreeze. Laboratory tests indicated that the antifreeze being sold by this station contained approximately 33 percent water. The judge found the defendant guilty and fined him \$25 plus \$6.25 court costs.

OTHER HIGHLIGHTS: Since Virginia discontinued calibrating vehicle compartments, we have encouraged industries to provide the necessary facilities for performing this service. During the past year another company began calibrating tank compartments. This makes three private businesses now in Virginia that are performing tank calibrations according to the requirements as set forth in National Bureau of Standards



Handbook 44. We train personnel performing these calibrations and make spot checks to determine if they are following recognized methods as well as performing accurate calibrations.

WORLD'S LARGEST SUBMARINE SANDWICH: On Sunday, March 16, 1975, Inspector G. W. Diggs certified the world's largest submarine sandwich. The sandwich, made by the University of Richmond's Student Union, was 796 feet long and weighed 1,370 pounds. The certification was necessary for recognition in the "Guinness Book of World Records."

#### Washington.

Our participation in the third Tri-State Weights and Measures Training Seminar was the highlight of our training efforts this year. The seminar, with Lyman Holloway of Idaho as host and Richard N. Smith of the National Bureau of Standards as training officer, was a very positive meeting. Representatives of area scale firms provided the technical aspect of the day devoted to weighing devices. John Larsen, president of Petroleum Dynamics, Inc. of Los Angeles, provided the technical aspect in the measuring field. Harry Couden from the Oakland office of Safeway gave us a comprehensive overview on prepackaging. It is anticipated that we will make this venture an annual event with an attempt to establish the third week in March each year as our meeting date.

One of the interesting surveys in which we participated was that covering cedar shingle and shake products which is a rather extensive industry in our area. We found that the shingle aspect of the industry seemed to be well organized, well supervised, and basically without problems. The shake industry, however, was fraught with problems to the point that the industry welcomed our activities in checkmeasuring and inspection at the shake mill level. Our survey resulted in a definite improvement in quality and quantity, as well as serving as a stimulus for better inspection on the part of the inspector serving under the auspices of the industry.

#### Wisconsin.

The third year of the LP-vapor meter program indicates a significant increase in compliance. The larger companies have obtained test equipment to begin their own test program, while others have undertaken extensive replacement of meters. Test meters are adjusted in the laboratory and a complete training session is given to company personnel on the proper testing and adjusting of meters.

The successful prosecution of an LP-gas company has strengthened this enforcement program.

#### Ventura County, California.

VARIABLE FREQUENCY OF INSPECTION: This program, reported on at the 1973 National Conference on Weights and Measures, is now in full operation. We now have only 5 inspectors checking devices compared to 7 before. Next year will see us reduce this by 1 more. We have not experienced any decline in devices found out of compliance with the less frequent inspection.

COMPLAINTS: Weights and measures complaints are running 17 percent ahead of last year. In the past 5 years complaints have increased by about 200 percent. This dramatic increase is due to newspaper publicity and our educational programs. More consumers are becoming aware of the Department and the help it can give. Also, consumers today are tired of many fraudulent practices in the marketplace, service stations, and other stores and are quicker to file a complaint. Complaints received by the Consumer Affairs Division are showing the opposite trend and are down 9 percent from last year, which is also due to newspaper publicity and our educational programs. Consumers know how to handle their complaints now and are more knowledgeable in avoiding problem areas. Dollar savings are 36 percent ahead of last year and over \$75,000 has been returned to consumers since the Division's inception.

#### Washtenaw County, Michigan.

During this past year, this Department has instituted ten cases in the courts. Of these cases only two resulted in guilty pleas, proving that nothing comes easy any more. One case against a corporation for false advertising has been resolved in a court judgment of guilty. Another case against an oil company for possession and operation of an illegal device has also resulted in a judgment of guilty.

Four cases are still not resolved by the courts. Two are felonies, one in which the president of a small meat processing corporation jumped a \$2,000 bond and headed west. When efforts to reach him in Bakersfield, California, failed, it was learned that he went to Mexico. One unfinished case concerns the failure of a coin operated car wash to post a sign for the return of money when equipment fails to operate. This case has caused some confusion in the process as it

invokes Handbook 44 and its tie-in with the Michigan law. The judge, at first, was under the impression that this was a federal regulation formulated by federal bureaucrats who had sprung it on the unsuspecting and uninformed business community. He was ready to dismiss the case on advice of defense counsel when we were able to convince him that his suspicions were wrong and that the National Conference on Weights and Measures is, in fact, a wholly democratic commitment by state and local officials.

#### Birmingham, Alabama

We are now keeping a percentage record of package condemnations in all our prepack stores. This enables us to concentrate on the stores with the highest percentage records with follow-up inspections. To date, this procedure has worked very well. This enables us to keep our Division inspectors in the area where they are most needed. We are also trying this method of inspection in the testing of motor fuel dispensers.

#### Dallas, Texas.

The second program involves a new test purchasing program; purchasing advertised products from the retail food stores, with the stores' main offices then buying the products back. We feel this is a very unique program in that we have the full cooperation and backing of the food industry. We agreed with management that we would give the stores the first opportunity to correct any discrepancies we might uncover. If they failed to correct the discrepancy, then we would take the necessary steps to insure compliance under the law. Under this program we can purchase any item advertised through any media at any time. We then record the findings as to overcharges, items not available although advertised, misleading price tags, etc. At the end of the day we return all purchased items to a central location and receive our reimbursement. The management is contacted and the results are discussed. Since the inception of this program we have cut down the complaints of overcharging at the checkout counters, misrepresenting prices, and advertising products that are unavailable.

#### Philadelphia, Pennsylvania.

NEWSWORTHY ITEMS: The Indiana State Department of Weights and Measures shares some billing in this unusual matter of short measure in a liquid commodity sold to certain members of a profession. The investigation confirmed the complaint for the 16-fluid ounce product; it was found to have shortages from 1/8 to 1/4 fluid ounce! Thus, the users of the commodity could not really give the recipient a full measure of ... embalming fluid.

APPENDIX G. DIRECTORY OF STANDARDS LABORATORIES AND CAPABILITIES  
[309]

This section charts the various calibration capabilities of members and other participating standards laboratories. The information for this section has been transcribed from the questionnaires received from the participating laboratories through February 1976 and should not be construed as an endorsement or rating of the individual laboratories by either THE NATIONAL CONFERENCE OF STANDARDS LABORATORIES (NCSL), or THE NATIONAL BUREAU OF STANDARDS (NBS).

The laboratories are listed in zip code order.

Availability of calibration services is indicated by (O) when limited to parent organization only, (F) when calibration is generally available on a fee basis, and (N) indicates calibration on a no-fee basis (the latter group consists of some State Weights and Measures Laboratories). In the first column, the asterisk (\*) indicates that the laboratory is a member of NCSL.

### PRIVATE LABORATORIES

- O SERVICE TO PARENT ORGANIZATION ONLY
- F CALIBRATION SERVICES AVAILABLE ON A FEE BASIS
- N CALIBRATION SERVICES AVAILABLE ON A NO FEE BASIS

LABORATORIES	ZIP	ELECTRICAL - DC/LF ELECTRICAL - RF/MICROWAVE ELEC - MAGNETICS	TIME AND FREQUENCY MASS. FORCE DIMENSIONAL, OPTICS, SURFACES	ACOUSTICS, SOUND, NOISE VIBRATION FLUID FLOW GAS FLOW	HUMIDITY TEMPERATURE PRESSURE, VACUUM	IONIZING RADIATION, RADIOACTIVITY MEDICAL INSTRUMENTATION AUTOMATED MEASURING EQUIPMENT	TESTING MATERIALS & PRODUCTS CHEMICAL ANALYSIS WATER POLLUTION	AIR POLLUTION WEIGHTS & MEASURES RADIOMETRY & PHOTOMETRY
*EELL NORTHERN RESEARCH		O	O		O O	O		
*ERMES ELECTRONICS LIMITED		O O	O					
*INSTITUTE TWO FOR MECH. CONSTR			F F	F F F	F			
*GENERAL ELECTRIC COMPANY	01201							
*GENERAL RADIO COMPANY	01742	F						
*FAYTECH COMPANY	01778	O O	O	O	O O			
FCA	01801	O O	O O	O				
MANCIB CO.	01803	F						
MCNEYWELL INC.	01803	F	F			F		
*MICROWAVE ASSOCIATES, INC.	01803	O O	O O		O O O	O		O
*FAYTECH COMPANY	01810	O O O	O O	O	O O O			
*UNIV. OF LOWELL RESEARCH FOUND	01854	F F	F		F	F F	F F	
TRANSITRON ELECTRONIC CORP.	01880	O	O O	O	O	O		
*AVCC CORP.	01887	F F F	F F F	F	F F F	F	F F	F
*FCXCRRC CO.	02035	F F F	F F F	F F	F F			
FAYTECH CO	02062	F						
*STONE + WEBSTER ENGINEERING CO	02107	O O	O O	O O O	O O O	O O	O O O	O O O
*CHARLES STARK DRAPER LABORATORY	02139	O O	O		O			
FAYTECH COMPANY	02154	F	F					
HEWLETT PACKARD CO.	02154					F		
GENERAL DYNAMICS CORPORATION	02169							
ITEK CORP.	02173	O O	O O O	O	O O			O
EPPLEY LABORATORY, INC.	02840	F			F			F
*FAYTECH COMPANY	02871	F	F F F	F	F		F	F
KILLSMAN INST. CO.	03053	O	C O O		O O O		O O	O O
*SANDERS ASSOCIATES, INC.	03060	F F	F F F	F F	F F F			F
EATH IRON *CFKS CORP.	04530	O O	O					
*PRECISION INSPECTION INC.	06051		F			F		
*COMBUSTION ENGINEERING INC.	06055	O		O	O O		O O O	O
*FFATT & WHITNEY AIRCRAFT	06108	O O	O O O	O O O	O O O	O O	O O O	O O O
*GENERAL DYNAMICS CORPORATION	06340	O O	O C C	O O	O O O			O
*MCCHE SPECIAL TOOL CO., INC.	06607		O					
*FERKIN FLMER CORP.	06810	O O	O C O	C O	O O			O
HARPEL, INC.	06855				O			
*INCAL SERVICE CORP.	06902							



# PRIVATE LABORATORIES

O SERVICE TO PARENT ORGANIZATION ONLY  
 F CALIBRATION SERVICES AVAILABLE ON A FEE BASIS  
 N CALIBRATION SERVICES AVAILABLE ON A NO FEE BASIS

LABORATORIES	ZIP	ELECTRICAL - DC/IF ELECTRICAL - RF/MICROWAVE ELEC - MAGNETICS	TIME AND FREQUENCY MASS. FORCE DIMENSIONAL OPTICS, SURFACES	ACOUSTICS, SOUND, NOISE VIBRATION FLUID FLOW GAS FLOW	HUMIDITY TEMPERATURE PRESSURE, VACUUM	IONIZING RADIATION RADIOACTIVITY MEDICAL INSTRUMENTATION AUTOMATED MEASURING EQUIPMENT	TESTING MATERIALS & PRODUCTS CHEMICAL ANALYSIS WATER POLLUTION	AIR POLLUTION WEIGHTS & MEASURES RADIOMETRY & PHOTOMETRY
*CAPITAL MAGNETIC PRODUCTS	06906	O O	C C O	O	O O		O O	O
RFL INDUSTRIES, INC.	07005	O O			O			
*ELANCHETTE TOOL + GAGE MFG. CO	07012		F			F	F	F
*ITT--DEFENSE COMMUNICATIONS DI	07014	O			O			
*ITT--AVIONICS DIVISION	07014	O O	O O	O	O			
*LOCKHEED ELECTRONICS CO., INC.	07061	F F F	F F F	F	F F F	F	F	
*CRANETZ ENGINEERING LABS, INC.	07080	U						
HONEYWELL INC.	07090	F F	F			F		
*WESTON INSTRUMENTS, INC.	07114	O O O	O O	O	O O			O
*CCOI CORP.	07410	F						
*SINGER COMPANY	07424	O O O	O O O	O O O	O O O			O O
*BENDIX CORP/CRATICN	07608							
RCA	08057	O O	O O		O			
*SWEETMAN CALIBRATION SERVICES	08109	F F F	F F F	F F F	F F F	F F F	F F F	F F
*METTLER INSTRUMENT CORPORATION	08520							
RCA	08540	O O O	O O O	O	O O O	U		O
*RCA SOLID STATE DIVISION	08876	O O	O O		O O O			O
*COX + COMPANY	10003	O		O O	O O			
NILSSON ELECTRICAL LABORATORY.	10013	F	F					
*ELECTRICAL TESTING LABORATORIE	10021	F F	F F F	F	F F F	F	F F	F
*JULIE RESEARCH LAB.	10023	O				O	O	
*ELECTRICAL INSTRUMENT SERVICE.	10550	F F F	F		F			
*SPERRY GYROSCOPE	11020	O O O	O O O	O	O O	O	O O	O
*TURNER BALANCES AND WEIGHTS	11040							
*GRUMMAN AERCSPACE CORP.	11714	F F F	F F F	F F F	F F F			F
*GENERAL ELECTRIC COMPANY	12345							
*GENERAL ELECTRIC COMPANY	13201	F F F	F	F F F	F F F	F	F F F	F F
NIAGARA MOHAWK POWER CORP.	13202	O O	O O O	O O	O O O		O O O	O O O
SPERRY RAND CORP.	13501	O O	O	O	O O		O	O
*BENDIX CORP/CRATICN	13838							
*UNION CARBIDE CORPORATION	14150	F	F	F F	F F F			O O
*EASTMAN KODAK COMPANY	14650	O O	O O O	O	O O O	O		O O
*EASTMAN KODAK COMPANY	14650	O O	O O	O	O O			
*WESTINGHOUSE ELECTRIC CORPORAT	15230	O	O O O	O O O	O O O	O O O	O O	O
*WESTINGHOUSE ELECTRIC COMPANY	15235	O O	C		O O	O	O	
*CANNON INSTRUMENT COMPANY	16801							
*AMP, INC.	17105	O O O	O O O	O O O	O O O	O O O	O	O O O
HAMILTON TECHNOLOGY, INC.	17604		O O O	O	O		O O	
*GAGE LAB CORPORATION	19006	F F	F F F	F F F	F F F	F F	F F	F
*CLIFTON PRECISION	19018	O O	O O O	O	O O O		O	
*GENERAL ELECTRIC	19101	O O	C O		O O O			O
*AMERICAN INSTRUMENT SERVICE, I	19123	F F F	F		F F	F		F
HONEYWELL INC.	19406	F F	F			F		
EMERSON ELECTRIC CO.	19440			F F				
*AMERICAN ELECTRONIC LABS., INC	19446	F F	F F F	F	F F			
*LEEDS + NORTHROP COMPANY	19454	F	F		F F			
*FLO ASSOCIATES	19454							
*BIDDLE, JAMES G. COMPANY	19462	F						
*CCMSAT LABORATORIES	20734	O O	O O O		O O			O
*FAIRCHILD SPACE + ELECTRONICS	20767	F F	F F F	F	F F F	F	F	F

# PRIVATE LABORATORIES

O SERVICE TO PARENT ORGANIZATION ONLY

F CALIBRATION SERVICES AVAILABLE ON A FEE BASIS

N CALIBRATION SERVICES AVAILABLE ON A NO FEE BASIS

LABORATORIES	ZIP	ELECTRICAL - DC/LF ELECTRICAL - RF/MICROWAVE ELEC - MAGNETICS	TIME AND FREQUENCY MASS. FORCE DIMENSIONAL OPTICS, SURFACES	ACOUSTICS, SOUND, NOISE VIBRATION FLUID FLOW GAS FLOW	HUMIDITY TEMPERATURE PRESSURE, VACUUM	IONIZING RADIATION, RADIOACTIVITY MEDICAL INSTRUMENTATION AUTOMATED MEASURING EQUIPMENT	TESTING MATERIALS & PRODUCTS CHEMICAL ANALYSIS WATER POLLUTION	AIR POLLUTION WEIGHTS & MEASURES RADIOMETRY & PHOTOMETRY
*APPLIED PHYSICS LAB	20810	O O O	O O O	O O	O O O	O		
*AUTOMATION INDUSTRIES, INC.	20910	O O O	O O O		O O O			
*WESTINGHOUSE ELECTRIC CORPORAT	21203	F F F	F F F	F F F	F F F	F		F
*KOPPERS CO., INC.	21203	O O	C C O	O	O O O		O O O	O O
MARTIN MARIETTA CORP.	21220	O O	C C O	O	O O O	O	O O O	O
*MACK TRUCKS, INC.	21740		O					
*E-SYSTEMS	22046	F F	F F	F	F F			F
*MCNEYWELL INC.	22151	F F	F F	F	F F	F F		
*NEWPORT NEWS SHIPBUILDING	23607	F F	F F F	F F F	F F F		F F F	F
*INSTRUMENTS EAST	23703	O	O	O	O O			
*MARTINSBURG ELECTRONICS	25401	F	F			F		F
MCNEYWELL INC.	27407					F		
*CITACEL, THE	29409	O						
LOCKHEED AIRCRAFT CORP.	30063	O O O	O O O	O O C	O O O	O O	O O	O O O
SPERRY RAND CORP.	32601	F F F	F F	F F	F F	F		
MCNEYWELL INC.	32803	F F	F			F		
*MARTIN MARIETTA AEROSPACE	32805	O O O	O O O	O	O O O	O O	O O	O O
*HARRIS CORPORATION	32901	F F F	F F	F F	F F F	F	F F	F F
*PAN AMERICAN AIRWAYS, INC.	32925		O C	O O O	O O O	O		
*RCA INTERNATIONAL SERVICE CORP	32925	O O O	O			O O		
FLORIDA STANDARDS LAB	33405	F F	F F F		F F			F
*GENERAL ELECTRIC COMPANY	33733	O O O	O		O O O	O O	O O	O O
*MCNEYWELL INC.	33733	O O	C O O	O	O O			O O
*CAK RIDGE NATIONAL LABORATORY	37830	O	O			O		
*UNION CARBIDE CORPORATION	37830	F	F F F	F F F	F F F	F F	F F F	F F
*EATTELLE MEMORIAL INSTITUTE	43201	O O	C C O	O O C	O O O	O		
ROCKWELL INTERNATIONAL	43216	O O	O O	O O	O O			O
*EATLEY METER COMPANY	44092	O	O C O	O	O O			O
*COULD, INC.	44114	O	O		O O			O
MCNEYWELL INC.	44135	F F	F			F F		
*BABCOCK & WILCOX RESEARCH CTR.	44601			O				
*TIMKEN COMPANY	44706	O		O				
*NORTH ELECTRIC CO.	44833	O O O	O O O	O	O O O	O	O O	O
MCNEYWELL INC.	45324	F F	F			F		
*MONSANTO RESEARCH CORPORATION	45342	O	C C C	O O C	O O O	O		O O
*YELLCO SPRINGS INSTRUMENT CO.	45387	O			O		O	
*EENOIX CORPORATION	45403		F					
*GENERAL MOTORS CORPORATION	46206	O	O O O	O O C	O O	O		O
AVCO CORP.	47374	F F F	F F F	F	F F F		F F	F
MCNEYWELL INC.	48024	F F	F			F F		
*ESCO STANDARDS LABORATORY	48237	F F F	F F	F	F F F	F F	F F F	F F
HEATH CO.	49085	O	O					
*LEAR SIEGLER, INC.	49508	O	O O O	O	O O	O		
*ROCKWELL INTL. COLLINS RADIO G	52406	F F F	F F F	F F F	F F F	F		F F
*ALLIS CHALMERS CORP.	53201	F	F F F	F	F F			
*NJM COMPANY	55101							
*SPERRY UNIVAC, DEFENSE SYSTEMS	55165	O O O	O O O	O O	O O O	O		O
*TELEX COMMUNICATIONS INC.	55420							
*CNAK CORPORATION	55432	O	O		O			
*MEDTRONIC, INC.	55432	O O O	O O O		O O	O	O O	O

