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NBS TECHNICAL NOTE 594-4

Optical Radiation Measurements:

The Impact of Radiometry and Photometry and the Role of NBS

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[2] Part of the Center for Radiation Research.
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Optical Radiation Measurements:

The Impact of Radiometry and Photometry and the Role of NBS

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Preface

This is the fourth issue of a series of Technical Notes entitled OPTICAL RADIATION MEASUREMENTS. The series consists primarily of reports of progress in or details of research conducted in radiometry and photometry in the Optical Radiation Section of the Heat Division and appears about every six weeks. The current issue, however, is an exception. It presents the impact of radiometry and photometry on a number of problems of national concern and NBS' role in the measurement aspects of these problems. The document was originally prepared for internal use. It is being included in this series because of the belief that it would be of interest and use to a much wider audience.

Henry J. Kostkowski, Chief
Optical Radiation Section
National Bureau of Standards

Foreword

Individual scientists and scientific institutions are being asked increasingly to identify specific long-term effects of their work. This identification is at best difficult and imprecise. Nevertheless it provides as quantitative a basis as is possible for establishing specific programs and priorities.

This examination of potential effectiveness has been stimulated by the increased concern for national problems, such as the energy crisis, pollution, and public safety. In the development of solutions for these problems, the suitability of technical approaches must be assessed. The promise of specific experimental and theoretical procedures must be evaluated. Thus increasingly the relationship of various technical fields to national goals and problems must be identified.

One technical area of major potential impact on many problems of national concern is the field of electro-optics. This field has experienced exceptionally rapid growth in the last five years. Though this growth has strengthened markedly the ability of the field to provide solutions to certain problems, it has created its own problems in terms of increased disagreements among measurements. Disagreements in optical radiation measurements of commercial and public significance are now widely evident and are growing in severity.

Therefore the National Bureau of Standards is now reviewing its traditional concern for optical radiation measurement accuracy, the new emphasis on national needs, and the application of sophisticated technical measurement to national problems. Its review of these national questions, the answers to which depend on progress in optical radiation measurement, may interest a wider audience than the Department of Commerce, for which this report was initially prepared.

The study is designed not only to describe present important problems but to concentrate on those of future impact. It must therefore anticipate the development of technology and its problems. It must extrapolate. Therefore this review presents only a cursory summary of many complex issues and some supporting evidence.

Commercial questions are also intimately involved. Any improvement in industrial technology stems from and in turn will stimulate keen competitive interest. We are indeed extremely grateful to our correspondents in industry, especially those in the Council for Optical Radiation Measurement, for the insights that they have given us. But because of the commercial impact of technical forecasting in this area, this version of the NBS study excludes individual reference to particular companies and the exact data they have given us.

A comprehensive study of the issues might well be expected to include a detailed program for action. In Chapter 5 some general comments are made that suggest such a program. Detailed programs have in fact been constructed separately in the various projects covering areas of this review. A comprehensive, centralized solution has not been proposed here. Nevertheless one initial component in a new NBS approach to these problem-studded fields is the present survey of the issues ultimately involved. In an improved measurement system, NBS must make a sensible contribution derived from an understanding of these ultimate issues.

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Serious measurement discrepancies universally plague quantitative measurement in the electro-optics industry. The impact of the resulting problems is reviewed and the role of NBS explored. The measurement discrepancies arise chiefly through the recent explosive expansion of this industry. The growth has precipitated a complex development in the variety and accuracy of measurements required. The impact of problems in optical radiation measurement falls in many areas. One is the increasing Federal responsibility for public life defined in recent legislation. Another is the influence of good optical radiation measurement on the technical development of the electro-optics industry. The impact of these measurements on a number of public issues is reviewed: public health, public safety, the energy crisis, meteorology, pollution, agriculture, crime prevention, and surveillance from air and space. The economic impact of improved measurement both on a fair domestic market and on the balance of payments operates through unit production cost, quality control, product improvement, and innovation. Leadership by NBS has been urged by the industry not only in fulfillment of its legislative responsibility but also to permit the focus of elaborate and impartial resources on the complex problem of optical radiation measurement. In keeping with its mission to help improve industrial technology and the competitiveness of American industry, NBS has an opportunity of major proportions in the electro-optics industry. Leaders of this industry are calling for NBS initiatives to resolve many of the measurement problems now hindering further progress.