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N CALIBRATION SERVICES AVAILABLE ON A NO FEE BASIS

LABORATORIES	ZIP	ELECTRICAL - DC/AC ELECTRICAL - RF/MICROWAVE ELEC. - MAGNETICS	TIME AND FREQUENCY MASS, FORCE	GEOMETRICAL, OPTICS, SURFACES	ACOUSTICS, SOUND, NOISE VIBRATION	FLUID FLOW GAS FLOW	HUMIDITY TEMPERATURE PRESSURE, VACUUM	IONIZING RADIATION, RADIOACTIVITY MEDICAL INSTRUMENTATION AUTOMATED MEASURING EQUIPMENT	TESTING MATERIALS & PRODUCTS CHEMICAL ANALYSIS WATER POLLUTION	AIR POLLUTION WEIGHTS & MEASURES RADIOMETRY & PHOTOMETRY
*LAKE CENTER INCUS.	55987	O	O			G	O			
*WIDWEST GAGE LABORATORY	60007							F	F	F
*RANK PRECISION INDUSTRIES, INC	60018			O						
*NCTCFCLA, INC.	60172	O O	O				O			
*ARGENNE NATIONAL LABORATORY	60439	O	O	O			O			
*IIT RESEARCH INSTITUTE	60616	F F F	F				F			
*WESTERN ELECTRIC COMPANY	60623	O O O	O O O	O			O		O O O	O O
*MCNEYWELL INC.	60634	F F F	F					F F		
*MCNEILL OUGLAS CORP.	63166	F F F	F F F	F F F	F F F	F F F	F F F	F F	F F F	F F F
*BENDIX CORPORATION	64141									
*BEECH AIRCRAFT CORPORATION	67201	O O O	O O O	O O O	O O O	O O O	O O		O	O
*BEECH AIRCRAFT CORP.	67201	O O O	O O O	O O O	O O O	O O O	O O		O	O
*BEECH COMPANY	67210	F F F	F F F	F F F	F F F	F F F	F F F	F F	F F F	F F F
*ROCKWELL INTERNATIONAL - TULSA	74151	F F F	F F F	F F F	F	F F F	F F F	F F	F F F	F F F
*TUCKER ELECTRONICS COMPANY	75040	F F	F							
CLLINS RADIO COMPANY	75080	F F	F		F					
GENERAL ELECTRIC COMPANY	75220	F F	F		F		F	F		
*SCHLUMBERGER WELL SERVICES	77001	O	O O O				O O			
*RUSKA INSTRUMENT CORPORATION	77036		F				F			
MCNEYWELL INC.	77042	F	F					F		
*LOCKHEED ELECTRONICS CO., INC.	77058	O O O	O O O	O O O	O O O	O O O	O O O	O	O O O	O O O
TEXAS METROLOGY LAB.	78701									F
*TRACOR, INC.	78721	O O O	O O O	O		O O O	O O O	O	O	O
*ROCES-CRCS LABORATORIES	78724	F F	F				F F			
*MASCN + HANGER-SILAS MASON CO.	79177	O O O	O O O	O O O	O O O	O O O	O O O	O	O	O
*MCNEYWELL INC.	80217	F F F	F				F	F F		
CCLCRADC ENGINEERING EXPERIMEN	80302					F				
*ROCKWELL INTERNATIONAL	80401	O	O O O	O C	O O O	O O O	O O O	O O O	O O O	O O
HEWLETT PACKARD CO.	80537	F F								
*AERJET NUCLEAR COMPANY	83401	O O	O O O	O O O	O O O	O O	O O	O		O
*HERCULES INC.	84044	O	O O O			O O O	O O O			O
SPERRY RAND CORP.	84116	O O O	O O O	O		O O O	O O O	O O O		O
*THICKEL CORP.	84302	O O O	O O O	O		O O O	O O O			O
MCNEYWELL INC.	85017	F F	F					F		
*CARRETT CORPORATION	85034	O	O O	O O O	O O O	O O O	O O O	O		O
*SANDIA LABS	87115	F F F	F F F	F F F	F F F	F F F	F F F	F F	F	F F
*LOCKHEED ELECTRONICS CO., INC.	88001	O O	O O O	O O	O O O	O O O	O O O		O	O
*EG&G INC.	89101	F F	F F F	F F F	F F F	F F F	F F	F	F	F
*QUALITY CONTROL COMPANY	90004									
MCNEYWELL INC.	90040	F F	F	F				F F		
*FUGHES AIRCRAFT COMPANY	90230	O O O	O O O	O O C	O O O	O O O	O O O	O O		O O
*ROCKWELL INTERNATIONAL	90241									
*XEROX CORPORATION	90245	O	O O O			O O				O
NORTHROP CORP.	90250	O O O	O O O	O		O O O		O O		
VOLUMETRICS	90301				F	F F F				
GENERAL ELECTRIC INSTRUMENTATI	90301	F F	F	F				F		
GAUGE REPAIR SERVICE	90304						F			
*MCNEILL OUGLAS CORPORATION	90846	O O O	C O O			O O O	O O O	O O	O O	O O
*CALIFORNIA INSTITUTE OF TECHNO	91103	O O	O O O	O		O O O	O O O	O O		O O
*BELL + HOWELL ELECT. + INSTR.	91109	O O	O O O				O			O



# PRIVATE LABORATORIES

O SERVICE TO PARENT ORGANIZATION ONLY  
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 N CALIBRATION SERVICES AVAILABLE ON A NO FEE BASIS

LABORATORIES	ZIP	ELECTRICAL - DC/LF ELECTRICAL - RF/MICROWAVE ELEC - MAGNETICS	TIME AND FREQUENCY MASS. FORCE DIMENSIONAL OPTICS SURFACES	ACOUSTICS, SOUND, NOISE VIBRATION FLUID FLOW GAS FLOW	HUMIDITY TEMPERATURE PRESSURE, VACUUM	IONIZING RADIATION RADIOACTIVITY MEDICAL INSTRUMENTATION AUTOMATED MEASURING EQUIPMENT	TESTING MATERIALS & PRODUCTS CHEMICAL ANALYSIS WATER POLLUTION	AIR POLLUTION WEIGHTS & MEASURES RADIOLOGY & PHOTOMETRY
*TELECYNE SYSTEMS CO.	91224	F F	F F F	F	F F F		F	
*LITTON GUIDANCE + CONTROL SYST CERTIFIED SERVICES	91364 91406	O O F F	O O O F F F	O O	O O O F F	O	O	O
*LITTON SYSTEMS, INC.	91409	O	O O O					
*NATIONAL ASTRO LABS., INC.	91505							
*LOCKHEED-CALIFORNIA COMPANY	91520	F F F	F F F	F F F	F F F	F	F F F	F
*AEROCJET ELECTROSYSTEMS COMPANY	91702	O O O	O O O	O F F	F O O	O		F O O
*GENERAL DYNAMICS/POMONA DIVISI	91766	F F F	F F F	F F F	F F F	F	F F	F F
*TELEDYNE RYAN AERONAUTICAL	92112	O O O	O O O	O	O O O			O O
*GENERAL DYNAMICS CORPORATION	92138	F F F	F		F	F		
*GENERAL DYNAMICS CORPORATION	92138	F F F	F F F	F F F	F F F	F F F		F
*CELESCOP INDUSTRIES, INC.	92626	O O	O O		O O O		O	
*AEROJET MANUFACTURING CO.	92631	O	O	O C	O O O		O O	F O
*BECKMAN INSTRUMENTS, INC.	92634	F F F	F F F	F F F	F F F	F F	F F F	F F F
*MCDONNELL DOUGLAS AERONAUTICS	92647	F F	F F F	F F F	F F F			F F F
*AERONUTRONIC-CORP CORPORATION	92663	O O	O C O	O	O O O			O
*ENDEVCO	92675			F				
*ROCKWELL INTERNATIONAL	92803	F F F	F F F	F F F	F F F	F F F	F	F F
*DALMC VICTOR COMPANY	94002	F F	F	F	F F F		F	F
*FAIRCHILD CAMERA AND INSTRUMEN	94042	O O	O O		O O	O	O O O	
HEWLETT PACKARD CO.	94043	F F	F					
*AMFEX CORPORATION	94063	O O O	O O O	O O O	O O O			O
HEWLETT PACKARD CO.	94086					F		
*LOCKHEED MISSILES AND SPACE CO	94088	F F F	F F F	F F F	F F F	F F	F F F	F F F
*WESTINGHOUSE ELECTRIC CORPORAT	94088	O O	O O O	O	O O O	O	O O	O
*VARIAN	94303	F F F	F F F	F F F	F F	F F		F
*HEWLETT PACKARD CO.	94304		F					
HEWLETT PACKARD CO.	94304	F						
*HEWLETT PACKARD CO.	94304	F F	F F			F F	F	
*ATKINS-JOHNSON CO.	94304							
*KAISER AEROSPACE + ELECTRONICS	94306	O	O O O	O	O O		O	O O
*SYSTRON-COMMER	94518	O O	O		O			
*CONEYWELL INC.	94545	F F	F			F		
*UNIVERSITY OF CALIFORNIA E-H RESEARCH LABORATORY, INC.	94550 94604	O	O		O			
HEWLETT PACKARD CO.	95050	F F	F F		F			
*CONEYWELL INC.	95110	F F	F			F F		
HEWLETT PACKARD CO.	95401	F						
TELETEK ENTERPRISES, INC.	95670	F F	F	F	F F	F		
*TEKTRONIX, INC.	97077	O O	O O O		O O	O		O
*ELECTRO-SCIENTIFIC INDUSTRIES,	97229	F						
*JOHN FLUKE MFG. CO., INC.	98043	F	F			F		
CONEYWELL INC.	98109	F F	F			F		
*BOEING COMPANY	98124	O O O	O O O	O O O	O O O	O O O	O O O	O O O
*ATLANTIC RICHFIELD HANFORD CO.	99352					O	O O	

# GOVERNMENT LABORATORIES

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LABORATORIES	ZIP	ELECTRICAL - DC/AC ELECTRICAL - RF/MICROWAVE ELEC - MAGNETICS	TIME AND FREQUENCY	MASS. FORCE DIMENSIONAL, OPTICS, SURFACES	ACOUSTICS, SOUND, NOISE VIBRATION	FLUID FLOW GAS FLOW	HUMIDITY TEMPERATURE PRESSURE, VACUUM	IONIZING RADIATION, RADIOACTIVITY MEDICAL INSTRUMENTATION AUTOMATED MEASURING EQUIPMENT	TESTING MATERIALS & PRODUCTS CHEMICAL ANALYSIS WATER POLLUTION	AIR POLLUTION WEIGHTS & MEASURES RADIOMETRY & PHOTOMETRY
*DEPARTMENT OF NATIONAL DEFENCE		O O O O	O O O O	O	O O O O	O O O O	O	O O	O O O	O
*NAVAL UNDERWATER SYSTEMS CENTER	02840	O O O O	O O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*PORTSMOUTH NAVAL SHIPYARD	03801	O O O O	C O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*U.S. ARMY ELECTRONICS COMMAND	07703	F O O O	F O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*NEW CUMBERLAND ARMY DEPOT	17070	O O O O	C O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*NAVY EASTERN STOS LAB	20374	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F
*DEPARTMENT OF DEFENSE	20755	O O O O	O O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*HARRY DIANCO LABS, AMXDC-EDG- NCAA/NOIC	20783 20852	O O O O	C O O O	O O O O	O O O O	O O O O	O O O	O O O	O O O	O O O
U.S. NAVAL SURFACE WEAPONS CENTER	20910	O O O O	C O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*NAVAL AIR REWORK FACILITY 370 NORFOLK NAVAL SHIPYARD	23511 23709	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F
*U.S. MARINE CORPS TYPE II STANDARDS LABORATORY	31704 32508	O O O O	C O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*UNDERWATER SOUND REFERENCE DIV	32806	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F
*NASA/IN-VSD-4	32899	O O O O	C C C C	O O O O	O O O O	O O O O	O O O	O O O	O O O	O O O
*U.S. ARMY METRC + CALIB CENTER	35809	O O O O	O O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*NASA	35812	Z N N N	N N N N	N N N N	N N N N	N N N N	N N N N	N N N N	N N N N	N N N N
*TENNESSEE VALLEY AUTHORITY	37401	O O O O	C O O O	O O O O	O O O O	O O O O	O O O	O O O	O O O	O O O
*NATIONAL OCEANOGRAPHIC INSTR.	39520	O O O O	C O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*AEROSPACE GUIDANCE + METROLOGY DEPARTMENT OF THE ARMY	43055 47250	O O O O	O O O O	O O O O	O O O O	O O O O	O O O	O O O	O O O	O O O
U.S. ARMY ROCK ISLAND ARSENAL	61603	O O O O	O O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O
*NASA JOHNSON SPACE CENTER	77058	O O O O	O O O O	O O O O	O O O O	O O O O	O O O	O O O	O O O	O O O
*USN METROLOGY ENGINEERING CENTER	91766	O O O O	O O O O	O O O O	O O O O	O O O O	O O O	O O O	O O O	O O O
*NAVAL AIR REWORK FACILITY	94501	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F	F F F F
*U.S. BONNEVILLE POWER ADMIN.	98660	O O O O	O O O O	O	O O O O	O O O O	O O O	O O O	O O O	O O O

STATE LABORATORIES	ZIP	ELECTRICAL - DC/AC ELECTRICAL - RF/MICROWAVE ELEC - MAGNETICS	TIME AND FREQUENCY	MASS. FORCE DIMENSIONAL, OPTICS, SURFACES	ACOUSTICS, SOUND, NOISE VIBRATION	FLUID FLOW GAS FLOW	HUMIDITY TEMPERATURE PRESSURE, VACUUM	IONIZING RADIATION, RADIOACTIVITY MEDICAL INSTRUMENTATION AUTOMATED MEASURING EQUIPMENT	TESTING MATERIALS & PRODUCTS CHEMICAL ANALYSIS WATER POLLUTION	AIR POLLUTION WEIGHTS & MEASURES RADIOMETRY & PHOTOMETRY
MASSACHUSETTS, COMMONWEALTH OF	02108			N						
NEW HAMPSHIRE BUREAU OF TESTS +	03301									
MAINE DEPT OF AGRICULTURE	04330									
VERMONT DEPT OF AGRICULTURE	05602									
CONNECTICUT STATE OFFICE BLDG	06115			F						
NEW JERSEY STATE	08625									
PENNSYLVANIA, COMMONWEALTH OF	17120			N						
DEL. DEPT. OF AGRICULTURE	19901			F	N					
MARYLAND DEPT. OF AGRICULTURE	20748			F			F			
*VIRGINIA DEPT OF AGRICULTURE +	23219									
NORTH CAROLINA DEPT OF AGRICULTURE	27611									
S. C. DEPT OF AGRICULTURE	29211									
GEORGIA DEPT OF AGRICULTURE	30050			N	N					
ALA. DEPT OF AGRICULTURE + IND	36109			N	N					
TENNESSEE DEPT OF AGRICULTURE	37204			N	N					

# STATE LABORATORIES

O SERVICE TO PARENT ORGANIZATION ONLY

F CALIBRATION SERVICES AVAILABLE ON A FEE BASIS

N CALIBRATION SERVICES AVAILABLE ON A NO FEE BASIS

LABORATORIES	ZIP	ELECTRICAL - DC/AC/RF ELECTRICAL - RF/MICROWAVE ELEC - MAGNETICS	TIME AND FREQUENCY MASS, FORCE DIMENSIONAL, OPTICS, SURFACES	ACOUSTICS, SOUND, NOISE VIBRATION FLUID FLOW GAS FLOW	HUMIDITY TEMPERATURE PRESSURE, VACUUM	IONIZING RADIATION, RADIOACTIVITY MEDICAL INSTRUMENTATION AUTOMATED MEASURING EQUIPMENT	TESTING MATERIALS & PRODUCTS CHEMICAL ANALYSIS WATER POLLUTION	AIR POLLUTION WEIGHTS & MEASURES RADIOLOGY & PHOTOMETRY
KENTUCKY DEPT. OF AGRICULTURE	40601							
INDIANA DIV OF WEIGHTS + MEASU	46206							
MICHIGAN DEPT OF AGRICULTURE	48913		F					
WISCONSIN DEPT OF AGRICULTURE	53705							
MINNESOTA DEPT OF PUBLIC SERVI	55403							
NORTH DAKOTA PUBLIC SERVICE CO	58501							
ILLINOIS DEPT. OF AGRICULTURE	62706							
MISSOURI DEPT OF AGRICULTURE	65701							
KANSAS DEPT OF AGRICULTURE	66612							
ARKANSAS WEIGHTS + MEASURES LA	72209		N	N				
OKLAHOMA STATE DEPT. OF AGRICU	73105							
COLORADO DEPT OF AGRICULTURE	80211							
WYOMING DEPT OF AGRICULTURE	82001							
IDAHO DEPARTMENT OF AGRICULTUR	83701							
UTAH DEPT OF AGRICULTURE	84107							
NEVADA DEPT OF AGRICULTURE	89501							
BUREAU OF WEIGHTS + MEASURES	95814			F	F			
HAWAII, STATE DEPARTMENT OF AG	96814		F					
OREGON AGRICULTURE DEPT	97310							
ALASKA STATE	99503							



APPENDIX H. NBS CALIBRATION ACTIVITY SUMMARY FOR FISCAL YEAR 1975 [255,271].

Table H-1. Calibration data for NBS by state

	<u>Public</u>		<u>Government</u>		<u>Total</u>	
	Count	Cost	Count	Cost	Count	Cost
Alabama	10	\$ 1,267	260	\$171,366	270	\$ 172,633
Alaska	0	0	0	0	0	
Arizona	43	14,493	0	0	43	14,493
Arkansas	0	0	0	0	0	
California	613	237,805	48	37,284	661	275,089
Colorado	101	33,242	2	910	103	34,152
Connecticut	116	41,463	0	0	116	41,463
Delaware	2	260	0	0	2	260
District Columbia	17	7,283	80	48,700	97	55,983
Florida	81	15,344	18	8,477	99	23,821
Georgia	40	16,018	1	340	41	16,358
Hawaii	1	150	0	0	1	150
Idaho	4	1,333	0	0	4	1,333
Illinois	44	14,066	4	1,174	48	15,240
Indiana	40	11,357	1	417	41	11,774
Iowa	4	1,063	0	0	4	1,063
Kansas	5	750	0	0	5	750
Kentucky	20	5,632	5	3,680	25	9,312
Louisiana	12	6,192	0	0	12	6,192
Maine	5	752	0	0	5	752
Maryland	113	81,531	30	27,692	143	109,223
Massachusetts	197	63,040	7	2,447	204	65,487
Michigan	63	16,838	0	0	63	16,838
Minnesota	87	37,387	0	0	87	37,387
Mississippi	9	3,416	3	1,080	12	4,496
Missouri	82	30,690	0	0	82	30,690
Montana	0	0	0	0	0	
Nebraska	15	5,389	0	0	15	5,389
Nevada	4	1,266	2	207	6	1,473
New Hampshire	26	6,780	0	0	26	6,780
New Jersey	166	37,575	46	24,842	212	62,417
New Mexico	80	41,350	3	1,244	83	42,594
New York	332	139,267	0	0	332	139,267
North Carolina	57	17,598	2	205	59	17,803
North Dakota	2	153	0	0	2	153
Ohio	204	71,440	192	159,515	396	230,955
Oklahoma	17	8,651	1	660	18	9,311
Oregon	12	7,771	6	1,430	18	9,201
Pacific Islands	0	0	0	0	0	
Pennsylvania	283	94,868	1	1,200	284	96,068
Puerto Rico	1	110	0	0	1	110
Rhode Island	21	8,892	0	0	21	8,892
South Carolina	23	6,629	0	0	23	6,629
South Dakota	0	0	0	0	0	
Tennessee	69	32,125	1	89	70	32,214
Texas	130	36,379	49	13,597	179	49,976
Utah	12	5,024	3	1,273	15	6,297
Vermont	5	974	0	0	5	974
Virginia	48	10,071	25	19,785	73	29,856
Washington	47	40,891	4	1,717	51	42,608
West Virginia	7	1,943	0	0	7	1,943
Wisconsin	26	5,793	0	0	26	5,793
Wyoming	2	208	0	0	2	208
Unzipped Entries	32	12,325	3	13,481	35	25,806
TOTALS	3,330	1,234,844	797	542,812	4,127	1,777,656

Table H-2. Summary of calibration data for FY-75.			1.6 Flatness, Straightness & Roundness		20	5.1
Item	No.	Cost (k\$)				
1.1 Mass, Volume and Density	103	37.9	1.6A Optical reference planes--flats	12	3.8	
1.1A Mass measurement services			1.6B Surface plates & straight edges	1	0.2	
1.1B Calibration of reference stds of mass (individual weights or weight sets)	53	21.7	1.6F Roundness stds	3	0.6	
1.1C Mass Measurement Assurance Program	6	2.3	1.6G Roundness calibration specimens	3	0.6	
1.1D Railroad track scales			1.6H Roundness measurements	1	0.1	
1.1G Volume meas. services			1.7 Angular	15	7.1	
1.1H Calibration of reference std volumetric apparatus	20	6.3	1.7A Angle gage blocks	10	5.8	
1.1P Density meas. services			1.7B Optical polygons	2	1.0	
1.1Q Density determinations of liquids or solids	20	6.3	1.7C Angle calipers & step mirrors			
1.1R Reference std hydrometers	4	1.3	1.7D Wedges	2	0.3	
1.2 Office of Weights and Measures			1.7E Cylindrical & machinist squares	1	0.1	
1.2A Special weights & measures services			1.7F Rotary & indexing tables			
1.2B Weights & measures calibration (LP gas provers, class F weights, etc.)			1.7G Autocollimating telescopes			
1.2C Device prototype testing (for compliance to handbook 44)			1.7H Angle generators			
1.3 Length	153	92.9	1.8 Surface Texture	19	13.0	
1.3A Special length meas. services	2	1.0	1.8A Instrument calibration specimens	1	0.2	
1.3B Linear thermal expansion--solids			1.8B Surface roughness measurements	18	12.8	
1.3C Calibration of gage blocks	84	73.9	1.9 Image Optics and Photography	8	2.2	
1.3D Gage block thermal expansion (new FY76)			1.9A Refractive index	5	1.8	
1.3E Gage block comparator stylus tip radius (new FY76)			1.9B Optical lens evaluation			
1.3H Line stds--40 in. or less long	9	5.9	1.9C Step tables	3	0.4	
1.3J Tapes--steel or invar	49	8.3	1.9D Microscopy resolution test charts			
1.3K Surveying instruments--other	5	1.7	1.9E Lens test			
1.3M Sieves			1.9J Special microdensitometer meas. (new FY76)			
1.3N Haemacytometers			1.9K&L Photographic edge calibrations (new FY76)			
1.3R Precision circles			1.9M Photographic sinusoidal calib. (new FY76)			
1.4 Length & Diameter Dimensional Metrology	27	15.1	2.1 Acoustic Measurements	14	5.6	
1.4A End stds of length	5	4.4	2.1A Acoustical meas. services	1	0.1	
1.4B Step gage stds of length--up to 40 inches	1	0.5	2.1BC&D Microphone WE type 640 AA or equivalent	13	5.6	
1.4C Plug gages	4	2.4	2.1H&I Earphones			
1.4D Measuring wires for threads and gears	16	7.3	2.2 Vibration Measurements	47	42.1	
1.4E Spherical diameter stds--balls			2.2A Vibration meas. services	3	2.4	
1.4F Internal diam. stds--ring gages	1	0.5	2.2BCD&E Vibration pickups	44	39.7	
1.5 Complex Std's of Length & Diameter	51	19.7	2.2F Shock pickups			
1.5A Plain conical plug & ring gages	1	0.7	2.3 Humidity Measurements	11	13.1	
1.5B Threaded plug & ring gages	1	0.1	2.3A Humidity meas. services	8	8.8	
1.5C API threaded plug & ring gages	38	16.0	2.3B&C Dewpoint hygrometers automatic	2	3.8	
1.5D Master gears			2.3D&E Dewpoint hygrometers manual	1	0.5	
1.5E Length & diameter calipers			2.3F Electric hygrometer			
1.5F Micrometer screws, dial micrometers	3	1.2	2.3G Coulometric hygrometer			
1.5G Penetration needles	8	1.7	2.3H Aspirated hygrometer			
1.5H Polariscope tubes			2.3I Pneumatic bridge hygrometer			
1.5J Two dimensional gages (new FY76)			2.4 Engineering Mechanics	14	2.4	
			2.4A Engineering mechanics meas. services	1	0.3	
			2.4B&C Services of staff members	13	2.1	
			2.5 Calibration of Force Transducers	265	134.7	
			2.5AB&C 100-25,000 lbf	135	60.8	
			2.5DE&F 25,001-112,000 lbf	86	42.9	
			2.5GH&I 112,001-300,000 lbf	33	22.6	
			2.5JK&L 300,001-1,000,000 lbf	11	8.5	
			2.5M 1,000,001-12,000,000 lbf			

<u>Item</u>	<u>No.</u>	<u>Cost</u> <u>(k\$)</u>				
			3.4	<u>Voltage Measurements</u>	<u>263</u>	<u>55.8</u>
2.7	<u>Fluid Quantity &amp; Flow Rate Meters</u>	<u>33</u>	<u>53.1</u>			
2.7A	Flow rate meas. services	2	6.0	3.4A	Special voltage meas. services	4 1.2
2.7C	Liquid quantity meter	10	11.3	3.4B	Volt transfer program	13 9.4
2.7D	Flow rate meter (direct reading)	13	17.0	3.4C&D	Std cell calibrations	184 40.8
2.7E	Flow rate meter (orifice, nozzles, laminar flow, etc.)	8	18.9	3.4E	Pt thermometer temp. determination of cells in air enclosures	1 0.1
2.8	<u>Hydraulics</u>	<u>3</u>	<u>0.8</u>	3.4F	Std cell calib., unsaturated std cell	36 3.4
2.8A	Hydraulic meas. services			3.4GH&I	Solid state voltage reference sources	5 0.3
2.8B	Water current meters	3	0.8	3.4J&K	Special handling	20 0.6
2.9	<u>Aerodynamics</u>	<u>24</u>	<u>18.6</u>	3.5	<u>Electrical Instruments (AC-DC)</u>	<u>102</u> <u>26.6</u>
2.9A	Aerodynamic meas. services	8	12.8	3.5A	Special dc meas. services	1 0.1
2.9B	Air speed instruments	16	5.7	3.5BC&D	RMS ac-dc transfer std	98 26.1
2.9C	Pitot-static tubes			3.5F	Ac-dc wattmeters	2 0.4
3.1	<u>Resistance Measurements (Electric)</u>	<u>439</u>	<u>87.1</u>	3.5H	4-terminal ac resistors	1 0.1
3.1A	Special resistance meas. services			3.6	<u>Instrument Transformers &amp; Comparators</u>	<u>89</u> <u>41.7</u>
3.1B	Resistance Meas. Assurance Prog. Standard resistors:	5	2.2	3.6A	Special ac meas. services	18 25.6
3.1C	4 terminal, Thomas types, 1 ohm	97	14.7	3.6BCD&E	Voltage transformers, ratio & phase angle	18 2.2
3.1DE&F	4 terminal, decimal multiples of 1 ohm	153	30.6	3.6G	Voltage transformer comparators	2 0.9
3.1G&H	2 terminal, " " " "	73	12.4	3.6PQRS&T	Current transformer, ratio & phase angle	43 10.7
3.1I	Four terminal, other	1	0.1	3.6W&X	Current transformer comparator	8 2.2
3.1J	Two terminal, other	2	0.5	3.7	<u>High Voltage &amp; Energy Measurements</u>	<u>103</u> <u>26.2</u>
3.1KL&M	Multiple megohm, 10 <sup>6</sup> ohm up	51	14.9	3.7A	Specialized high voltage meas. services	9 4.6
3.1N&O	Temperature coefficient data			3.7B	Resistors & resistive dividers	6 1.2
3.1P	Pressure coefficient, Thomas-type			3.7D	Watt-hour meters: Measurement Assurance Program	
3.1QR&S	For current meas. (shunts)	54	10.1	3.7EFGH&J	Watt-hour meters	81 19.7
3.1T	Adjustable low resistance std	3	1.5	3.7KLM&N	Kilovoltmeters	6 0.6
3.2	<u>Precision Apparatus (Electrical)</u>	<u>86</u>	<u>31.9</u>	3.7O	High voltage capacitors & capacitance bridges	1 0.1
3.2A&B	Decade variable resistors	1	0.8	3.7P	Kerr electro-optical, pulse-voltage-measuring systems	
3.2C	Hamon devices	1	0.3	3.7Q	X-ray machines, pulse-voltage-measuring systems	
3.2D	High resistance transfer device			3.7Z	High voltage field calibrations	
3.2E	Precision Wheatstone bridges	1	0.8	3.8	<u>Magnetic Measurements</u>	<u>46</u> <u>4.6</u>
3.2F	Thermometer bridges	3	3.1	3.8A	Magnetic meas. services	
3.2G	Double ratio set ratio device	1	0.9	3.8BC&D	Normal induction	2 0.4
3.2H	Kelvin ratio box, plug type	3	1.0	3.8E&F	Demagnetization	1 0.1
3.2IJ&K	Ratio device--resistive decade voltage divider	16	5.6	3.8G&H	Permeability	1 0.1
3.2L&M	Direct reading ratio sets	1	0.4	3.8J&K	Magnetic materials, core loss	6 0.4
3.2NO&P	Potentiometers	18	10.2	3.8L&M	Magnetic materials, ac permeability	1 0.1
3.2Q&R	Inductive voltage dividers	14	3.4	3.8P&Q	Magnetic testing apparatus	3 0.1
3.2ST&U	Fixed dc voltage dividers	27	5.4	3.8R&S	Area turns of a search coil	2 0.1
3.2V&W	Silsbee type divider			3.8T&U	Flux meter calibrations	8 0.5
3.2X&Y	Measurement Assurance Programs for dc voltage ratio			3.8V	Calibration of a std magnet	21 2.6
3.3	<u>Impedance Measurements (Electric)</u>	<u>185</u>	<u>39.5</u>	3.8W	Solenoids & Helmholtz coils	1 0.2
3.3A	Special inductance & capacitance meas. services	1	0.1	3.9	<u>Dielectric Measurements</u>	
3.3B	Capacitance Meas. Assur. Prog.	1	0.8	3.9A	Dielectric constant & dissipation factor	
3.3C&D	Inductors, fixed, self or mutual	174	36.4			
	Standard capacitors:					
3.3EF&G	Fixed, 3-terminal	3	1.0			
3.3H&I	Variable or decade	6	1.3			
3.3J	Fixed, fused silica dielectric					



<u>Item</u>	<u>No.</u>	<u>Cost</u> (k\$)				
4.0 ELECTROMAGNETICS: METROLOGY AT RADIO, MICROWAVE AND LASER FREQUENCIES				4.6 <u>Noise Temperature (Effective)</u>	<u>22</u>	<u>35.1</u>
				4.6A Special calibrations	5	8.9
				4.6B&C Coaxial noise generators	6	9.0
				4.6D&E Rectangular waveguide noise sources	11	17.1
4.1 <u>Attenuation (RF &amp; Microwave)</u>	<u>184</u>	<u>116.1</u>		4.7 <u>Phase Shift (RF &amp; Microwave)</u>	<u>9</u>	<u>13.3</u>
4.1A Special calibrations	18	20.3		4.7A Special calibrations		
4.1B&C Coaxial fixed attenuators	92	43.4		4.7B Fixed coaxial phase shifter		
4.1EF&G Coaxial variable attenuators	3	3.1		4.7CD&E Variable coaxial phase shifter	4	3.7
4.1H Waveguide below-cutoff (piston) attenuators	53	33.4		4.7F Coaxial delay lines		
4.1I&J Coaxial fixed directional couplers				4.7G Variable reactangular waveguide phase shifters	5	9.6
4.1K&L Coaxial variable directional couplers				4.7H Pulse time delay		(new FY76)
4.1M Fixed rectangular waveguide attenuators	2	1.3		4.8 <u>Power (RF &amp; Microwave)</u>	<u>273</u>	<u>247.9</u>
4.1N Variable rectangular waveguide attenuators	16	14.7		4.8A Special calibrations	76	76.1
4.1O Wideband attenuation or gain of coaxial networks	(new FY76)			4.8B Coaxial bolometer units	70	70.6
				4.8C Coaxial bolometer-coupler units	31	20.2
4.2 <u>Fields (EM) &amp; Antennas</u>	<u>38</u>	<u>47.2</u>		4.8DE&F Rectangular waveguide bolometer units	46	50.2
4.2A Special calibrations	16	40.0		4.8G&H Rectangular waveguide bolo- meter-coupler units	16	11.5
4.2BC&D Field strength receivers	12	1.6		4.8I Coaxial peak pulse power meters	13	9.1
4.2E Loop antennas	3	1.9		4.8J Coaxial & waveguide pulse power meters at 8.2-12.4 GHz	18	7.8
4.2F Dipole antennas	7	3.6		4.8K&L Coaxial RF calorimeters & RF power meters	3	2.4
4.2G Antenna gain						
4.2H Antenna polarization				4.9 <u>Voltage (RF &amp; Microwave)</u>	<u>438</u>	<u>111.7</u>
4.3 <u>Impedance (RF &amp; Microwave)</u>	<u>206</u>	<u>86.5</u>		4.9A Special calibrations	52	29.6
4.3A Special calibrations	16	16.1		4.9B Attenuator-thermoelement voltmeters	12	5.1
4.3B Capacitance meas., 2 terminal	7	1.4		4.9C Thermal voltage converters	230	45.2
4.3C Capacitance meas., 3 terminal	33	7.8		4.9D RF millivoltmeters & RF signal sources		
4.3D Inductance meas. (high Q)	31	18.1		4.9E RF micropotentiometers	144	31.8
4.3E Resistance meas. (low Q)	1	0.2		4.9F Coaxial peak pulse voltmeters		
4.3F Q-standards	77	7.3		4.9G Coaxial peak pulse generators		
4.3G&H Coaxial impedance (magnitude, phase angle, VSWR, reflec- tion coeff., phase angle)	22	9.7		4.9H Impulse generator spectrum amplitude		(new FY76)
4.2I Reflection coefficient of coax- ial terminations (magnitude)	2	1.2		4.9I Pulse generator risetime		(new FY76)
4.2J Reflection coefficient of rect- angular waveguide reflectors (mismatches) (magnitude only)	11	13.2		4.9J Low pass filter risetime		(new FY76)
4.3K&L Reflection coefficient of non- reflecting rectangular wave- guide ports & matched loads (magnitude only)	6	11.4		5.1 <u>Frequency Measurements</u>	<u>9</u>	<u>10.1</u>
				5.1A Special time/frequency meas.	9	10.1
				5.1B Frequency meas., 5 & 10 MHz		
4.4 <u>Laser Parameters</u>				6.0 CRYOGENICS		
4.4A Special calibrations				7.1 <u>Laboratory Thermometers</u>	<u>211</u>	<u>80.6</u>
4.4B Measurement Assurance Programs for power and energy				7.1A Thermometry services	28	53.5
4.5 <u>Material Properties (Electromagnetic)</u>				7.1BCDE&F Laboratory thermometers	142	23.1
4.5A Special calibrations				7.1G Calorimeter thermometers	7	1.4
4.5BCDE&G Permittivity measurements				7.1H Beckmann thermometer	7	2.2
4.5H Saturation magnetization std ref. spheres of Fe & Ni				7.1I Preliminary examination	19	0.2
				7.1J Additional copy of report	8	0.1