Key Words: Agriculture; clinical analysis; economic impact; energy crisis; meteorology; photometry; phototherapy; pollution, radiometry; remote sensing.

1. THE PROBLEM IS SERIOUS DISCREPANCY

Quantitative measurements of optical radiation typically disagree seriously with comparable measurements. Such discrepancies vary in size between several percent and several hundred percent. They arise both within and among laboratories, nationally and internationally. They occur in all spectral regions, in the ultraviolet, visible, and infrared.

This situation is widely considered to be intolerable. Concern has been expressed in conversations and in voluminous correspondence with industry, other governmental agencies, and universities. It has also been expressed by the electro-optics field as a whole through the organization of the Council for Optical Radiation Measurement. Reports of Working Groups of this Council furnish the beginning of an industry-wide consensus on the broad incidence and the great urgency of the problem.

The basic purpose of this study is to examine the issues. These are studied in Section 3. Alternatives for dealing with them are covered in Section 4. The contributions NBS can make and why it should do so are covered in Section 5. The fundamental question, however, is the general technical basis for this situation: "How we got here and why?" This is reviewed in Section 2. It must be examined first, because it bears on the severity of the problem. This technical basis also suggests the ultimate range of solutions.

2. THE REASON IS GROWTH: WORKING AT THE STATE OF THE ART

2.1 Introduction

Primary responsibility for serious disagreement in optical radiation measurements rests on technical growth. On the one hand, there is the recent exceptionally rapid growth of electro-optics technology. Moreover, expansion also in public concern is making new demands on this technology. Specific issues will be cited and examined in the next chapter. However, both the significance of these issues, and the present ability of NBS to respond to them, are strongly affected by three factors: 1) the rapidity of recent growth, 2) the present undeveloped nature of radiometry* and photometry*, and 3) the polydimensionality of recent development. Both commerce and the public interest require measurement frequently at or beyond the state of the art. The implications of this situation are severe.

2.2 Rapid Growth

a. U.S. Growth

The present rapid expansion of our electro-optics industry is characterized by two types of growth. In some cases, established companies are expanding rapidly. At the same time, new high-technology companies are proliferating in number.

Large sections of the industry are expanding by a factor of two to four every nine years (Table 1). The lamp (light bulbs) and lighting fixtures industries are doubling every nine years. The manufacture of television receiving sets triples in nine years. The dollar value of cathode ray tubes production quadruples after nine years. The manufacture of light sensitive diodes nearly doubles in four years. The value of equipment for photogrammetry nearly tripled in the four years between 1963 and 1967. Optical instrument manufacturing quadruples in nine years. The manufacture of photographic equipment triples in a nine-year period. Several of these components are now individually multibillion dollar industries.

Table 1. Examples of growth in optical radiation industry

Millions of Dollars

(Source: U.S. Census of Manufacturers)

Industry	1967	1963	1958
Lamps (Bulbs)	756.	546.	394.
Lighting Fixtures	1,543.	1,116.	765.
TV Sets	2,260.	1,092.	727.
TV Tubes	766.	249.	177.
Light Diodes	19.	11.	not separated
Photogrammetry	5.9	2.2	not separated
Optical Instruments	452.	270.	116.
Photographic Equipment and Supplies	3,138.	1,631.	1,061.

Much of this growth has been reflected in the growth of industrial giants such as Eastman Kodak and General Electric. But the electro-optics industry also contains a large number of small companies. In fact, the most recent Optical Industry and Systems Directory lists over 1,400 suppliers, a number of which are small businesses.