<u>Item</u>	<u>No.</u>	<u>Cost</u> <u>(k\$)</u>	<u>7.8 Spectrophotometric Standards</u>	<u>22</u>	<u>4.5</u>
7.2 <u>Thermocouples &amp; Thermocouple</u> <u>Materials</u>	<u>194</u>	<u>33.6</u>	7.8A Spectrophotometric meas. services	8	2.1
7.2A Thermocouple meas. services	8	0.4	7.8B Spectral transmittance std, cobalt blue glass	1	0.2
7.2B Type S calib. vs. thermocouple	91	14.1	7.8C Same, copper green glass		
7.2C Type R vs. thermocouple	12	1.5	7.8D Same, carbon yellow glass		
7.2D&E Type B vs. thermocouple	8	1.0	7.8E Same, selenium orange glass		
7.2F Base metal vs. thermocouple	1	0.1	7.8FG&H Wavelength std, didymium glass	2	0.3
7.2G Thermocouple materials tested against Pt thermoelectric std	10	1.7	7.8I Same, holmium oxide glass	6	1.3
7.2H Comparison calib., per point	8	0.9	7.8JK&L Vitrolite white glass std of diffuse reflectance	5	0.6
7.2KL&M Type S vs. metal freezing pts	25	10.4	7.9 <u>Pressure &amp; Vacuum Measurements</u>	<u>30</u>	<u>26.5</u>
7.2N&O Portable potentiometer pyrometer indicator	8	0.5	7.9A Special pressure & vacuum meas. services	21	17.0
7.2RS&T Comparison vs. Pt thermoelec- tric std, with Pt resist- ance thermometer	20	3.0	7.9B Deadweight piston gages	9	9.6
7.2U Type T thermocouple	3	0.1	7.9C Controlled clearance piston gages		
7.3 <u>Resistance Thermometers</u>	<u>61</u>	<u>34.7</u>	7.9D Mercurial barometer or manometer		
7.3A Resistance thermometry meas. services	2	2.2	7.9E Pressure gages & transducers		
7.3B&C Long stem PRT	41	23.1	7.9F Pressure transfer std perf. test		
7.3D Calorimetric type PRT			7.9G Vacuum gages		
7.3E&F Capsule type PRT	11	9.2	8.1 <u>Neutron Sources</u>	<u>7</u>	<u>4.2</u>
7.3G&H Additional copies of reports	7	0.3	8.1A Special meas. services		
7.3J Measurement Assurance Program			8.1B&C Emission rate in MnSO <sub>4</sub> bath	3	3.3
7.3P Germanium resistance thermometer capsule type			8.1H Thermal neutron dosimeters		
7.4 <u>Radiation Thermometry</u>	<u>56</u>	<u>25.9</u>	8.1P Neutron irradiation of foils	4	0.8
7.4A Radiation thermometry meas. services	7	3.0	8.2 <u>Radioactivity</u>	<u>29</u>	<u>9.0</u>
7.4BCD&E Optical pyrometers	31	15.7	8.2A Radioactivity meas. services & tests	6	1.5
7.4F&G Ribbon filament lamp	18	7.2	8.2B Radium	6	1.6
7.5 <u>Basic Radiometric Calibrations</u>	<u>30</u>	<u>36.6</u>	8.2C&D Gamma-ray emitting samples	7	2.3
7.5A Radiometric meas. services	3	3.4	8.2HI&J Alpha-particle emitting sample	6	2.7
7.5BC&D Spectral radiance std., ribbon filament lamp	2	3.4	8.2K Polonium-210 sources	1	0.2
7.5E&F Spect. rad. std, blackbody			8.2P&Q Beta-particle emitting samples	3	0.8
7.5GH&I Spectral irradiance std., quartz-halogen lamp	10	17.4	8.3 <u>X- &amp; Gamma-Ray Meas. Instruments</u>	<u>105</u>	<u>45.6</u>
7.5J&K Irrad. std, 33 or 144 mw/cm <sup>2</sup>	10	8.2	8.3A Special meas. services	2	0.3
7.5Y Spectral radiance standard, UV, deuterium arc lamp	5	4.1	8.3B&C Calib. factor for cavity ionization chamber	26	14.8
7.6 <u>Basic Photometric Calibrations</u>	<u>24</u>	<u>12.8</u>	8.3D&E Correction factor for electro- meter + ionization chamber	72	29.7
7.6A Photometric meas. services	4	2.6	8.3F&G Gamma-ray irradiation of passive dosimeters	5	0.8
7.6BC&D Luminous intensity std., 100 W tungsten lamp	7	3.3	8.4 <u>Gamma-Ray Sources</u>	<u>5</u>	<u>0.6</u>
7.6E&F Same, 500 W tungsten lamp	9	5.2	8.4A Special meas. services	1	0.2
7.6G&H Same, 1000 W tungsten lamp	3	1.5	8.4B 0.1 to 3 microroentgen per second at one meter	1	0.2
7.6IJKL&M Luminous flux stds	1	0.2	8.4C 3 to 20 " " " " " "	3	0.2
7.7 <u>Radiometric &amp; Photometric</u> <u>Gage Calibrations</u>	<u>18</u>	<u>9.9</u>	8.4D 20 to 60 " " " " " "		
7.7A Irradiance of 253.7 nm line of Hg from low pressure Hg lamp			8.5 <u>Dosimetry in High-Energy Electron</u> <u>Beams</u>	<u>34</u>	<u>7.2</u>
7.7BC&D Color temperature std., airway beacon lamp	8	5.4	8.5A Special meas. services		
7.7E Luminous flux stds, min. lamps	8	4.0	8.5B&C 4 ferrous-ferric dosimetes	34	7.2
7.7F Luminous directional transmit- tance std, opal glass	2	0.5	9.1 <u>Computer Science</u>	<u>2</u>	<u>1.3</u>
			9.1A&B Magnetic disk calibration	2	1.3
			9.2 <u>Engineering Tests</u>		
			9.3 <u>Interlaboratory Testing Programs</u>		
			TOTALS	<u>4127</u>	<u>1777.7</u>





Table J-2. Direct users of NBS Outputs--SIC Major Groups 1-32.

DIRECT USERS FINDS & TESTS	MEASUREMENTS SECTOR	STANDARD INTERNATIONAL CLASSIFICATION OF MAIN GROUPS																							
		1 TIME & FREQUENCY	2 LENGTH & RELATED DIMENSIONAL MEASUREMENTS	3 VIBRATION & SHOCK	4 SURFACE FINISH	5 MASS, VOLUME, & DENSITY	6 FORCE	7 FLUID FLOW	8 PRESSURE	9 TEMPERATURE	10 HUMIDITY & MOISTURE	11 THERMODYNAMIC PROPERTIES OF GASES	12 CONVECTICS	13 ELECTRICITY	14 ELECTROMAGNETICS	15 MEDICAL ULTRASONICS	16 ACOUSTICS	17 RADIOLOGY & PHOTOMETRY	18 SPECTROSCOPY	19 FAR ULTRAVIOLET RADIOMETRY	20 OPTICS	21 LASERS	22 PHYSICAL PROPERTIES OF SOLIDS & LIQUIDS	23 CHEMICAL PROPERTIES	
01 FORESTRY, FISHING, AND RELATED ACTIVITIES		4	4			2	1	2																	
02 AGRICULTURE, FORESTRY, AND FISHING										10,32				10			10								
03 MINING, QUARRYING, AND OIL AND GAS EXTRACTION																									
04 MANUFACTURING INDUSTRIES																									
10 FOOD AND KINDRED PRODUCTS																									
11 TEXTILE MILLS																									
12 APPAREL AND OTHER TEXTILE PRODUCTS																									
13 LUMBER AND WOOD PRODUCTS																									
14 FURNITURE AND FIXTURES																									
15 PAPER AND ALLIED PRODUCTS																									
16 LEATHER AND LEATHER PRODUCTS																									
17 MISCELLANEOUS MANUFACTURING INDUSTRIES																									
20 CHEMICAL AND ALLIED PRODUCTS																									
22 NONMETALLIC MINERALS, EXC. FUELS																									
23 METALS AND ALLOYS																									
24 METAL PRODUCTS																									
25 MACHINERY, ELECTRICAL, ELECTRONIC, AND INSTRUMENT																									
26 TRANSPORTATION EQUIPMENT																									
27 COMMUNICATIONS EQUIPMENT																									
28 INSTRUMENTS																									
29 OPTICS																									
30 PHYSICAL PROPERTIES OF SOLIDS & LIQUIDS																									
31 CHEMICAL PROPERTIES																									

Entries in the horizontal "heading" rows are from transactions matrices; see table 17 for key. Other numbers indicate SIC codes; the first 2 or 3 are in left-hand column, the balance in the table. X indicates that all codes in category are relevant.

Table J-3. Direct users of NBS Outputs--SIC Major Groups 33-49.

DIRECT USERS OF NBS OUTPUTS STANDARD INDUSTRIAL CLASSIFICATION CODE AND SHORT TITLE	MEASUREMENT SECTOR																									
	1-TIME + FREQUENCY	2-LENGTH + RELATED DIMENSIONAL MEASUREMENTS	3-VIBRATION & SHOCK	4-SURFACE FINISH	5-MASS, VOLUME, & DENSITY	6-FORCE	7-FLUID FLOW	8-PRESSURE	9-TEMPERATURE	10-HUMIDITY + MOISTURE	11-THERMODYNAMIC PROPERTIES OF FLUIDS	12-CRYSTALS	13-ELECTRICITY	14-ELECTROMAGNETICS	15-CHEMICAL ULTRASONICS	16-Acoustics	17-RADIOLOGY + PHOTOMETRY	18-SPECTROPHOTOMETRY	19-FAR ULTRAVIOLET RADIOLOGY	20-OPTICS	21-LASERS	22-PHYSICAL PROPERTIES OF MOLECULES	23-SURFACE PROPERTIES	24-CUSTOMIZING RADIATION		
PRIMARY AND FABRICATED METAL PRODUCTS (SIC Major Gps 33, 34, part 39)	3	4		1	1	2		1	2	3	1	1	2	1						4			3	2	4	3
33 PRIMARY METAL INDUSTRIES																										
331 Blast Furnace + Basic Steel Prod	X			3,5,6				2,5,6		X			2								7			1	2	
332 Iron + Steel Foundries	X									X											X					
333 Primary Nonferrous Metals	2,9									X																
334 Secondary Nonferrous Metals	1									X																
335 Nonferrous Rolling + Drawing				X				X		X														3	7	
336 Nonferrous Foundries								1		X											X					
339 Misc. Primary Metal Products										X										X						
34 FABRICATED METAL PRODUCTS																										
341 Metal Cans + Shipping Containers	X				X																					
342 Cutlery, Hand Tools + Hardware																										
343 Plumbing + Heating, Exc. Elect.																										
344 Fabricated Structural Metal Prod	1,3,9							1		3	3	3	3								X				3	
345 Screw Machine Prod., Bolts, etc	X							2																		
346 Metal Forgings and Stampings	X							X																		
347 Metal Services, nec																										
348 Ordnance + Accessories, nec	3	9						3,9	3	3	3										3,9				9	3
349 Misc. Fabricated Metal Products	4,7,8							3,5	4,8																	
39 MISC. MANUFACTURING INDUSTRIES																										
391 Jewelry, Silverware, + Plated Ware																										
393 Musical Instruments																										
MACHINERY, EXCEPT ELECTRICAL (SIC Major Group 35)	3	4	2	3	2	1	2	1	1	2	2	2	2	1							4					
35 MACHINERY, EXCEPT ELECTRICAL																										
351 Engines and Turbines	1	X	X			1	1	1	1			1,9									X					
352 Farm and Garden Machinery										3																
353 Construction + Related Machinery	1,3,7					1,6		2	1,4	1																
354 Sawing Machinery	X								1,2																	
355 Special Industrial Machinery	2,3,5							1	2	9		1,9	1													
356 General Industrial Machinery			1-4			7,8,9	3,4,6	5,6,8	2	3	3,9	3,8	8													
357 Office + Computing Machines	2,4,9					3,6		2-4,9	3			3	3	1												
358 Refrig. + Service Machinery	5					6		5	5	5		5,6														
359 Misc. Machinery, Exc. Electrical	9					1	2,5,6	5	5	2																
ELECTRIC AND ELECTRONIC EQUIPMENT (SIC Major Group 36)	1	3	2	3	2	1	2	3	4	2	2		3	3	2		3	1	2	3	4	2	3	2	2	2
36 ELECTRIC AND ELECTRONIC EQUIP.																										
361 Electric Distributing Equipment	X			2				X	2	X	2	X	2													
362 Electrical Industrial Apparatus	1,2,4		1	1		1		1,2	1,2,4			1,3	2													
363 Household Appliances						4	4,5	1,2,4													2,4					
364 Electric Lighting + Wiring Equip																					1,6,8					
365 Radio + TV Receiving Equipment	1	1						1	1											X	X	1,6				
366 Communication Equipment	2	2		9		1		1,2	X	X													2		X	1
367 Electronic Components + Accessor	4	1,3,9				9		3,4,9	3			4	1,4-9	1,3-9											X	2
369 Misc. Electrical Equip + Sup.																										
TRANSPORTATION EQUIPMENT (SIC Major Group 37)	1	3	1	2	2	1	1	2	1	4	2	1	3	2	2	2	1	2	2	3	3	2	3	2	2	2
37 TRANSPORTATION EQUIPMENT																										
371 Motor Vehicles + Equipment	X	X	X	X		X	X	X	X	X											X	X	X		X	X
372 Aircraft and Parts	X	X	X	X		X	X	X	X	1,4		X									X	X	X		X	X
373 Ship + Boat Building + Repairing	X	X	X	X		X	X	X	X	1	X	X									X	X	X		X	X
374 Railroad Equipment	X	X	X	X		X	X	X	X		X	X									X	X	X		X	X
375 Motorcycles, Bicycles, + Parts	X	X	X	X		X	X	X	X		X	X									X	X	X		X	X
376 Guided Missiles, Space Vehicles	X	X	X	X		X	X	X	X	X	1	X	X								X	X	X		X	X
379 Misc. Transportation Equipment						5		5				2														
INSTRUMENTS + RELATED PRODUCTS (SIC Major Group 38)	3	1	1	2	2	2	1	2	3	3	4	2	3	3	3	4	1	3	4	2	2	3	4	2	2	4
38 INSTRUMENTS + RELATED PRODUCTS																										
381 Engineering + Scientific Instrum	X	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	1
382 Measuring + Controlling Devices	5	3,4,9				4	3,9	2,3,4,9	3	2,3,9	2,3,9	3	4,5	3,5	5,9						2,3				2,5,9	3
383 Optical Instruments and Lenses	X					2	1					1									X	X	X	X	X	2
384 Medical Instruments + Supplies	X																				X	X	X	X	X	1
385 Ophthalmic Goods	X																				X	X	X	X	X	1
386 Photographic Equipment, + Sup.	X	X																			X	X	X	X	X	1
387 Watches, Clocks and Watchcases	X	X																			X	X	X	X	X	1
TRANSPORTATION + PUBLIC UTILITIES (SIC Division E)	3	1	1	2	2	1	2	3	4	1	2	1	2	2	2	1	3	4	1							4
40 RAILROAD TRANSPORTATION	10																									
41 LOCAL AND INTERURBAN PASSENGER TRANSIT								70		70																
42 TRUCKING AND WAREHOUSING																										
43 U.S. POSTAL SERVICE																										
44 WATER TRANSPORTATION	11,20							63																		
45 TRANSPORTATION BY AIR	11	21	82					X	82	X	11		83	82,83	11,82	83										11
46 PIPE LINES, EXCEPT NATURAL GAS																										
47 TRANSPORTATION SERVICES								82																		
48 COMMUNICATION	11,21	32,33																								
49 ELECTRIC, GAS + SANITARY SERV.	11	20	11					X	20	11,20	20		22,23	32	11,20	30,52										20

Table J-4. Direct users of NBS Outputs--SIC Major Groups 50-89.

DIRECT USERS OF NBS OUTPUTS STANDARD INDUSTRIAL CLASSIFICATION CODE AND SHORT TITLE	MEASUREMENT SECTOR																								
	1 TIME + FREQUENCY	2 LENGTH + DIMENSIONAL MEASUREMENTS	3 VIBRATION & SHOCK	4 SURFACE FINISH	5 MASS, VOLUME, & DENSITY	6 FORCE	7 FLUID FLOW	8 PRESSURE	9 TEMPERATURE	10 HUMIDITY + MOISTURE	11 THERMODYNAMIC PROPERTIES OF FLUIDS	12 CRYOGENICS	13 ELECTRICITY	14 ELECTROMAGNETICS	15 MEDICAL ULTRASOUND	16 ACOUSTICS	17 RADIOLOGY + PHOTOMETRY	18 SPECTROPHOTOMETRY	19 FAR ULTRAVIOLET PHOTOMETRY	20 OPTICS	21 LASERS	22 PHYSICAL PROPERTIES OF SOLIDS	23 SURFACE PROPERTIES	24 IONIZING RADIATION	
50 WHOLESALE TRADE--DURABLE GOODS	3	3 1																							
51 WHOLESALE TRADE--NONDURABLE GOODS		10,30 84																							
52 WHOLESALE TRADE--NONDURABLE GOODS					22,70 80																				
53 FILMING MATERIALS + GARDES. SUPPLIES																									
54 GENERAL MERCHANDISE STORES																		11		x					
55 FOOD STORES					11,51				x																
56 AUTOMOTIVE DEALERS + SERVICE STATIONS			11,21 91		41																				
57 APPAREL + ACCESSORY STORES																									
58 FURNITURE + HOME FURNISHINGS STORES																									
59 EATING AND DRINKING PLACES																									
60 MISCELLANEOUS RETAIL	44																								
61 BANKING																									
62 CREDIT AGENCIES OTHER THAN BANKS																									
63 SECURITY, COMMODITY BROKERS + SERVICES																									
64 INSURANCE CARRIERS																									
65 INSURANCE AGENTS, BROKERS + SERVICE																									
66 REAL ESTATE																									
67 COMBINED REAL ESTATE, INSURANCE, ETC.																									
68 HOLDING + INVESTMENT OFFICES																									
70 HOTELS + OTHER LODGING PLACES																									
72 PERSONAL SERVICES																									
73 BUSINESS SERVICES	91,92 97	91,92 97			91,97	91,92 97,99		91,97	91,97	91,97		91,97	91	91,97	91			91			x				91,97
74 PRINTING AND PUBLISHING		53,93			53,54 93,95				21,31 41										41,53		51,52 93				21,31
75 AUTO REPAIR, SERVICES + GARAGES			49																						
76 MISC. REPAIR SERVICES	31,99		94																						
78 MOTION PICTURES																									
79 AMUSEMENT + RECREATION SERVICES																									
81 LEGAL SERVICES																									
83 SOCIAL SERVICES																									
84 MUSEUMS, BOTANICAL, ZOOLOGICAL GARDENS											11														11,21
86 MEMBERSHIP ORGANIZATIONS (EXC. BUSINESS + PROFESSIONAL)																									99
88 PRIVATE HOUSEHOLDS					x																				
89 MISCELLANEOUS SERVICES		11				22	11,22		11,22	11,22 99	22														11,22
HEALTH SERVICES (EXC. MAJOR GROUP 80)				2 2 1	2			1 3	1				2 1	1 3 2 2 3				2 1 2 2 1			1 1				4 3
HEALTH SERVICES				71,72	60,71			60,71				11,60 71		71	x	11,60 81		60,71		11,21 50,60 71,72	71	60			11,21 50,60 71,91





This section of this report is a combination of three sections originally prepared for separate purposes, namely, the *References* section for the report proper, a *Bibliography* section which listed in chronological order all of the significant background materials accumulated or noted during the course of the 1972-75 NBS Study of the National Measurement System, and a *Summary of Background Documents* section which summarized the essential content and impact of some of the more important items contained in the *Bibliography*. The *Bibliography* is the author's personal compilation of the source materials that he wishes to list as part of the permanent archival record of this project. As such, it includes many items that are of only limited availability, especially some of the NBS internal working documents that are now available only in fragmentary forms.

Items are listed in chronological order. A cross-referenced, alphabetized author index follows the bibliographic entries. The sources for abbreviations of journal citations are the Chemical Abstracts Service Source Index (American Chemical Society, Chemical Abstracts Service, The Ohio State University, Columbus, Ohio, 1975) and the NBS Manual for Scientific and Technical Communications (U.S. Dept. Commerce--Nat. Bur. Stand., June 1969, rev. June 1971).

- [1] Jefferson, Thomas, Secretary of State, Plan for establishing uniformity in the coinage, weights, and measures of the United States, Report of the First Congress, second session, No. 15, pp. 13-30 (July 4, 1790), published in American State Papers, Class X, Miscellaneous, v. I, p. 13 (Gales and Seaton, Washington, D.C., 1834).

Purpose: Response to request of 15 January 1790 by House of Representatives "to prepare and report a proper plan or plans for establishing uniformity in the currency, weights, and measures of the United States."