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*Radiometry: science of quantitative optical radiation measurement
Photometry: eye-response-weighted radiometry

The most rapid growth is now found in non-Federally related activity. By contrast, the initial impetus had been furnished by the defense and space efforts. This Federal activity formerly provided administrative as well as financial focus. But with the slowdown in these communities, growth is reflected by a change from centralized Federal sponsorship to diverse Federal and private interests. This change requires an even greater intercomparability of measurements than would have otherwise been the case.

b. Foreign Growth

Other countries have just begun to move into this very promising field [1][1]. An important indicator of the rate of growth is the number and variety of demands that the whole industry is presenting to its national laboratories. The severity of the American situation is yet approached abroad only by NRC in Canada. Figure 1 gives a qualitative picture of the development of this field with time. In the figure, assistance requested and time are both normalized in terms of the point at which national expectation of assistance seriously outdistances the capacity of the respective national laboratory to respond. The data is taken from personal conversations of the author with those responsible for the programs in radiometry and photometry in the various national laboratories. NBS and NRC find themselves in a position to anticipate problems and provide leadership in a situation that will surely arise in the other national laboratories: NPL, PTB, ETL, NSL, BNM, and IMM. It is interesting to observe that there is a rough correlation between the severity of their present optical measurement crisis and proximity to the U.S. We shall return to the important foreign trade implications of this picture in Section 3.

2.3 The Rickety Technical Base

a. Radiometry

The initial demands of defense and space technology have been met in radiometry by the establishment of a few basic standards. These of necessity were tied to fundamental physical measurement, but as often as not only loosely by contemporary standards. Very few pillars of this radiometric foundation go to bedrock as seen today. And those few that do are available only at an enormous cost in effort by highly trained and painstaking workers. The utilization of these standards for measurements of immediate practical interest is so challenging that most efforts become research projects in themselves. The level of agreement among measurements is frequently no better than that in exploratory research.

The previously modest commercial requirements in radiometry were met by spin-off. They were accommodated within the focused attention of DOD and NASA in a few basic areas. However, DOD interest in radiometry and photometry is now being curtailed at a time of rapidly increasing non-defense need for attention. In a similar way, a modest amount of accurate radiometric measurement of academic long-range interest has also been entertained within this Federal framework. However, academic requirements are now increasing in severity at the same time that this skeleton framework has ceased to develop.

b. Photometry

Visual evaluation of light preceded the ability of the physicist to measure its spectral power distribution. But the best photometric measurements are still comparable only to an accuracy of a few percent. Their conversion to and from purely physical quantities, e.g. watts, is even now possible at best to about 3%. In the absence of a firmer physical foundation, agreement among photometric measurements has depended heavily on the limited variety of objects measured and the limited types of measurements made. It has also been aided by the traditionally modest level of agreement expected.

This system held together tolerably well for incandescent lamps. For a small variety of film types, it also worked: film and the photographer were relatively "forgiving" of imprecise exposure. In other more specialized areas of interest, DOD was able to fund the

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[1]Figures in brackets indicate the literature references at the end of this paper.

GROWTH OF ELECTRO-OPTICS INDUSTRY

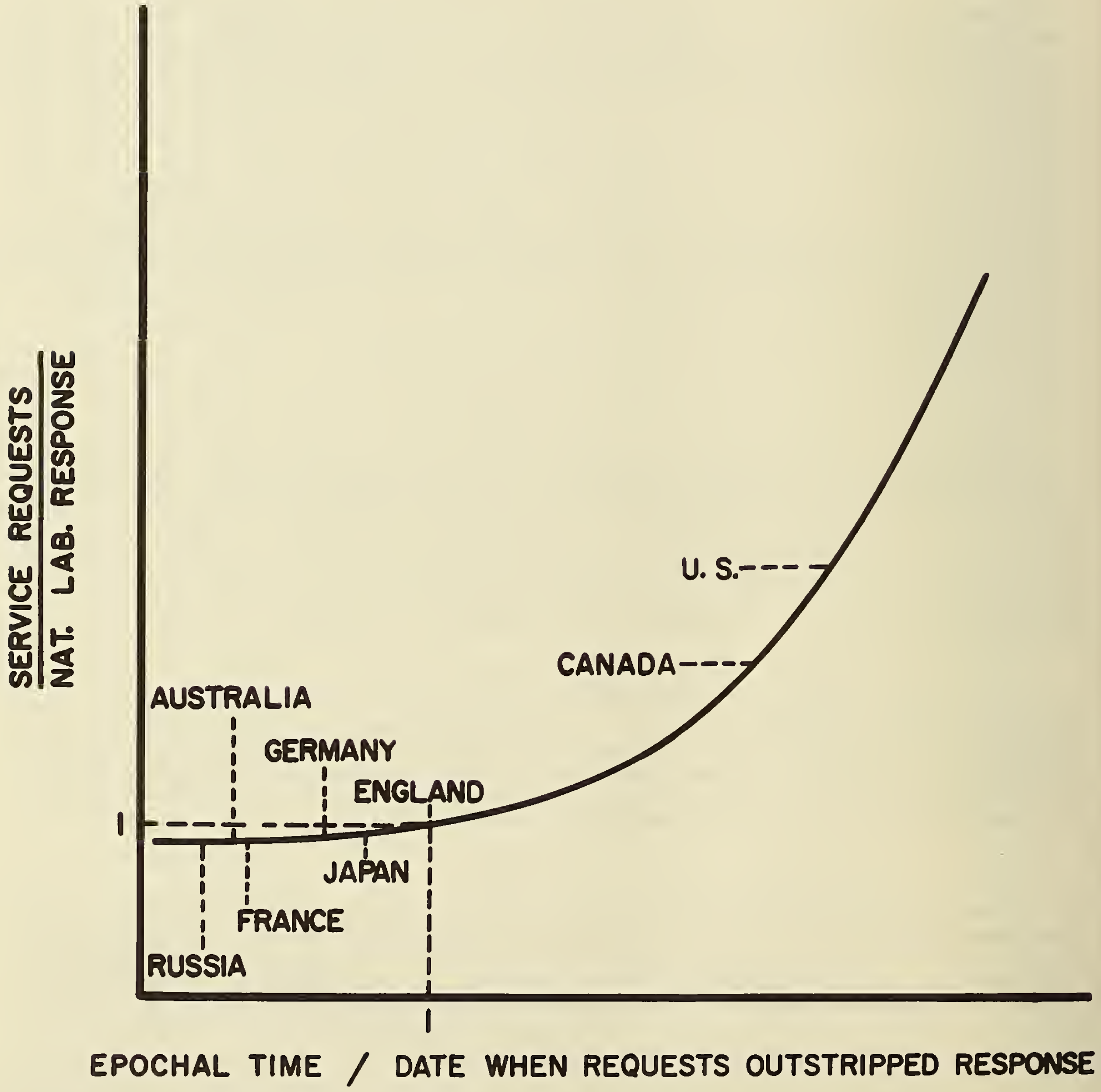

FIGURE 1

establishment and separate maintenance of special standards, gages that were not tied closely to basic physical measurement.

But no longer. Apart from the comparison of similar incandescent lamps and a few other specialized objects, photometric measurement can now be performed only with unacceptable agreement and even then only with great effort by contemporary standards. Since the archaic structure has a weak physical basis it cannot be patched or extended.

c. Recapitulation

For differing reasons, then, the structures of photometry and radiometry have been minimally responsive to relatively undemanding isolated and non-interrelated requirements. That era has ended. We shall see that the existing small but firm radiometric foundation achieved by great labor will accommodate neither the quantity, the variety, nor the interrelation of present needs of the electro-optics industry. A major new thrust will be required for NBS to make substantial progress in meeting the rapidly evolving expectations of its constituency in radiometry and photometry.

2.4 Wide Diversification of Growth in the Art and in Public Interest

A few specific examples of recent growth may provide a useful framework for understanding Section 3.

a. New Kinds of Technology

A dominant feature of the present growth of the electro-optics industry is the development of very new technology. This technology throws into relief the limitations of much of classical radiometry and photometry [2]. For present measurements to be meaningful, they must be comparable with others. One cannot continue arbitrarily to set up new gages.

(1) Light Emitting Diodes

The newest and most rapidly growing type of source is the light emitting diode (LED). It has a unique spectral distribution (color) very different from that of the incandescent lamp. The use of this lamp has developed very rapidly within the past year [3]. It promises ultimately to replace the incandescent lamp at low levels. Measurement of these new lamps is becoming a very serious problem [4-7; app. A].