Approach: (1) Technology assessment of means of achieving uniform weights and measures.  
 (2) Survey of weights and measures system in current use in the United States.  
 (3) Correspondence with England and France.  
 (4) Construction of two alternative scenarios for future U.S. measurement system.

Findings: (1) Decision by the U.S. should be postponed pending resolution of similar concerns in England and France.

(2) The *second* (pendulum) *rod* is the preferred invariable natural standard of length: "a uniform cylindrical body of iron, of such length, as, in latitude 45°, in the level of the ocean, and in a cellar, or other place, the temperature of which does not vary throughout the year, shall perform its vibrations, in small and equal arcs, in a period of one second of mean time."

(3) "To render uniform and stable the system that we already possess [basically that of England] [requires] ... 1st, That the present measures of length be retained, and fixed by an invariable standard. 2d, That the measures of surface remain as they are... 3d, That the unit of capacity, now so equivocal, be settled at a medium and convenient term, and defined by the same invariable measures of length. 4th, That the more known terms in the two kinds of weight be retained, and reduced to one series.... And 5th, That the quantity of pure silver in the money unit be expressed in parts of the weights so defined." A minute change in the weight of silver in the recently established decimal coinage system is recommended, so "that this, as the unit of coin, will link in system with the units of length, surface, capacity, and weight, whenever it shall be thought proper to extend the decimal ratio through all these branches."

(4) As an alternative, a completely decimal system of weights and measures is proposed, which is based on the second rod being set equal to exactly five (new) feet, the new foot being experimentally equal to 11.744736 present inches.

Effects: The report was used as a basis for deliberation by a series of Congressional committees. The first, in 1791, opted for delay. The second, in 1792, opted for adoption of Jefferson's decimal system. The third recommended adoption of revision of the English system; a bill passed the House in May 1796 but died in the Senate. Difficulties in seeing a way through the technical perplexities inherent in the problem are probably the primary reason for the lack of Congressional action, despite repeated urgings by President Washington and urgent requests from the States for action to relieve the existing confusion in commercial transactions.

[2] Adams, John Quincy, Secretary of State, Report of the Secretary of State upon weights and measures, 245 pages (J. D. Moore, Feb. 22, 1821), published in American State Papers, Class X, Miscellaneous, v. II, p. 656 (Gales and Seaton, Washington, D.C., 1834).

Purpose: Response to Senate resolution of March 3, 1817, to prepare and report to the Senate "a statement relative to the regulations and standards for weights and measures in the several states, and relative to proceedings in foreign countries, for establishing uniformity in weights and measures, together with such propositions relative thereto, as may be proper to be adopted in the United States."

Approach: (1) "Natural philosophy" of weights and measures.  
(2) Development of the history of weights and measures from the earliest times, especially in England.  
(3) Systematic consideration of the three major points defined in the Senate resolution.

Findings: (1) "While decimal arithmetic for the purposes of computation shoots spontaneously from the nature of man and of things, it is not equally adapted to the numeration, the multiplication, or the division, of material substances," so that it is not inherently obvious that a decimal measurement system is fully desirable.

(2) The power of the legislator is limited by the extent of his territories and the numbers of his people, and is limited over time. He has neither power over the facts of nature nor the will of his subjects. He is liable to enact laws in this field inadequate to their purpose and inconsistent with one another.

(3) "Such was originally the system of English weights and measures and such is it now in its ruins."

(4) "If that universal uniformity, so desirable to human contemplation, be an obtainable perfection, it is now obtainable *only* by the adoption of the new French system of metrology, in all its important parts.... This system... whether destined to succeed, or doomed to fail, will shed unfading glory upon the age in which it was conceived, and upon the nation by which its adoption was attempted, and has in part been achieved." "...the establishment of such a system so obviously tends to that great result, the improvement of the physical, moral, and intellectual condition of man upon earth; that there can be neither doubt nor hesitation in the opinion, that the ultimate adoption, and universal though modified application of that system, is a consummation devoutly to be wished."

(5) "But where is the steam engine of moral power to stem the stubborn tide of prejudice, and the headlong current of inveterate usage?"

(6) "A single and universal system can be finally established only by a general convention, to which the principal nations of the world shall be parties, and to which they shall all give their assent."

(7) "Of all nations of European origin, ours is that which least requires any change in the system of their weights and measures. With the exception of Louisiana, the established system is, and always has been, throughout the Union, the same."

(8) "A particular statement of the regulations of the several states relative to weights and measures, is subjoined to this report, in the appendix."

(9) Substantial inconsistencies exist among the several states in the measurement standards that are in use, and in the measurement capabilities that they possess.

(10) "In the exercise of the authority of Congress, with a view to the general uniformity of weights and measures, there are four different courses of proceeding which appear to be practicable: 1. To adopt, in all its essential parts, the new French system of weights and measures.... 2. To restore and perfect the old English system of weights, measures, moneys, and silver coins.... 3. To devise and establish a system by adaptation of parts of each system to the principles of the other. 4. To adhere, without any innovation whatever, to our existing weights and measures, merely fixing the standard."

(11) "The substitution of an entire new system of weights and measures, instead of one long established and in general use, is one of the most arduous exercises of legislative authority. There is indeed no difficulty in enacting and promulgating the law; but the difficulties of carrying it into execution are always great, and have often proved insuperable. Weights and measures may be ranked among the necessities of life, to every individual in human society. They enter into the economical arrangements and the daily concerns of every family. They



are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian; to the navigation of the mariner, and the marches of the soldier: to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use, is among the first elements of education, and is often learnt by those who learn nothing else, not even to read and write. This knowledge is rivetted in the memory by the habitual application of it to the employments of men throughout life. Every individual, or at least every family, has the weights and measures used in the vicinity, and recognized by the custom of the place. To change all this at once, is to affect the well being of every man, woman, and child in the community... Were the authority of Congress unquestionable to set aside the whole existing system of metrology, and introduce a new one, it is believed that the French system has not yet attained that perfection which would justify so extraordinary an effort of legislative power at this time."

(12) "The restoration of the old English... system... would require an exercise of authority no less transcendent than the introduction of the French system."

(13) Pursuing the third alternative seems to have little practical value.

(14) While our current system of weights and measures can certainly be improved, it would not be wise to do this unilaterally, independently of Great Britain, France, and Spain. To most effectively pursue the ultimate objectives implicit in the charge from Congress, "it is supposed to be most congenial to the end, to attempt no present change whatever in our existing weights and measures; to let the standards remain precisely as they are; and to confine the proceedings of Congress at this time to authorizing the Executive to open those communications with the European nations..., and to such declaratory enactments and regulations as may secure a more perfect uniformity in the weights and measures now in use throughout the Union. The motives are four:" a. We cannot afford to lose the present uniformity with Great Britain. b. The present system possesses virtues that we should not lightly sacrifice. c. French experience proves "that binary, ternary, duodecimal, and sexagesimal divisions are as necessary in the practical use of weights and measures, as the decimal divisions are convenient for calculations resulting from them; and that no plan for introducing the latter can dispense with the continued use of the former." d. "The only *material* improvement, of which the present system is believed to be susceptible, would be restoration of the identity between weights and silver coins," and it would not be worthwhile to give up our new coinage system to get this advantage.

(15) "In the mean time, should Congress deem it expedient to take immediate steps... the act of Congress should embrace the following objects: 1. To declare what are the weights and measures to which the laws of the United States refer as the legal weights and measures of the Union. 2. To procure positive standards... of the yard, bushel, wine and beer gallons, troy and avoirdupois weights; to be deposited in such public office at the seat of government as may be thought most suitable. 3. To furnish the executive authorities of every state and territory with exact duplicates of the national standards.... 4. To require, under suitable penal sanctions, that the weights and measures used at all the custom-houses, and land surveys, and post offices, and, generally, all the offices under the authority of the United States, in the execution of their laws, should be conformable to the national standards. 5. To declare it penal to make or to use, with intent to defraud, any other weights and measures than such as shall be conformable to the standards." "In fixing... a definition of the foot, its exact proportion to the standard metre of France should be declared." "The proportion of the troy and avoirdupois pounds to the kilogramme might be... declared in like manner."

(16) That the French system is worthy of the acceptance of the nations of the world, "is believed to be beyond question. But *opinion* is the Queen of the world; and the final prevalence of this system beyond the boundaries of France's power must await the time when the example of its benefits, long and practically enjoyed, shall acquire that ascendancy over the opinions of other nations which gives motion to the springs and direction to the wheels of power.

Respectfully submitted, John Quincy Adams."

Effects: There was no immediate reaction on the part of Congress to the Adams report. On May 29, 1830, the Senate adopted the following resolution:

*"Resolved*, That the Secretary of the Treasury be directed to cause a comparison to be made of the standards of weights and measures now used at the principal custom-houses of the United States, and report to the Senate at the next session of Congress."

This resolution marked the beginning of Federal *action* in this field.

- [3] Hallock, W., and Wade, H. T., *The Evolution of Weights and Measures and the Metric System* (Macmillan Co., New York, N.Y., 1906).
- [4] *Measurements for the Household*, Nat. Bur. Stand. (U.S.), Circ. 55, 149 pages (Aug. 1915).
- [5] *Functions, standards, purpose* (one page statement), Nat. Bur. Stand. (U.S.) (1917).
- [6] Whitney, A. W., *The place of standardization in modern life* (Central Executive Council, Inter American High Commission, Washington, D.C., 1924).
- [7] Jones, S. A., *Weights and measures in Congress. Historical summary covering the period of the Continental Congress to and including the adoption of the joint resolutions of 1836 and 1838*, Nat. Bur. Stand. (U.S.), Misc. Publ. M122 (Mar. 1936).
- [8] Briggs, L. J., *The national standards of measurement*, Ind. Stand., 227 (Sept. 1939).
- [9] Moreau, H., *The genesis of the metric system and the work of the International Bureau of Weights and Measures*, J. Chem. Educ. 30, 3-20 (Jan. 1953).

Purpose: Definitive discussion of subject, published in scholarly journal.

Approach: Historical description of field, institutions, and technical efforts.

Findings: A definitive and concise history of the origins and activities of one of the oldest international institutions.

Appraisal: A key reference document for those needing such a concise summation.

- [10] Perry, J., *The Story of Standards* (Funk and Wagnalls, New York, N.Y., 1955).
- [11] McNish, A. G., *Dimensions, units, and standards*, Phys. Today, 19-25 (Apr. 1957).
- [12] Huntoon, R. D., and McNish, A. G., *Present status of research on physical constants*, Nuovo Cimento, Suppl. 6, Ser. X., 146-84 (Jan. 1957).
- [13] Smith, R. W. *The Federal Basis for weights and measures*, Nat. Bur. Stand. (U.S.), Circ. 593, 23 pages (June 1958).

Purpose: A historical review of Federal legislative efforts, statutes, and administrative action in the field of weights and measures in the United States.

Approach: Updating, expansion, and systemization of material contained in earlier NBS publications on this subject, especially NBS Misc. Publ. 64 and 122 by Louis A. Fischer and Sarah Ann Jones, respectively.

Findings: A connected and reasonably comprehensive story of the Federal contribution to the legislative basis for weights and measures administration in the United States.

Effects: A ready response to the continuing demand on NBS for information on various phases of weights and measures administration.

- [14] McNish, A. G., *Classification and nomenclature for standards of measurement*, IRE Trans. Instrum. I-7, 371-8 (Dec. 1958).
- [15] McNish, A. G., *The basis of our measuring system*, Proc. IRE 47, 636-43 (May 1959).

Purpose: Description of current status and opportunities for improvement of physical standards which form the basis of our system for making physical measurements.

Approach: Historical survey; discussion of use of physical constants as standards.

Findings: (1) "We see a transition taking place now from a system based on man-made standards to a system based mainly on physical constants...."

(2) "The prototype standards seem to need little improvement. The advances that we must make in our metrology are in extension of the range over which accurate measurements can be accomplished. Particularly, we need techniques to measure accurately new quantities and new aspects of old quantities to meet the requirements of our expanding technology."

Appraisal: This is the first major publication in the train of thinking at NBS that has led directly to this present study of the National Measurement System.

- [16] Bendick, J., *How Much and How Many, The Story of Weights and Measures* (McGraw-Hill, New York, N.Y., 1960).

[17] Irwin, K. G., Romance of Weights and Measures, 144 pages (Viking Press, New York, N.Y., 1960).

Purpose: Description of the basic evolutionary history connecting our current weights and measures with their root sources, stripped of as much of the transient effects of accidental and regional eccentricities as possible. Correlation of the history of weights and measures with the general history and social conditions of different eras and nations.

Approach: Intense research into original sources and a very humanistic way of presenting the results.

Findings: The measurement systems of the ancient Middle East--Egypt, Phoenicia, and Babylon--were oriented to the purposes of peace and commerce, and formed a substantially uniform and rationalized decimal system, in its fullest development conceptually quite similar to today's metric system. Greece introduced the pace and the foot into this system, for military purposes, and in the process of doing so destroyed the decimal simplicity of the earlier system. Rome followed Greece. The Goths acquired the old Phoenician system. When the Goths conquered the Roman empire, the measurement system fragmented as different paths were followed in reconciliation of the Gothic and Roman systems. The Angles, Saxons, and Danes imported the simple Gothic system into England. The Normans brought in the French-Roman system. Our current customary system evolved from the marriage of the two. Meanwhile, the French started all over again with the metric system, which is coming to dominate the world.

Appraisal: A very fascinating story, not told elsewhere to my knowledge. I would like to see an independent verification of Irwin's interpretations.

[18] The 1960 Conference on Standards and Electronic Measurements, IRE Trans. Instrum. I-9, No. 2 (Sept. 1960).

[19] Lance, H. W., The Nation's electronic standards program: Where do we now stand?, IRE Trans. Instrum. I-9, 94-100 (Sept. 1960).

[20] McNish, A. G., and Cameron, J. M., Propagation of error in a chain of standards, IRE Trans. Instrum. I-9, 101-4 (Sept. 1960).

[21] A special report on measurement standards, ISA J 8, No. 2, 38-75 (Feb. 1961).

[22] Hachey, L. E., Better measurements through user feedback, ISA J 8, No. 2, 60-63 (Mar. 1961).

[23] The Old Market, site of "first standard system of weights and measures," picture postcard from St. Augustine, Fla. (mailed 1961).

[24] Huntoon, R. D., Standards for the future, preprint, Annual Spring Conference, American Standards Association and Standards Engineers Society, Boston, Mass., 18 pages (May 24-25, 1962).

Purpose: Technological forecasting in the measurement standards field, for the guidance of attendees at 1962 standardization conference.

Approach: Trend extrapolation.

Findings: (1) Precision of measurement will continue to be of overriding importance and there will be a continuing demand to push it ahead on all fronts.

(2) The goal that the unit of measurement for physical quantities of the same kind should be the same, will be approached but not reached until the pace of progress diminishes greatly.

(3) The shrinking world will bring into being in the not too distant future the goal that all who are to be engaged in the cooperative process of making measurements and exchanging data should agree to the same unit and all should use it.

(4) The five basic quantity system with its units will continue for some time, with units for all other quantities defined in an independently reproducible way from them.

(5) In the next decade we may see the number of units established on our independent basis decreased to 3 or possibly 2, but we will continue to consider five physical quantities with their units as basic.

(6) We must hope for progress toward uniformity of approach to the problem of using standards which are more precisely intercomparable than they can be related to the unit definitions.



(7) We will see more and more of our standards tied to nuclear, atomic, or molecular properties.

(8) Advances in instrumentation and measurement brought about by discoveries such as the Mossbauer effect and lasers will permit the definition of all units in terms of arbitrary assignment of values to fundamental constants.

(9) The whole system will tend toward its inherent goals of simplicity, uniformity, and consistency.

(10) National standards laboratories will become free of the job of calibration and concentrate almost entirely upon development and dissemination of instrumentation and procedures which will put every major laboratory on a sound independent basis. The extensive problem of traceability will essentially disappear.

Appraisal: This paper almost but did not quite coin the phrase National Measurement System. The last conclusion today seems overstated.

[25] Selby, M. C., et al., A program to provide information on the accuracy of electrical measurements, Proc. IEEE 51, 569-74 (April 1963).

[26] Eisenhart, C., Realistic evaluation of the precision and accuracy of instrument calibration systems, J. Res. Nat. Bur. Stand. (U.S.), 67C (Eng. and Instr.), No. 2, 161-87 (April-June, 1963).

[27] McNish, A. G., Fundamentals of measurement, Electro-Technology (Beverly Shores, Indiana), 113-28 (May 1963).

Purpose: A basic tutorial paper.

Approach: Examination of historical concepts of measurement and the evolution of various measurement systems and techniques. The discussion covers both primary and derived quantities, precision and accuracy, physical constants, and the keystone position of centralized standards laboratories.

Findings: Implicit in the statements above.

Appraisal: A basic tutorial paper.

[28] Judson, L. V., Weights and measures of the United States, a brief history, Nat. Bur. Stand. (U.S.), Misc. Publ. 247, 30 pages (Oct. 1963).

Purpose: Partial satisfaction of the continuing demand for information about the origins of the metrological standards of the United States on the part of students, educators, authors, government officials, and the general public.

Approach: Revision and updating of an earlier paper by Louis A. Fischer, NBS Misc. Publ. 64.

Findings: An historical account of the subject matter, plus a description of current and historical standards of mass and length now in the possession of NBS.

Appraisal: A strictly hardware and "museum" oriented paper.

[29] White, L. T., Jr., The medieval roots of modern science and technology, from Book, Perspectives in Medieval History, Ed. K. F. Drew and F. S. Lear (Univ. Chicago Press, Chicago, Ill., 1963); reprinted in Book, The Economic Development of Western Europe, v. I, The Middle Ages and the Renaissance, Ed. W. Scoville and C. LaForce, pp. 60-75 (D. C. Heath and Co., Lexington, Mass., 1969).

[30] Lescure, W. J., Preliminary inventory of the records of the National Bureau of Standards (record group 167), General Services Administration, National Archives and Records Services, The National Archives (Oct. 1964).

[31] Man and his measures--the weights and measures mural, brochure, Nat. Bur. Stand. (U.S.), (undated--1965?).

[32] Egyptian Royal Cubit of Amenhotep I, single page, unattributed (undated--1965?).

[33] Huntoon, R. D., and Wildhack, W. A., Planning for better measurement accuracy, ISA J 12, No. 1, 57-60 (Jan. 1965).

[34] Huntoon, R. D., Our measurement system and its future, Res. Dev. 16, No. 1, 16-21 (Jan. 1965).

[35] Huntoon, R. D., Role of laboratory measurement in physics teaching at the high school and college level, talk presented to Chesapeake section of the American Association of Physics Teachers (April 10, 1965).

[36] Wildhack, W. A., Powell, R. C., and Mason, H. L., Accuracy in measurements and calibrations, 1965, Nat. Bur. Stand. (U.S.), Tech. Note 262, 151 pages (June 1965).

[37] Powell, R. C., Accuracy in electrical and radio measurements and calibrations, 1965, Nat. Bur. Stand. (U.S.), Tech. Note 262-A, 93 pages (June 1965).