(2) Other New Lamp Types

The proper role of NBS with respect to the lamp industry will be examined closely in Sections 4 and 5. For the moment we postulate the argument that accurate measurement of total flux of a variety of lamps is in the national interest and clearly relates to the mission of the Bureau. The recent rapid development of new lamp technology then places an enormous new burden on the present system [8]. The variety of lamps produced is such that the few incandescent lamp standards now available are inadequate to the job.

(3) New Detectors

The rapid development of new detectors has led to a new emphasis in an area that formerly received little attention. The stability of new solid state detectors has aroused serious interest in a detector that might serve as a secondary standard. This is an attractive idea particularly for photometry, a field built conceptually on a natural detector, the eye [7,9]. Furthermore, a need has arisen for characterization of totally new detectors such as vacuum photomultipliers incorporating III - V compounds. These provide an unusually flat wavelength response [10].

(4) New Optical Instrumentation

The growth of the entire electro-optics field is leading to the entry of a number of new radiometers and photometers that offer substantially higher reliability than in the past [2]. Firms already established in other areas are now entering the field [11]. With the increasing commercial availability of optical measurement technology and its increasing precision, the need for both higher accuracy and more reliable verification of measurement performance is becoming a pressing problem.

b. Broadened Spectral Range and Distribution

The growth in demand for better measurements is particularly keen in the infrared [6,12-13; app. B]. Measurements in this region promise to be particularly useful in finding solutions to a number of social problems explored in Section 3 [6].

The growth in ultraviolet requirements is also remarkable. Both spectral radiance and irradiance are becoming of primary interest to the ultraviolet user [13]. In addition, the measurement of ultraviolet total flux is important to the manufacturer of equipment, production and replacement part verification, serving photochemistry, graphic arts, and chemical production [5].

Sources of light with a spectral distribution different from that of current standards become more important [7] as the distribution of natural daylight is recognized to be of considerable health and safety significance (Section 3) and as the spectral distribution of artificial light sources becomes increasingly bizarre (Plate 1).

c. Low Level

Measurements at low light levels have presented a new set of problems. Commercially important sources are presenting serious measurement problems at these lower levels [4-7, 14; app. A].

Looking to the future, the ultimate feasibility of photon counting as a basic measurement tool, whether as a primary realization or a secondary standard, will depend on the ability to couple single photon techniques with classical power measurement. A far-sighted program in radiometry will have to include work in this area if NBS is to prepare itself for future demands of a basic nature. No standards here presently exist.

d. High Level

At the other extreme, the measurement of high level sources is also increasingly important [7]. High total flux measurements bear on foreign trade as we shall see in Section 3 [8]. The importance of high irradiance measurement in new safety requirements [15] for the photographic industry is now recognized by Underwriters Laboratories. NBS presently has no high level standards in the range of this new concern.

e. Pulsed Measurements

An area of desultory NBS activity that generally has a very low level of reliability, but one of increasing commercial and technological importance, is the measurement of pulsed sources. These are used in photography and traffic control; they are of great importance in growing laser technology [4,7,14; app. A].

f. New Public Interest

The growth of public concern, as reflected in new and anticipated governmental action, poses many new measurement problems that require firm, reliable solutions.

(1) Transportation

Recent Federal entry into the regulation of safety in transportation is leading to new requirements in automobile lighting. Both head lighting and tail lighting [7] are involved. Newer materials are complicating the measurements and making obsolete most former measurement techniques [16].

The problems in this as well as related fields are complicated by the lack of recognition that even the barely tolerable level of past agreement is no longer possible. Diversification in the types of sources and materials being measured is further complicated by new types of instruments now used to measure them [9]. Continued lack of attention to this