- [38] Huntoon, R. D., Role of NBS in the National Measurement System, internal NBS memorandum, to list (Aug. 24, 1965).
- [39] Astin, A. V., Away from arbitrary man-made standards toward a system based on physical constants, Res. Dev. 16, No. 10, 68-69 (Oct. 1965).
- [40] Scientists discuss NBS role in the national measurement system, Nat. Bur. Stand. (U.S.), press release, TRG-6441, 5 pages (Oct. 5, 1965).
- [41] Huntoon, R. D., Status of the national standards for physical measurement, Science 150, 169-78 (8 Oct. 1965).
- [42] McNish, A. G., Measurement standards, Int. Sci. Technol., 58-66 (Nov. 1965).
- [43] Huntoon, R. D., The basis of our measurement system, Physics Teacher 4, 113-20 (Mar. 1966).
- [44] Eskite, W. H., Jr., Studies of the national measurement system, final report on Department of Commerce Science and Technolgu Fellowship Program assignment, NBS internal working document (July 1, 1966).

Purpose: Assisting the Director of the Institute for Basic Standards in developing further the concept of the National Measurement System.

Findings: (1) Definition of the functional relationships between the organizations that make up the National Measurement System from the system's point of view, and the intellectual activities that govern their functioning.

(2) Identification, description, and definition of the users of the system as a group.

(3) Identification, description, and definition of specific users of the output of the system and of their problems in a quantitative fashion.

(4) Recommendations for future studies of the system.

(5) Provision of more meaningful data to management for decision making where programs interact with the National Measurement System.

Appraisal: This was a key intermediate study, which has by now been largely superseded by the effects of the passage of time, and the results of more recent studies. It contained the first attempt at a macroeconomic analysis of the National Measurement System.

- [45] Huntoon, R. D., letter to Dr. D. Fishlock, describing calculation of numbers of measurements made per day in U.S. (Nov. 30, 1966).
- [46] Cochrane, R. C., Measures for Progress--A History of the National Bureau of Standards, Nat. Bur. Stand. (U.S.), Misc. Publ. 275, 728 pages (1966).

Purpose: This book is designed to provide a better understanding of a highly specialized Federal agency among the community of scientists and engineers that the agency serves directly, among the general public whose taxes support it but who are usually only indirectly aware of its existence, and among Government officials who depend upon it for services or whose policy actions control its destiny.

Approach: That of a professional historian, relating the history of his primary subject to that of the larger society around it.

Findings: (1) In creating a National Bureau of Standards in the Federal structure at the turn of the century, Congress sought to redress a long-standing need, to provide standards of measurement for commerce and industry, the public, and the Government. Inevitably, the focus was on industry.

(2) In its first two decades the Bureau won an international reputation for its outstanding achievements in physical measurements, development of standards, and test methods. Through its new standards of measurement, instrumentation, and performance, it sought to raise the scientific level of industry.

(3) During World War I, NBS became a scientific laboratory for the military services.

(4) Determined to foster the new industries born of the war, the Bureau sought to become the national research laboratory for all industry.

(5) When the Great Depression came, the Bureau shared the obloquy heaped on commerce and industry. With greatly reduced appropriations and staff, the Bureau turned increasingly to fundamental research.

(6) By December 1941, fully 90 percent of the Bureau staff was already engaged in war research.

(7) Following World War II, the Bureau found itself in the forefront of the scientific revolution that had overtaken the Nation.

(8) As the Bureau prepared to move to its new laboratories in Gaithersburg, its organization and functions underwent a new realignment of focus and purpose, as a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce.

(9) The Bureau's history over nearly three-quarters of a century discloses a highly viable form, responsive to national needs as they arise. As crusader and arbiter, creator and counselor of standards, it works for the future, as it has in the past, for the good society, and by its learning and good will makes itself felt throughout the Nation and the world.

Appraisal: A very readable and fascinating document.

[47] Measurement, Pacemaker of American Economic Growth, booklet, U.S. Dept. of Commerce (U.S. Govt. Print. Off., Washington, D.C., 1966).

Purpose: A simplified explanation of the role measurement plays in our economy.

Approach: Popularized and basic discussion of measurements, and of the purpose and functioning of the national measurement system.

Findings: As Pacemaker, measurement can serve to limit the introduction of new technology if the system is inadequate, or it can open the door to new products, processes, and markets, if the system is proficient in all areas of science and technology. Measurement gives us knowledge and understanding. Actions and decisions based on knowledge and understanding cannot help but be superior to those based on an "educated guess", on estimates, or on ignorance.

Appraisal: A good popularized booklet, that should be reissued by NBS or the Department.

[48] Huntoon, R. D., Measurement system of the United States, Part 1, Automot. Ind., 75-78 (Jan. 15, 1967).

[49] Van de Houten, J., The standards laboratory as an element in the national measurement system, Preliminary report at 22nd Annual Meeting of the Standards and Metrology Division, American Ordnance Association (April 12-13, 1967).

[50] Brady, E. L., and Wallenstein, M. B., The National Standard Reference Data System, Science 156, 754-62 (12 May 1967).

Purpose: Definitive public description to the scientific community of the purpose, nature, and functioning of the National Standard Reference Data System.

Approach: Historical review and summary of current status and trends.

Findings: (1) The National Standard Reference Data System is a government-wide effort to give to the technical community of the United States optimum access to the quantitative data of physical science, critically evaluated and compiled for convenience.

(2) The System is a decentralized operation of national scope, with central coordination by NBS.

Effects: The desired information was put clearly on the record in a journal widely read by the members of the scientific community.

[51] Wildhack, W. A., Mason, H. L., and Powers, R. S., Jr., Accuracy charts for RF measurements, Proc. IEEE 55, 1056-63 (June 1967).

[52] Astin, A. V., Program memorandum and program and financial plan for Commerce Program Category V, The Physical Measurement System, NBS memorandum to Dr. J. Herbert Hollomon, Acting Undersecretary for Commerce (June 12, 1967).

Purpose: Program and budget justification.

Approach: Extensive discussion of the interaction of the National Bureau of Standards with major national programs and of the policy issues it faces in the operation of established programs; presentation of descriptive material describing ongoing programs in only a greatly condensed fashion. The term "Physical Measurement System" is used to describe total, nationwide measurement activities.

Findings: (1) The complex, extensive system of physical measurement which has developed with our industrialized society and which has, in fact, made its growth possible, represents a fixed investment and annual growth rate of many billions of dollars, distributed to all segments of the national economy.

(2) An underlying fact is that the Government has provided and will continue to provide the central facility and the tie-points upon which the system rests.



(3) Although governmental, as well as private, industrial and scientific activities have grown rapidly in magnitude and sophistication, with consequent needs for more and better measurement and data capabilities, the basic NBS program which supports these needs has, by administrative decision, been held nearly constant for the past several years. This plan proposes to correct this situation.

(4) A comprehensive study to develop a better understanding of the physical measurement system has been going on at NBS for two years and will continue for several more.

(5) It has been estimated, roughly, that more than twenty billion measurements are made in this country each day in science, industry, commerce, and everyday life. All of us make measurements and all of us make use of measurements.

(6) The physical measurement system meets three basic needs of society: for basic measurements and standards, for matter-materials data and standards, and for technological measurements and standards.

(7) Improvement of coupling to industry can best be achieved by expanding the Industrial Research Associate program to provide greater participation in NBS research programs by industry's staff and more cooperative links with the industrial sectors.

(8) The Bureau should initiate its own preliminary study to gather information to plan for the major study, when authorized by the Congress, of the issues connected with what the United States can do to adjust to the trend toward worldwide use of the metric system and the role that the Department of Commerce should play in this adjustment.

(9) Too large an allocation of NBS resources to *planning studies* would seriously impede research operations and could reduce outputs to the Nation to the point where NBS would not be fulfilling its mission and maintaining broad areas of existing competences. On the other hand, it is obvious that a certain amount of planning must be done more systematically than in the past.

(10) NBS should proceed as rapidly as possible in the direction of extending "self-calibration" capabilities in the national measurement system, when it is clear that to do so makes the system more effective. Pilot studies are in order.

(11) The proper NBS role with respect to independently reproducible standards is not clear. In most cases, the economics of duplication are so strongly prohibitive that the problem does not arise. National tie points at NBS are still essential.

Appraisal: This is the first major, thorough, conscious use by NBS of the National Measurement System concept for program planning and justification purposes.

[53] Galvin, H. B., Dollar investment in instruments, NBS internal memorandum to W. A. Wildhack (July 13, 1967).

[54] Huntoon, R. D., The measurement system of the United States, Proc. 1966 Standards Laboratory Conference, Nat. Bur. Stand. (U.S.), Misc. Publ. 291, 89-98 (July 13, 1967).

[55] Huntoon, R. D., Program memorandum for Departmental Program Category V: The Physical Measurement and Standards Program, NBS memorandum to Dr. John F. Kincaid, Acting Assistant Secretary for Science and Technology (Oct. 4, 1967).

[56] Huntoon, R. D., Concept of a national measurement system, Science 158, 67-71 (6 Oct. 1967).

Purpose: Public presentation of NBS use of the systems approach to improve understanding of the nation's measurement activities.

Approach: Narrative discussion of current state of NBS approach and of the understanding so far achieved.

Findings: (1) The systems approach in this subject is profitable.

(2) The value to the nation of the National Measurement System is in excess of \$15 billion a year.

(3) Like other social systems, the National Measurement System consists of two basically different interacting structures, the "conceptual system" and the "operational system." The former is universally applicable, the latter varies from nation to nation.

(4) Three general, ever-present needs of society have brought the System into being: needs for (a) basic measurements and standards, (b) data and standards on materials, and (c) technological measurements and standards.

(5) The System has three major technological networks: for instrumentation, for data, and for techniques.

(6) The role of NBS as a key functional element of the National Measurement System is to provide (a) the central basis in the United States for a complete and consistent system for physical measurement, and (b) federal leadership to insure effective and efficient performance of the System.

(7) Trends in the System: (a) The inherent advantages of simplicity and coherence of the International System of Units (SI) will lead eventually to widespread use of this modern version of the metric system within the United States as in other countries. (b) An ability of any qualified laboratory to independently reproduce the SI units. (c) Self-calibration by the secondary laboratories of the System. (d) "The principle of stringency" will continue to guide NBS: It must focus its efforts on meeting the most stringent requirements of the system wherever there is enough need to justify the necessary investment in research. (e) Other elements of the System are giving serious, productive consideration to their respective roles and are generating recommendations for improvement in its operation.

Effects: Brought to the general scientific public attention a systematic new approach to understanding the role of measurements and of NBS in our society.

- [57] Howlett, L. E., International basis for uniform measurement, *Science* 158, 72-74 (6 Oct. 1967).
- [58] Schafer, G. E., Economic dimensions of the national measurement system, NBS internal memorandum to W. A. Wildhack (Dec. 12, 1967).
- [59] Yates, J. T., Jr., Morgan, H. E., and Huntoon, R. D., Exploratory NBS studies of benefit-cost measurement in research and development, NBS internal working document, 33 pages (1967)
- [60] Decrease in uncertainty of NBS measurements, unsigned, unattributed, undated document (about 1967).
- [61] Dantzig, T., Number, *The Language of Science*, 4th edition (Macmillan Co., New York, N.Y., 1967).
- [62] Atomic second adopted as international unit of time, *Nat. Bur. Stand. (U.S.), Tech New Bull.*, No. 1, 10-12 (Jan. 1968).
- [63] Worth her weight in gold, brochure, 8 pages (Gordons Transports, Inc., Memphis, Tenn., Mar. 1968)
- [64] Astin, A. V., Statement on the utilization of Federal laboratories, before the subcommittee on Science, Research and Development of the House Committee on Science and Astronautics (Mar. 27, 1968).
- [65] Gentilini, A. V., Summary of national measurement system, NBS internal memorandum to members of motion picture committee, 35 pages (May 3, 1968).

Purpose: A source file from which an NBS film script on the subject may be developed, a reference for miscellaneous purposes, and a basis for articles, speeches, and feature stories.

Approach: Synthesis from pre-existing sources.

Findings: These are largely a recapitulation of points made in sources discussed above. The significance of this memorandum is that it is perhaps the earliest document on the NBS record that is aimed at substantially the same purpose as this report.

Effects: All available insight regarding the national measurement system is summarized in one document, as of 1968. Tentative discussions regarding a motion picture did take place, but no film was developed.

- [66] Astin, A. V., Standards of measurement, *Sci. Am.* 218, No. 6, 50-62 (June 1968).

Purpose: Communication of state of art in physical measurement standards, to the general scientific community.

Approach: Historical review and summary of current status and trends.

Findings: The task of finding more accurate ways to measure length, mass, time and temperature never ends. The base units should be defined in terms of basic constants of nature, and this has been done for all except mass.

Effects: Definitive communication to the general scientific public.

- [67] Eisenhart, C. Expression of the uncertainties of final results, *Science* 160, 1201-4 (14 June 1968).
- [68] Wildhack, W. A., NBS outputs and impacts, NBS internal working document, 5 pages (Sept. 1968).

- [69] GOST 1 "The state standardization system," Izmer. Tekh., No. 9, 21-22 (Sept. 1968) (UDC 389.69093.2).
- [70] Resko, S. I., ed., Metrological Service of the USSR, booklet, 84 pages (Publ. House of Standards, Moscow, USSR, 1968). Translated by M. C. Selby as Nat. Bur. Stand. (U.S.), Report 9756, 98 pages (May 27, 1970).
- [71] Brief history and use of the English and metric systems of measurement, Nat. Bur. Stand. (U.S.), Spec. Publ. 304A, 4 pages (1968).
- [72] Precision Measurements and Calibration, Nat. Bur. Stand. (U.S.), Spec. Publ. 300, 12 volumes (1968).
- [73] Zupko, R. E., A Dictionary of English Weights and Measures from Anglo-Saxon Times to the Nineteenth Century (Univ. Wisconsin Press, Madison, Wisc., 1968).
- [74] The exotic pursuit of precision, photo essay. Fortune, 80-87 (May 1969).
- [75] Mason, H. L., ed., Making Valuable Measurements (Proc. 1968 Standards Laboratory Conference, NBS, Boulder, Colo., Aug. 26-29, 1968), Nat. Bur. Stand. (U.S.), Spec. Publ. 313, 177 pages (May 1969).

Purpose: Proceedings of the 1968 Standards Laboratory Conference.

Approach: Answering the Who? Where? How? and Why? of making valuable measurements.

Findings: Best summarized by the session titles:

- (1) DOD Activities
- (2) NCSL Liaison Delegate Reports
- (3) NBS Activities
- (4) International Measurements
- (5) NCSL Committee Reports
- (6) The Value of Measurement Agreement Comparison
- (7) The Management of Equipment and Data
- (8) The Management of Valuable Measurements

Appraisal: An early attempt by a major component group in the System to focus on improvement of the effectiveness of the entire National Measurement System.

- [76] Morgan, H. E., The economic value of making measurements, Proc. 1968 Standards Laboratory Conference, NBS, Boulder, Colo., Aug. 26-29, 1968, Ed. H. L. Mason, Nat. Bur. Stand. (U.S.), Spec. Publ. 313, pp. 27-36 (May 1969).

Purpose: Definition of the word valuable in the context of a conference which has as its theme "Making Valuable Measurements," and indication of how one might measure the value of "valuable measurements."

Approach: Application of concepts and analytical approaches of the science of economics to the subject of measurements and the measurement system.

Findings: (1) Measurements are made primarily to provide information which leads to decisions which (a) alter the method of attaining a given objective or (b) result in pursuing new objectives.

(2) The economic value of measurement data in case (a) will be the cost of resources saved by substitution of these data in reaching the stated goal.

(3) Economic value in case (b) relates to the effectiveness with which the new resources can be used in achieving the new goals.

(4) The economic value of a unit of measurement data to an individual producer of goods or services is the change, in total revenue from the sale of goods and services, induced by that additional unit of measurement service.

(5) The economic value of measurement data used directly by consumers of goods and services is given by the extent to which these data enable consumers to *save* other resources in attaining a given level of satisfaction, or to *use* other resources in reaching a higher level. Measurement of secondary effects is complex.

(6) Two methods of approximating the *aggregate economic value* of measurements are based on (a) the concept of consumer's surplus, and (b) input-output analysis. Both require detailed information about the way measurement data are used and information about the demand for final goods. *Consumer's surplus* measures value which users obtain and which they would be willing to pay more for than they actually pay, rather than go without the product. Where market prices of measurement related goods are known, *input-output analysis* may permit tracing through the consequences of interactions in the economic system, to indicate net economic value.



(7) The value of publicly produced or used measurement data, which often involve a formal zero price to the public, is most basically determined by the trade-off value of substitutes.

(8) The value of measurement *reliability* can be handled in the fashions outlined above. Trade-offs between the cost of higher precision or reliability in general and the costs of other inputs must be made until minimum cost has been attained, in achieving any given goal.

(9) Empirical measurement of economic value requires (a) case studies of specific applications of measurement services, or (b) statistical data which indicate how measurements may have affected firms or industries. The latter are seldom sufficiently detailed to permit meaningful generalizations.

Appraisal: This is the only formal study (until now) on the public record of the use of economic techniques in evaluating the National Measurement System.

- [77] Wolzien, E. C., New directions for NBS outputs, Proc. 1968 Standards Laboratory Conference, NBS, Boulder, Colo., Ed. H. L. Mason, Nat. Bur. Stand. (U.S.), Spec. Publ. 313, pp. 38-42 (May 1969).
- [78] Modus operandi for production of NBS film dealing with the national measurement system, internal NBS working document (13 May 1969).
- [79] Stiehler, R. D., History of measurement and the SI units, Mater. Res. Stand. 9, No. 6, 14-18 (June 1969).

Purpose: A brief summarization for the general technical public of the subject.

Approach: Historical narrative; analysis of strengths and weaknesses of SI; trend extrapolation.

Findings: (1) The so-called English units did not originate in England; they descended from antiquity.

(2) The confusion caused by the multiplicity of ancient units that were in use in Europe during the Renaissance was the stimulus that led to the development of the metric units.

(3) Similarly, the multiplicity of metric units for the same quantity that have arisen since 1800 led to the SI.

Appraisal: An excellent and unique article.

- [80] Huntoon, R. D., Lichtenstein, S., and Finger, G. A., The National Bureau of Standards prepares for the 1970's, Science 165, 867-74 (29 Aug. 1969).
- [81] Kushner, L. M., The NBS contributions to technological measurements and standards, Mater. Res. Stand. 9, No. 10, 8-10 (Oct. 1969).
- [82] Silverman, S., The national measurement system--a concept to assist the private sector, Mater. Res. Stand. 9, No. 10, 11-14 (Oct. 1969).
- [83] Meinke, W. W., The NBS Standard Reference Materials program: past, present, and future, Mater. Res. Stand. 9, No. 10, 15-18 (Oct. 1969).
- [84] Brady, E. L., The National Standard Reference Data System, Mater. Res. Stand. 9, No. 10, 19-21 (Oct. 1969).

Purpose: The preceding four items were published as a group under the general title "Measurement in the Public Sector," to provide a description to the technical public of the breadth of NBS programs supporting the national measurement system.

Approach: Historical review, philosophical discussion, narrative description.

Findings: (1) Technological measurements and standards are use-related and are at the interface between science and its application in industry and government. The NBS program extends the principles of good measurement to the engineering fields and to the complex needs of today's society. Specific aspects include measurements for performance-based standards, of subjective human factors, and of the functioning of complete systems.

(2) The concept of a National Measurement System involves the entire complex of measurement activities within the United States. The central element of this system is NBS.

(3) Standard Reference Materials provide a basis for comparison of measurements on materials and aid in control of production processes in industry. About 600 different items are available from NBS.

(4) The National Standard Reference Data System aims to give the technical community optimum access to the quantitative data of physical science. NBS provides central coordination.

Effects: Concise public statement of several key NBS programs in support of the national measurement system.

- [85] Koester, R. L., ed., Report of the 54th National Conference on Weights and Measures 1969, Nat. Bur. Stand. (U.S.), Spec. Publ. 318, 270 pages (Nov. 1969).
- [86] Simson, B. G., and Radlinski, R. W., The accuracy of air tower pressure gages in suburban Washington, D.C., Nat. Bur. Stand. (U.S.), Tech. Note 512, 10 pages (Dec. 1969).
- [87] Gorozhanina, R. S., Freedman, A. Y., and Shaievitch, A. B., Standard Reference Materials: Standard Samples Issued in the USSR, booklet, 81 pages (Publishing House of Standards, Moscow, USSR, 1969). Translated by M. C. Selby as Nat. Bur. Stand. (U.S.), Spec. Publ. 260-30, 86 pages (June 1971).
- [88] Burton, W. K., Measuring systems and standards organizations, 45 pages (American National Standards Institute, New York, N.Y., undated, estimated 1969).
- [89] National measurements requirements committee report, 1970 Standards Laboratory Conference, 12 pages (5 May 1970).
- [90] Clark, R. F., The impact of advanced electronic technology on measurements, preprint, 1970 Standards Laboratory Conference, 6 pages (June 1970).
- [91] Root, L. W., New U.S. Air Force audit program, preprint, 1970 Standards Laboratory Conference, 19 pages (June 1970).
- [92] Ritchie-Calder, Lord, Conversion to the metric system, Sci. Am. 223, No. 1, 17-25 (July, 1970).
- [93] Taylor, B. N., Langenberg, D. N., and Parker, W. H., The fundamental physical constants, Sci. Am. 223, No. 4, 62-78 (Oct. 1970).

Purpose: Communication of importance of experiments designed to redetermine the numerical values of the fundamental physical constants to ever greater levels of accuracy.

Approach: Description of role of these quantities, of the importance of accuracy, of lessons from the past, of examples of the consequences that have stemmed from improvements in knowledge of these quantities, and of current technical approaches to this field; plus trend extrapolation.

Findings: (1) These efforts can yield information concerning the overall correctness of the basic theories of physics, in addition to improving the precision of the quantitative predictions of these theories.

(2) Experimenters tend to "debug" their work until they get agreement with generally accepted values, and may fail to keep going long enough to recognize the total range of errors involved. Consequently, good agreement among successive independent measurements may be illusory and only shown up by a later, truly definitive experiment.

(3) Precision determination of fundamental constants depends intimately upon the adequacy of the national physical measurement reference standards.

(4) This work is not finished.

Appraisal: A definitive publication on the physical importance of precise knowledge of the fundamental constants, that stopped short of description of the metrological importance of these quantities.

- [94] Calibration and test services of the National Bureau of Standards, Nat. Bur. Stand. (U.S.), Spec. Publ. 250--1970 edition (Dec. 1970).

- [95] Slattery, W. J., ed., An Index of U.S. Voluntary Engineering Standards, Nat. Bur. Stand. (U.S.) Spec. Publ. 329, 1000 pages (March 1971).

Purpose: Provision of a basic reference compilation of voluntary engineering standards titles.

Approach: Key-word-in-context indexing by permutation of titles.

Findings: (1) 19,000 voluntary engineering and related standards, specifications, test methods, and recommended practices, in effect as of December 31, 1969, published by some 360 U.S. technical societies, professional organizations, and trade associations.

(2) 6,300 more are contained in Supplement 1, with a cut-off date of December 31, 1971 [139].

(3) An additional 5,700 are indexed in Supplement 2, with a cut-off date of July 1, 1974 [251].

Appraisal: A definitive reference publication.

- [96] Bell, F. C., and Wollin, H. F., ed., Report of the 55th National Conference on Weights and Measures 1970, Nat. Bur. Stand. (U.S.), Spec. Publ. 342, 315 pages (April 1971).

- [97] Noble, D. E., The challenge of intelligent decision making, Proc. Rome Air Development Center 20th Anniversary Celebration: The Next Twenty Years--the Promise and the Challenge, pp. 65-74 (Rome Air Development Center, June 9-11, 1971).
- [98] DeSimone, D. V., A Metric America: A Decision Whose Time Has Come, Nat. Bur. Stand. (U.S.), Spec. Publ. 345, 188 pages (July 1971).

Purpose: Report to Congress in response to Public Law 90-472, An Act To authorize the Secretary of Commerce to make a study to determine advantages and disadvantages of increased use of the metric system in the United States.

Approach: Summarization of results reported in twelve supplementary volumes. Polling of thousands of individuals, firms, and organized groups, representative of our society, by public hearings, questionnaires, and many other techniques. Historical analysis and trend extrapolation.

Findings: (1) Eventually the United States will join the rest of the world in the use of the metric system as the predominant common language of measurement.

(2) America is already metric in some respects, and is becoming more so.

(3) The great majority of businessmen, educators, and other informed participants in the Study reported that increased use of the metric system is in the best interests of America. They also believe that it is better for the nation to move to metric by plan rather than by no plan at all.

(4) The key question is not whether but how and when America will choose to make the change. The key comparison regarding costs and benefits is between changing *by plan* versus changing with *no plan*--with no framework to guide the nation.

(5) It would be best for the nation to change to metric under a coordinated program that provides for flexibility and encourages the various sectors of society to deal with their particular problems voluntarily.

(6) Educational efforts should begin immediately, in the schools and for the public.

(7) International standardization should be participated in vigorously, to protect American national interests.

(8) Congress should assign the responsibility for guiding the change to a central coordinating body responsive to all sectors of our society.

(9) In order to encourage efficiency and minimize the overall costs to society, the general rule should be that any changeover costs shall "lie where they fall."

(10) The Congress, after deciding on a plan for the nation, should establish a target date ten years ahead, by which time the U.S. will have become predominantly, though not exclusively, metric.

(11) There should be a firm government commitment to this goal.

Effects: Administration commitment to metric changeover by plan, in accordance with the findings above.

Essentially continuously pending bills in Congress to implement these findings.

Concern by organized labor and small business about the "costs lie where they fall" principle. A combination of these concerns, parliamentary tactics, and national preoccupation with other matters prevented final action until the passage of the Metric Conversion Act of 1975, in December 1975.

- [99] Huntoon, R. D., et al., U.S. Metric Study Report: International Standards, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-1, 157 pages (Dec. 1970).
- [100] Clark, R. E., and Tascher, J. M., U.S. Metric Study Interim Report: Federal Government: Civilian Agencies, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-2, 328 pages (July 1971).
- [101] Hatos, S. L., U.S. Metric Study Interim Report: Commercial Weights and Measures, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-3, 116 pages (July 1971).
- [102] Barbrow, L. E., coord., U.S. Metric Study Interim Report: The Manufacturing Industry, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-4, 172 pages (July 1971).
- [103] Cornog, J. R., and Bunten, E. D., U.S. Metric Study Interim Report: Nonmanufacturing Businesses, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-5, 200 pages (July 1971).
- [104] Robinson, B. D., U.S. Metric Study Interim Report: Education, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-6, 216 pages (July 1971).
- [105] Rothrock, B. D., ed., U.S. Metric Study Interim Report: The Consumer, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-7, 152 pages (July 1971).



- [106] Gordon, G. F., U.S. Metric Study Interim Report: International Trade, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-8, 188 pages (July 1971).
- [107] Lomas, L., et al., U.S. Metric Study Interim Report: Department of Defense, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-9, 132 pages (June 1971).
- [108] Treat, C. F., U.S. Metric Study Interim Report: A History of the Metric System Controversy in the United States, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-10, 312 pages (Aug. 1971).
- [109] Stiehler, R. D., U.S. Metric Study Interim Report: Engineering Standards, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-11, 264 pages (July 1971).
- [110] Odom, J. V., ed., U.S. Metric Study Interim Report: Testimony of Nationally Representative Groups, Nat. Bur. Stand. (U.S.), Spec. Publ. 345-12, 180 pages (July 1971).
- [111] Huntoon, R. D., Extending the measurement infrastructure to meet the needs of developing establishments, NBS internal working document, 55 pages (July 1971).

Purpose: Response to the question, What can or should NBS do, to aid developing establishments, domestic or foreign, to acquire a sufficient measurement capability?

Approach: Extension of reasoning and understanding developed for the U. S. National Measurement System to project solutions of problems of developing establishments.

Findings: (1) Newly developing countries of the world and developing establishments domestically face similar problems in acquiring an appropriate measurement capability.

(2) The traditional patterns upon which our growth was based are not optimum for new countries in today's world, nor even always for our own.

(3) Nominally identical measurement actions do not give identical results. There is always a dispersion. Of all of the terms that can be used in dealing with this dispersion, *compatibility* is the one of the broadest significance. If accuracy is injected in a compatible system, it propagates to all units in that system. Compatibility is best achieved by an active approach, rather than the traditional passive calibration approach.

(4) The standard sample approach, which uses a sample of acceptable product, thing, or substance, as a basis for transfer of compatible measurements, independent of the system of weights and measures in local use, is especially stressed as needing careful study.

(5) Tie points to the international measurement infrastructure exist wherever the printed word can reach, transportation can provide hardware, and people with the necessary skill exist. A tie-point represents the meeting of a need for some specific measurement or complex of measurements, with an established capability in the measurement infrastructure, national or international.

(6) The essence of the improvement that is needed in the international measurement infrastructure lies in the dissemination of compatible measurement capability through the tie-points of the system.

(7) Passive harmonization, e.g., through classical calibration procedures, is fraught with peril and associated with much nonsense, in which *paper* evidence of instrument compatibility rules, rather than physical demonstration of it.

(8) Active harmonization is more complex, but it forces demonstration of the end object--*compatible measurements*--rather than of the intermediate, *compatible instrumentation*. Independently reproducible standards are an ideal, ultimate approach to active harmonization; of the basic units, only mass cannot so far be realized this way.

(9) Published data from any trusted source can be used as the basis for an active transfer process. Standard Reference Data can be an ultimate for such purposes.

(10) Standard Reference Materials are essential when it is possible to find stable substances with properties useful in the measurement system, that can be precisely and reproducibly measured, but which cannot be described so that the materials themselves can be easily, precisely reproduced.

(11) Careful cataloging of the level of compatibility available at different potential tie-points in the international measurement infrastructure should be undertaken by NBS, and the specifications established for needed tie-points that do not exist.

(12) "How-to" documents are needed for each kind of measurement compatibility transfer available at each tie-point, showing how to establish compatible measurements with that transfer mechanism.

Appraisal: A very penetrating study.

[112] Langenberg, D. N., and Taylor, B. N., ed., Precision Measurements and Fundamental Constants, Nat. Bur. Stand. (U.S.), Spec. Publ. 343, 543 pages (Aug. 1971).

Purpose: Proceedings of an International Conference held at the National Bureau of Standards, Gaithersburg, Maryland, August 3-7, 1970.

Approach: Collection and editing of papers by the Conference speakers.

Findings: (1) The essential connection between the fundamental physical constants and our choice and definition of the base units for physical measurements has been apparent for many years.

(2) Precision measurement plays an essential and crucial role in the development of all science and technology.

(3) In all of our fundamental theories there appear a certain few parameters which characterize the fundamental particles and interactions we find in nature.

(4) The progress of our understanding of the physical world is very much intertwined with the advance of the art of precision measurement and its application to the determination of the fundamental physical constants.

(5) In recent years there have been notable advances in both theory and experiment relevant to the fundamental constants.

Appraisal: A definitive publication from a conference that was the first of its kind, and of fundamental importance in the measurement system infrastructure.

[113] A Metric America, Nat. Bur. Stand. (U.S.), Tech. News Bull., 222-30 (Sept. 1971).

[114] National Bureau of Standards at a Glance, Nat. Bur. Stand. (U.S.), booklet, 40 pages (Sept. 1, 1971).

[115] Science Policy Research Division, Library of Congress; National Bureau of Standards, A Review of its Organization and Operations: A study prepared for the Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics, U.S. House of Representatives, 236 pages (U.S. Govt. Print. Off., Washington, D.C., Sept. 8, 1971).

Purpose: A study prepared for the Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics, U. S. House of Representatives, Ninety-second Congress, First Session, at its request, to provide background information as it begins a comprehensive series of oversight hearings on the Bureau.

Approach: Compilation from materials in the public record, with special attention to developments concerning the National Bureau of Standards since the last general Committee review in 1961.

Findings: (1) Little information about the Bureau is available from independent sources.

(2) Diversity and technical nature of the Bureau's work make its comprehension difficult for the average citizen.

(3) There are significant uncertainties in the scope of NBS legal authority.

(4) Much NBS work is funded by other government agencies or private organizations with the result that the NBS budget is not reviewed as a whole in any public proceedings.

(5) NBS budget requests almost every year have been consistently reduced by the Department of Commerce, the Office of Management and Budget, and the Congress.

(6) Often the Bureau has been assigned urgent new tasks with no funds appropriated to carry them out, usually with no guidance as to what should be reduced to make room for the new work.

(7) The less visible and perhaps prosaic nature of its work has lacked the glamor needed to compete for recognition and support with the conquest of space, promoting nuclear power, and expanding national defense capabilities, despite the long-run pervasive impact of its work on American science, technology, and industry.

(8) Research and services for other organizations, currently at 40 percent of the total Bureau budget, have in the past been as high as 85 percent, and are a continuing source of potential imbalance in the Bureau's program.

(9) The proper role and extent of support by the Bureau of civilian technology *per se* is an unresolved question.

(10) Environmental problems affecting the Bureau's operations have grown up around it at its new site.

(11) Despite continuing changes in NBS programs and organization, there is evidence of undesirable delay in adapting the Bureau's output to the demands of U. S. industry, in response to continuing technological change and the commercial deployment of new products and services.

(12) Only a few major criticisms were found of NBS operations in the open literature during the 1960's.

(13) Suggested topics for further committee inquiry include (a) planning for the 1970's and beyond, (b) standard setting for the future, (c) U.S. conversion to the metric system (d) funding for the 1970's and beyond, (e) optimizing the utilization of the Bureau's facilities, (f) optimizing its location within the Executive Branch, (g) optimizing the administration within and of the Bureau.

(14) A basic question: To what goal should the NBS be oriented? The current statement used by the Director of the Bureau ("to strengthen and advance the Nation's science and technology and to facilitate their effective application for public benefit") is significantly broader than that of the Secretary of Commerce in the *U.S. Government Organization Manual--1970/71* ("assuring the maximum application of the physical and engineering sciences to the advancement of technology in industry or commerce"). The answer to this question must inevitably affect NBS planning for the future and the intellectual, physical, and financial resources it will require to attain the desired objectives.

Appraisal: A very even-handed and perceptive document.

[116] National Bureau of Standards Oversight Hearings, Hearings before the Subcommittee on Science, Research, and Development of the Committee on Science and Astronautics, U.S. House of Representatives, Sept. 16, 21-23, 28, 1971, 387 pages (U.S. Govt. Print. Off., Washington, D.C., 1971).

Purpose: Hearings for complete overview and review of the activities of the NBS.

Approach: Presentation of prepared statements by representatives of the Administration and other interested parties, and questioning by members of the Subcommittee.

Findings: A thorough review of the operations of NBS and the issues surrounding them.

Effects: The first time that NBS had been able to present, for about ten years, its complete story in a Congressional hearing. It was sympathetically received by the committee. Substantial statements of support were offered by the private sector.

[117] Branscomb, L. M., U.S. metric study, *Science Teacher* 38, No. 8, 58-62 (Nov. 1971).

[118] Ambler, E., Measurement standards, physical constants, and science teaching, *Science Teacher* 38, No. 8, 63-71 (Nov. 1971).

Purpose: Presentation during 1971 Convention of National Science Teachers Association.

Approach: Historical and philosophical review of field of metrology, discussion of current scientific status and trends in field, trend extrapolation.

Findings: (1) Human intuitive knowledge is basic to metrology, and is based on biological sensors of truly exquisite sensitivity.

(2) A most essential part in the process of developing primitive learning and intuitive conceptualization into a more sophisticated understanding of the concept and its relation to the physical world, is how we define our concept more exactly and measure it more precisely so that we all mean the same thing.

(3) The touchstone we adopt in changing the measurement system is one of practical utility: We look for accuracy, reproducibility, directness, and convenience. The system must be acceptable in science, engineering, and everyday life on an international basis.

(4) A major current challenge to metrology is development of an objective science for measurement of *subjective human phenomena*, perception of noise, for instance.

(5) Perhaps one of the most important things science teaching can do today is to try to reverse the present alienation the general public feels toward science, by reestablishing its original aura of humanistic *natural philosophy*.

Appraisal: A very thoughtful and penetrating discussion.

[119] Specifications, Tolerances, and Other Technical Requirements for Commercial Weighing and Measuring Devices, Nat. Bur. Stand. (U.S.), Handb. 44, 4th edition (Nov. 1971).



[120] Draft report of the Instrumentation Panel of NAS-NRC Physics Survey Committee (Nov. 12, 1971).

[121] Mason, H. L., and Peiser, H. S., ed., Metrology and Standardization in Less-Developed Countries: The Role of a National Capability for Industrializing Economies, Nat. Bur. Stand. (U.S.), Spec. Publ. 359, 390 pages (Dec. 1971).

Purpose: Proceedings of a Seminar of February 1-4, 1971. Definition of how NBS experience in metrology and standardization can be employed in collaboration with the U.S. Agency for International Development for assisting less-developed countries to build up their own technological infrastructures.

Approach: Presentations by expert participants from abroad and from NBS, with discussion.

Findings: (1) Caution is the best advice NBS has to offer.  
(2) Developing nations should not be over-awed by the achievements of industrialized nations and those of metrological laboratories like NBS.  
(3) We can all work together more effectively by comparing techniques, attitudes, and interests, as during this Seminar.

Appraisal: Established a sound basis for continuing NBS efforts in this field.

[122] Crane, B. M., Economic effects of an improved measurement, Ph.D. Dissertation, George Washington University (1971).

[123] Ambler, E., Entity Program Document for NBS Program A-1, Development, Maintenance and Improvement of the Standards of Physical Measurement, internal NBS working document (Jan. 7, 1972).

[124] Ambler, E., Entity Program Document for NBS Program A-3, Evaluation of the National Measurement System, internal NBS working document (Jan. 7, 1972).

[125] Ambler, E., Entity Program Document for NBS Program A-7, Research to Improve Physical Measurements, internal NBS working document (Jan. 7, 1972).

[126] Bell, F. C., and Wollin, H. F., ed., Report of the 56th National Conference on Weights and Measures 1971, Nat. Bur. Stand. (U.S.), Spec. Publ. 358, 252 pages (Mar. 1972).

[127] Branscomb, L. M., to help advance our Nation's science & technological capabilities for the greatest public benefit, Mater. Res. Stand. 12, No. 5, 8-12 (May 1972).