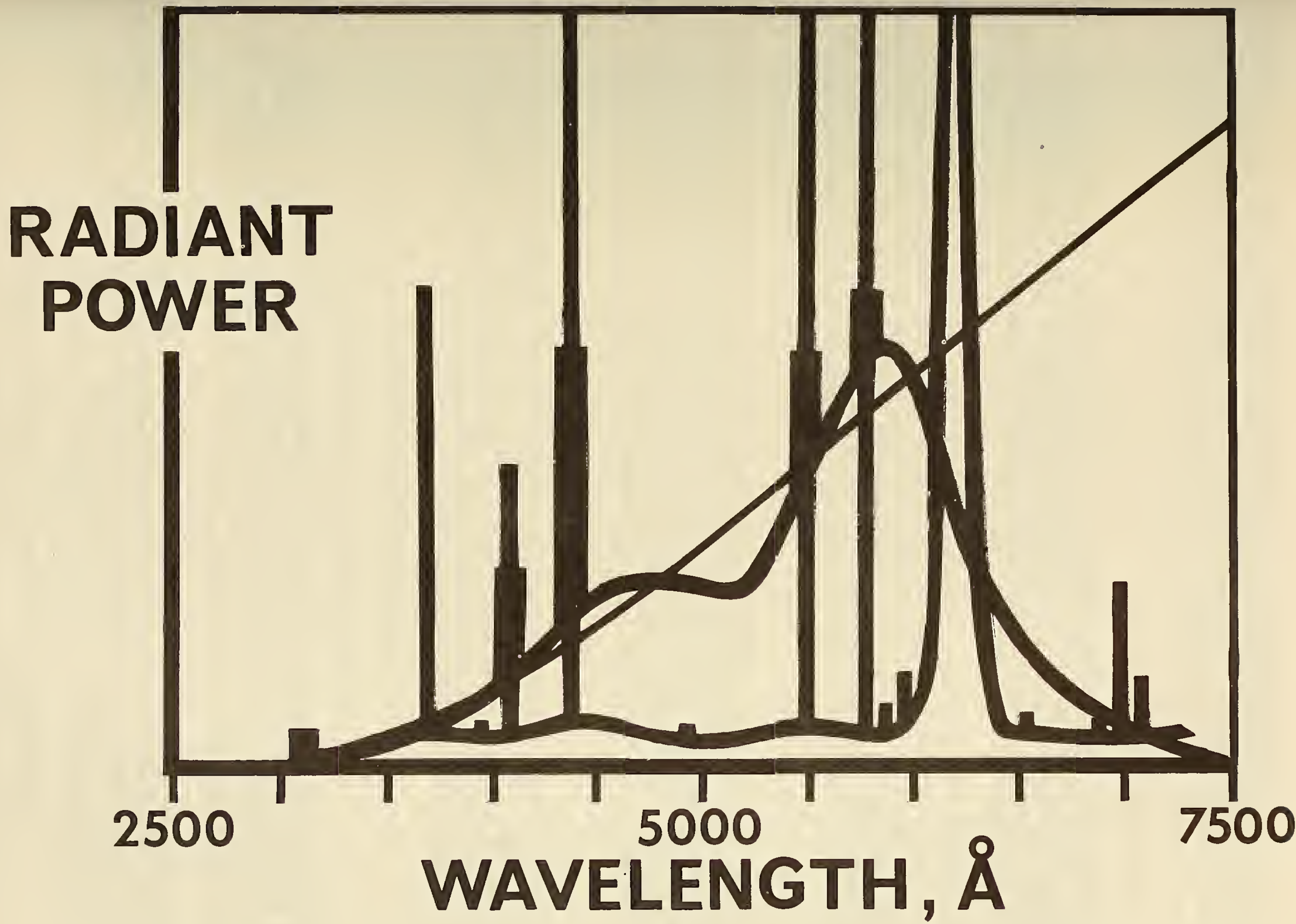

PLATE 1. Spectral power distribution of an incandescent lamp (monotonically increasing with wavelength), a fluorescent lamp (double-humped structure), and a high intensity discharge lamp (many-lined structure).

problem will result in much larger future measurement discrepancies. But at the same time, broad recognition of the influence of lighting on safety is calling for even tighter tolerances [17]. The transfer of responsibilities in this area to the Federal Government moreover provides a new focus for concern. This focus will make the poor measurement situation more visible, and thus more intolerable.

(2) Public Safety

The growth of concern for public safety is illustrated by activity after the ignition of clothes by lights on a movie set. Underwriters Laboratories are in the process of propagating for the first time a specification on the radiant heat a given distance from movie lights [15]. This particular specification calls for measurements not possible with current NBS standards.