[128] Kushner, L. M., We have decided to become more active at the policy level in voluntary standardization activities, Mater. Res. Stand. 12, No. 5, 13-14 (May 1972).

[129] Andrus, W. E., A focus for the Bureau and all voluntary standardization organizations, Mater. Res. Stand. 12, No. 5, 15-17 (May 1972).

[130] Ambler, E., A major innovation is our Measurement Assurance Program, Mater. Res. Stand. 12, No. 5, 18-23 (May 1972).

[131] Hoffman, J. D., IMR emphasizes accurate measurements and standards for materials, Mater. Res. Stand. 12, No. 5, 24-33, 71 (May 1972).

[132] Willenbrock, F. K., We can never afford to be technically wrong, Mater. Res. Stand. 12, No. 5, 34-36, 71-72 (May 1972).

Purpose: The preceding six items are interviews or statements presented by NBS managers to communicate with the membership of the American Society for Testing and Materials (ASTM) about current programs and policies of NBS.

Approach: Editorial commentary, interviews with NBS managers, publication of prepared papers.

Findings: Implicit in the titles quoted above.

Effects: Concise and broad-ranging communication to ASTM membership.

[133] Ambler, E., Program to insure that IBS capability is used in the field to the maximum degree of effectiveness and to develop new capability where necessary, NBS internal memorandum, directed to IBS Division Chiefs and Dr. Leiss, 6 pages (May 5, 1972).

[134] Corruccini, R. J., The Role of Basic Standards in the Economy, NBS internal working document, generated in response to the request of April 12, 1972, by the Assistant Secretary of Commerce for Administration, 41 pages (July 3, 1972).

Purpose: Study of the NBS standards of measurement to determine if their accuracy is sufficient for the needs of U. S. industry:

- (a) Do NBS standards meet the needs of U. S. industry?
- (b) What is the NBS plan for improving the accuracy of standards?
- (c) In cases where standards should be improved, how much should they be improved, what would be the benefits and the cost?

(d) What role do NBS standards play in increasing U. S. industry's ability to compete in foreign markets? Are there standards, presently unavailable or capable of improvement, that would give U. S. industry a competitive edge in foreign markets?

(e) Are there predictable technological developments that would create a need for NBS standards not now available?

Findings: (1) NBS maintains standards and calibration services for 49 measurement quantities and provides auxiliary services which ensure that the standards are applied to best effect in the economy, e.g., in manufacturing, exchange of goods, and the utilization of science and technology for economic growth.

(2) NBS standards do appear to meet most needs of U. S. industry. However, technology continually advances by means of new discoveries, and at any given time there will be new needs in certain areas that require attention. Since 1946, new needs have tended to appear first in the programs of government agencies using advanced technologies (e.g., defense, aerospace, and atomic energy), from whence they have diffused into client industries and then to civilian industry. More recently, a different pattern has emerged in which measurement needs are being generated by public concern for well-being and safety. Some measurement needs do arise directly from civilian industry.

(3) The dissemination of the standards is being increasingly monitored by NBS Measurement Assurance Programs which evaluate the adequacy of the user's procedures and assure that those measurement techniques are applied which are most appropriate for meeting user's real needs.

(4) The nature of these standards and services is subject to constant review to ensure that the most critical needs are met in a timely fashion and that on-going activities are phased out when appropriate.

(5) Needs are ascertained by contacts with the technological community, by questionnaires and publications, by special conferences and symposia, by advisory groups, and by special issue studies (technology assessments).

(6) NBS plans for improving the standards relate not only to accuracy but also to extension of the ranges in which standards need to be maintained, provision of needed standards of kinds which do not now exist, and continuing surveillance to assure their effective application in the field. Short-term plans are well described in current budget documents.

(7) The Institute for Basic Standards of NBS has begun a three-year study of the entire measurement system which will define the need for standards more comprehensively than before and lead to comprehensive plans for meeting these needs.

(8) Cost/benefit analyses are part of the objective of the long-range study. General answers cannot now be given.

(9) Availability of measurement standards--though necessary--cannot by itself assure success in foreign trade. However, we can see areas where improved standards are needed to support U. S. international trade.

(10) There are a number of foreseeable developments in measurement technology of such importance to the improvement of measurements that NBS could not responsibly neglect them.

(11) There are beneficial future technologies that cannot be brought to full fruition unless appropriate new kinds of standards are provided by NBS.

Effects: This was a preliminary report with respect to the current study of the National Measurement System. It served to set the tone and a pattern for the study. It provided reasonable answers to the immediate questions, and put the existence, motives, and nature of this study clearly on the record within the Department.

- [135] Kushner, L. M., The role and value of measurement, Nat. Bur. Stand. (U.S.), Tech. News Bull., 56, No. 9, 216-19 (Sept. 1972).
- [136] Brief History of Measurement Systems, Nat. Bur. Stand. (U.S.), Spec. Publ. 304A, rev. Oct. 1972. 4 pages (Oct. 1972).
- [137] Rossmassler, S. A., ed., Critical evaluation of data in the physical sciences--a status report on the National Standard Reference Data System June 1972, Nat. Bur. Stand. (U.S.), Tech. Note 747, 79 pages (Nov. 1972).
- [138] Jewkes, J., Government and high technology, Occasional Paper 37 (Institute of Economic Affairs, The Wincraft Foundation, Dec. 1972).

- [139] Slattery, W. J., ed., An Index of U.S. Voluntary Engineering Standards, Supplement 1, Nat. Bur. Stand. (U.S.), Spec. Publ. 329, Suppl. 1, 459 pages (Dec. 1972).
- [140] Proceedings of the 1972 Joint Measurement Conference, June 21-23 (Instrum. Soc. Am., Pittsburgh, Pa., 1972).

Purpose: Development of an interdisciplinary exchange of technical and managerial measurement concepts.

Approach: (1) The explanation to technical and management personnel of those aspects of measurement technology that form the common basis for, or are applicable to, various measurement fields and several measurement-dependent industrial functions.  
 (2) The interdisciplinary flow of measurement information (available in one field for application in another) on a technical level involving the electrical, thermal, dimensional, etc., fields.  
 (3) The generation of ideas and actions intended to increase in the universities the extent and quality of education in measurement science, and to identify ways of increasing the professionalism of those engaged in metrology.

Findings: These are most succinctly described by the session titles:

- (1) The Role and Value of Measurement.
- (2) The Measurement Effort as a Resource for Management.
- (3) The Measurement Effort as a Technical Resource.
  - (A) When are Measurements Relevant?
  - (B) When are Measurements Adequate?
- (4) Interdisciplinary Processes in Sensors/Transducers/Detectors.
- (5) Interdisciplinary Solutions to Measurement Problems.
- (6) Systems Metrology: The "Compleat" Problem Solver.
- (7) Measurement Education--What It Is; How to Get It; How to Improve It.

Appraisal: The beginning of a continuing series of conferences, serving to tie the field of metrology together in the U. S., at the professional level, both managerial and technical.

- [141] Executive Office of the President--Office of Management and Budget, Standard Industrial Classification Manual 1972 (U.S. Govt. Print. Off., Washington, D.C., 1972).
- [142] U.S. Bureau of Census, Census of Manufactures: 1972, Alphanumeric List of Manufactured Products (1967 SIC basis), series MC72-2 (Bureau of Census).
- [143] Steiner, B., Optical radiation measurements: the impact of radiometry and photometry and the role of NBS, Nat. Bur. Stand. (U.S.), Tech. Note 594-4, 56 pages (Mar. 1973).
- [144] Ambler, E., Progress of Study of the National Measurement System, NBS internal memorandum directed to IBS Division Chiefs, 6 pages (March 23, 1973).
- [145] Bell, F. C., and Wollin, H. F., Report of the 57th National Conference on Weights and Measures 1972, Nat. Bur. Stand. (U.S.), Spec. Publ. 379, 216 pages (May 1973).
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- [148] Risley, A. S., Time and Frequency Division progress report on the study of the national measurement system, NBS internal memorandum to J. R. Seed, 34 pages (June 5, 1973).
- [149] Preliminary report, Assessment of the national measurement system for length, from Dimensional Technology Section of NBS Optical Physics Division, 40 pages (June 1973).
- [150] Schweitzer, W. G., National measurement system study--wavelength, NBS internal preliminary report, 8 pages (June 1973).
- [151] Ramboz, J. D., Progress Report on the national measurement system in the area of mechanical shock and vibration, from Vibration Section, NBS Mechanics Division, 21 pages, (June 29, 1973).
- [152] Young, R. D., Technology assessment of the surface finish measurement system, preliminary report from Optics and Micrometrology Section, NBS Optical Physics Division, 17 mm (June 1973).
- [153] Preliminary report, Assessment of the national measurement system for mass, from Dimensional Technology Section, NBS Optical Physics Division, 26 mm (June 1973).
- [154] Preliminary report, Assessment of the national measurement system for volume and density, from Dimensional Technology Section, NBS Opt. Phys. Div., 17 mm (June 1973).
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- [158] Schooley, J. F., National measurement system for non-radiative thermometry, NBS internal preliminary report, 13 mm (June 1973).
- [159] Wexler, A., Analysis of the national measurement system: microstudy: humidity, preliminary report from the Humidity Section, NBS Mech. Div., 7 mm (June 29, 1973).
- [160] Flynn, T. M., Cryogenics study of the national measurement system, preliminary report from the NBS Cryogenics Division, 104 pages (June 29, 1973).
- [161] Belecki, N., et al., Analysis of the national measurement system, Electricity Division substudy, progress report, 7 mm (June 29, 1973).
- [162] Anson, W. J., National measurement system progress report of the Electromagnetics Division, NBS internal memorandum to Dr. James Seed, 4 mm (June 30, 1973).
- [163] Laser technology and the national measurement system (Quantum Electronics Micro Study Interim Report), 8 mm (July 6, 1973).
- [164] Cook, R. K., ed., Progress report on microstudy of acoustical measurements as part of part of the national measurement system, NBS internal interim report, 10 pages (June 29, 1973).
- [165] Kostkowski, H. J., Progress report, national measurement system study, radiometry and photometry, NBS internal preliminary report, 30 pages (June 29, 1973).
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- [167] Ott, W. R., Ultraviolet radiometry--Part I, a survey of the national measurement system, preliminary report from the Plasma Spectroscopy Section, NBS Optical Physics Division, 12 mm (May 16, 1973).
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- [169] Progress report, national radiation measurement system study, preliminary report from the NBS Center for Radiation Research, 9 mm (June 30, 1973).
- [170] Arthur, M. G., Test Procedures Handbook for Surveillance Receivers below 100 MHz, Nat. Bur. Stand. (U.S.), Internal Report 73-333, prepared for U.S. Army Security Test and Evaluation Center, Ft. Huachuca, Ariz., 439 pages (Oct. 1973).
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- [173] Seed, J. R., and Pawlik, P. U., National measurement system - NCSL, the value of making measurements, preprint of paper prepared for NCSL Newsletter (Dec. 12, 1973).
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- [177] Risley, A. S., and Howe, S. L., Study of the time and frequency portion of the national measurement system, NBS internal working document, 15 mm (Dec. 28, 1973).
- [178] Lazar, J. W., and Norden, B. N., Length and related dimensional measurement study of the national measurement system, NBS internal working document, 46 mm (Dec. 15, 1973).
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- [188] Flynn, T. M., Cryogenics division study of the national measurement system, NBS internal working document, 102 pages (Dec. 15, 1973).
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- [190] Sangster, R. C., Ries, F. X., Altschuler, H. M., and Anson, W. J., Study of the national measurement system in electromagnetics, NBS internal working document, 430 pages (Dec. 1973).
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- [198] Executive summaries, micro analytical studies of the national measurement system, 7 mm (Dec. 1973).
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Purpose: Establishment of an international documentary standard formally recognizing and defining the SI (International System of Units), for use in international standardization activities.

Approach: Committee and consensus; consistency with the International Bureau of Weights and Measures (BIPM).

Findings: Details of the use of SI.

Effects: Thorough entrenchment of SI as *the* measurement language for all international purposes. A basic reference document.

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- [201] The gallery, finer things from Amsterdam Co. (a catalog containing among other items many novel consumer measurement instruments)(1973).
- [202] The National Conference on Weights and Measures, its organization and procedure, booklet, 10 pages (U.S. Dept. Commerce, about 1973).
- [203] Mission, Office of Weights and Measures, U.S. Department of Commerce, National Bureau of Standards, booklet, 6 pages (about 1973).
- [204] The weights and measures men, a pamphlet for consumers (National Conference on Weights and Measures, about 1973).
- [205] Cohen, E. R., and Taylor, B. N., Specifications of the physical world: new values for the fundamental constants, Nat. Bur. Stand. (U.S.), Dimensions/NBS, 5 pages (Jan. 1974).

Purpose: Putting current best values for fundamental constants on the record.

Approach: International committee effort.

Findings: (1) A set of values that agree as closely as possible with the experimental results while conforming as closely as possible to the accepted theoretical relations connecting the constants with one another.

(2) The accuracy and consistency of this adjustment are significantly improved with respect to either the 1963 or 1969 analyses.

(3) There are critical areas where additional measurements and theoretical calculations are indicated.

(4) For the great bulk of physical and chemical data, these values should serve as a standard reference set for the next several years.

Appraisal: A basic reference compilation.

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- [208] Eads, G., U. S. Government support for civilian technology; economic theory versus political practice, Research Policy 3, 2-16 (1974).
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- [210] Wilson, A. C., Automatic test equipment applied to electromagnetic measurements -- an issue study in support of the Electromagnetics Division's national measurement system study, NBS internal working document, 48 pages (April 15, 1974).
- [211] Wilson, S. J., and Smith, R. N., ed., Report on the 58th National Conference on Weights and Measures 1973, Nat. Bur. Stand. (U.S.), Spec. Publ. 291, 208 pages (May 1974).
- [212] National Directory of Weights and Measures Personnel (Dept. Commerce, NBS, May 1974).
- [213] 1974 Membership Roster, Precision Measurements Association (Precision Measurements Association, Burbank, Calif., June 1974).
- [214] Jones, R. M., The Measurement of Lumped Parameter Impedance: a Metrology Guide, Ed. W. J. Anson, Nat. Bur. Stand. (U.S.), Monogr. 141, 211 pages (June 1974).
- [215] Arthur, M. G., The Measurement of Noise Performance Factors: a Metrology Guide, Ed. W. J. Anson, Nat. Bur. Stand. (U.S.), Monogr. 141, 211 pages (June 1974).
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- [219] Page, C. H., and Vigoureux, P., ed., The International System of Units (SI), Nat. Bur. Stand. (U.S.), Spec. Publ. 330, 49 pages (July 1974).

Purpose: Promotion of knowledge and understanding of the International System of Units, encouragement of its use in all realms of science, industry, and commerce, and securing uniformity of nomenclature throughout the English-speaking world.

Approach: Joint translation (and publications) by the USA and UK from the original French text published by the International Bureau of Weights and Measures (BIPM), with review for accuracy by BIPM.

Findings: The definitive statement in the English language of the SI.

Appraisal: A basic reference document.

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- [222] McCoubrey, A. O., Expanding the nation's measurement system, ASTM Standardization News 2, 14-17, 59 (Nov. 1974).
- [223] The National Conference of Standards Laboratories, ASTM Standardization News 2, 18-22 (Nov. 1974).
- [224] International quality assessment, ASTM Standardization News 2, 23-28 (Nov. 1974).
- [225] Porat, M. U., Defining an information sector in the U.S. economy, second year project report (Institute for Communication Research, Stanford University, Stanford, Calif., Nov. 1974).
- [226] Dalke, J. L., Why metric and when?, TAPPI 57, No. 12, 72-75 (Dec. 1974).
- [227] NBS Metric Kit, Nat. Bur. Stand. (U.S.), Spec. Publ. 410 (1974); contains the following items:
- [228] Metric conversion card, Nat. Bur. Stand. (U.S.), Spec. Publ. 365 (Nov. 1972).
- [229] For good measure, Nat. Bur. Stand. (U.S.), Spec. Publ. 376 (Dec. 1972) (a metric ruler).
- [230] What about metric?, Nat. Bur. Stand. (U.S.), brochure, 16 pages (1973).
- [231] Roberts, R. W., The metric changeover, Nat. Bur. Stand. (U.S.), brochure, 3 pages (Sept. 1974).
- [232] Brief history of measurement systems, Nat. Bur. Stand. (U.S.), Spec. Publ. 304A, 4 pages (Sept. 1974).



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- [237] Chapter 27, Photographic equipment and supplies, Chapter 36, Metalworking machinery and tools, Chapter 37, Instruments for measurement, analysis and control, and Chapter 38, Medical and dental instruments and supplies, U.S. Industrial Outlook 1975 with Projections to 1980, pp. 261-65, 347-56, 357-71, and 372-79 (U.S. Dept. Commerce, U.S. Govt. Print. Off., Washington, D.C., 1974).
- [238] Four papers on metric conversion: Clark, R. E., U.S. metrication - why? Barrow, L. E., Metrication in business and industry. Odom, J. V., Metric change and the role of education. Odom, J. V., The effect of metrication on the consumer. Nat. Bur. Stand. (U.S.), information document prepared by Metric Information Office, 21 pages (undated, estimated 1974).
- [239] Capabilities of the primary standards laboratory, January 1975, booklet, 34 pages (Measurement Standards Department, Sandia Laboratories, Albuquerque, N.M., Jan. 1975).
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- [241] Roberts, R. W., The other face of the measurement base, remarks at the Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Cleveland, Ohio, March 3, 1975, Nat. Bur. Stand. (U.S.), booklet, 24 pages (Mar. 1975).
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- [244] Principles and practical approaches for evaluating international standards, final report JACKFAU-75-136, 75 pages (Jack Faucett Associates, Inc., Chevy Chase, Md., Apr. 3, 1975).
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- [250] Page, C. H., and Vigoureaux, P., ed., The International Bureau of Weights and Measures, translation of the BIPM centennial volume, Nat. Bur. Stand. (U.S.), Spec. Publ. 420, 256 pages (May 1975).

Purpose: BIPM's official centennial volume.

Approach: Historical introduction followed by reviews of technical activities, written by technical staff of BIPM.

Findings: That which characterizes the BIPM at the time of its centennial is the blending of permanence, which comes from its mission, and of rapid renovation, as in the techniques used to accomplish this mission. BIPM furnishes standards to countries needing them, compares the standards of countries which are sufficiently advanced to establish their own standards, and contributes to research looking forward to the still higher precision of the future; it serves as a neutral and impartial scientific arbiter when national sensitivities impede an international agreement. It is also a center for discussion, for coordination, and for preparation of international decisions. The importance of the mission of the BIPM is well illustrated by the progressive adoption, in all countries, of the International System of Units.

Appraisal: A valuable, benchmark reference document.

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Purpose: Catalog of membership and capabilities.

Approach: Polling of members and other eligible organizations.

- Findings:
- (1) List of laboratories and capabilities
  - (2) Directory of standards laboratories
  - (3) NCSL member delegates
  - (4) List of standards laboratories in zip code order
  - (5) NCSL Board of Directors and Regional Representatives
  - (6) National Liaison Delegates to NCSL from other organizations

Appraisal: A comprehensive directory to one segment of the national measurement system.



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