Another example is the increased medical concern about the ultraviolet flux from lamps. Biological activity in this spectral region is being very widely recognized and will be covered in more detail in Section 3. Present standards go back 30 to 40 years with consequently very questionable accuracy [5]. The basis for new Federal administrative action has already been laid: new legislation will require both new total flux measurements not now possible and more reliable spectral irradiance measurements than are now available.

(3) Governmental Activity

Recent Federal activity in transportation has been noted. Increasing public concern about the environment has led to greater Federal concern with optical radiation measurement in the Radiation Health and Safety Act [5]. NBS is in the interesting position of a Federal agency asked by industry to become more actively involved in interaction with private enterprise [4]. The electro-optics industry clearly desires to fulfill its contractual agreements reliably, not by an unsatisfactory adherence to sparsely available standards [14].

g. Other Anticipated Areas of Impact

Among the many applications that are, or shortly will be, strongly affected by rapidly changing technology are: aerospace cockpit lighting [7]; photographic instruments and associated filters, sources, and detectors [7,18]; cathode ray tubes; and computers [7]. Graphic arts and television may shortly be greatly affected by a relatively unfamiliar type of color image production: liquid crystals [19].

2.5 Measurement Impact of Growth

a. Increased Necessity for Intercomparability

The general diversification of types of measurements made with rapidly developing technology places a severe strain on the use of a relatively static number of standards. That is, a new measurement will necessarily imply new techniques and new procedures. In general these will differ in a given laboratory from those in another in "geometry, polarization, and instrument spectral response" [4].

Although outside agencies have no legal power to commit NBS resources in order to provide "traceability", industries and other government agencies increasingly rely on NBS via "traceability" requirements. Our response to this situation will have broad impact on a substantial segment of industry. NBS, as noted above, has a unique opportunity here as well as some serious hazards to be avoided. Industry is looking actively to NBS.

b. Relationship of Photometric to Radiometric Measurements

A most important type of intercomparability now demanded is that between photometric (eye-response related) and radiometric (physical) quantities. Because photometric measurements preceded the more basic radiometric ones, a separate system arose. It has become hallowed first by usage, then by enshrinement as a "Base Unit", the candela, and finally, by a special legal responsibility of the Secretary of Commerce for maintenance of a special set of photometric standards (Section 3). Nevertheless, the physical separateness of the photometric system from the more clear radiometric system has become a serious commercial liability. In areas where both eye-response and power units are required, two separate not legally convertible sets of units are no longer economic [6-7,13,18,20]. Although few people question the advisability of using eye-related units for visually important quantities, the existence of a detached system for this purpose is increasingly a liability. Growth in both areas of measurement requires firm convertibility.

c. Generality of the Difficulty

The problems that have been described are widespread problems, as the redundancy in the referenced comments indicates. It is indeed largely the growth in the redundancy of these problems [6] that calls for a major new effort. Because of the wide number of measurements made and the interdependence of the results, a comprehensive program for attention is required. The constraints that this factor places on feasible NBS programs will be examined in Section 4.

3. THE ISSUES

3.1 Statutory Obligation

a. Direct Responsibility

(1) Organic Act

Direct NBS responsibility for national standards of measurement is defined in 15 U.S. Code 272, which authorized the Secretary of Commerce to undertake: "the custody, maintenance, and development of the national standards of measurement, and the provision of means and methods for making measurements 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".

Authorization that: "The Bureau shall exercise its functions for the Government of the United States: for any state or municipal government within the United States; or for any scientific society, educational institution, firm, corporation, or individual within the United States engaged in manufacturing or other pursuits requiring the use of standards or standard measuring instruments" has a renewed significance in connection with more recent legislation described below.

In carrying out these functions, activity for: "(1) the construction of physical standards; (2) the testing, calibration, and certification of standards and standard measuring apparatus; (3) the study and improvement of instruments and methods of measurements" is also authorized. Authorization for "(9) the investigation of radiation, radioactive substances, and X rays, their uses, and means of protection of persons from their harmful effects" is an incredibly broad responsibility with respect to the marked growth characterizing the electro-optics industry. "Cooperation with other governmental agencies and with private organizations in the establishment of standard practices, incorporated in codes and specifications; advisory service to Government agencies on scientific and technical problems, invention and development of devices to serve special needs of the Government" will be increasingly demanded as legislation and its authorized Federal activity expands rapidly.

(2) Specific Photometric Responsibility (Visible Light)

In addition to the important but general authorization in the Organic Act, 15 U.S. Code 224, Public Law 81-617, goes considerably further with respect to photometric (eye-related, that is, visible light) units: <u>"It shall be the duty of the Secretary of Commerce to establish the values of the primary electric and photometric units in absolute measure, and the legal values for these units shall be those represented by, or derived from, national reference standards maintained by the Department of Commerce."</u>

The growth described in Section 2 bears directly on the rapidly increasing obligation of NBS in connection with photometric units. As the variety of the applications of such measurement grows, the public expectation of NBS performance, with the substantial backing of the cited legislation, increases apace. This expectation is particularly demanding with respect to increasing industrial desire for the strong coupling of photometric and radiometric units [6-7,13,18,20].

b. Indirect Responsibility

(1) New Legislation

The preceding citations stressing cooperation with other government agencies convey renewed significance after the recent passage of several pieces of Federal legislation: "The Federal Hazardous Substances Act", 15 U.S. Code Chapter 30, The Radiation Health and Safety Act of 1968, Public Law 90-602, and the Occupational Safety and Health Act of 1970, Public Law 91-596. This significance for optical radiation measurement at NBS follows.

The "hazardous substances" referred to in the U.S. Code include: "any substance or mixture of substances which (i) is toxic, (ii) is corrosive, (iii) is an irritant, (iv) is a strong sensitizer, (v) is flammable or combustible, or (vi) generates pressure through decomposition, heat, or other means, if such substances or mixture of substances may cause substantial personal injury or substantial illness during or as a proximate result of any customary or reasonably foreseeable handling or use, including reasonably foreseeable ingestion by children." This act provides for the removal from commerce of substances found by the Secretary of HEW to be hazardous. The lamp industry is already concerned about the compliance of some of its products [5]. As the biological effects of ultraviolet light become more widely recognized many other conventional lights may be brought shortly under this legislation. In addition, eye damage produced by flash lamp radiation in the IR, may also be recognized within the foreseeable future [20]. Laser damage will be of increasing concern. Provision has already been made for the monitoring of hazardous substances.

The Radiation Control for Health and Safety Act of 1968, Public Law 90-602, also implies a similar major new thrust of government concern and government action. It covers "any manufactured . . . product which . . . acts as part of an electric circuit and emits . . . ionizing or nonionizing electromagnetic . . . radiation". The Secretary of HEW is authorized to "plan, conduct, coordinate, and support radiation research" . . . to minimize the emission of . . . unnecessary electronic product radiation" and to "consult and maintain liaison with the Secretary of Commerce . . . on techniques, equipment, and programs for testing". HEW is to monitor "measures to assure consistent and effective control of the aforementioned health hazards" and to "invite the participation of other . . . agencies having related responsibilities and interests". "The Secretary of HEW shall by regulation prescribe performance standards . . . "and shall give consideration to . . . "the adaptability of such standards to the need for uniformity. "In case of actual controversy . . . any person who will be adversely affected . . . may at any time . . . file a petition with the United States Court of Appeals". Provision is made also for inspection of testing procedures.

With the increasing public concern for biological effects of radiation, both of visible and of near visible ultraviolet described later, these provisions indicate a substantial growth in radiometric expectation. This will evolve into support service requests in the next few years.

Finally, the Occupational Safety and Health Act of 1970, Public Law 91-596 notes that "occupational health standards present problems often different from those involved in occupational safety". The Secretary of Labor is responsible for assuring that "no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life". Provision is made for complaint by any employee and subsequent investigation by Labor. "The United States district courts . . . have jurisdiction, upon petition of the Secretary to restrain any conditions or practices . . . If the Secretary arbitrarily or capriciously fails to seek relief under this section, any employee who may be injured by reason of such failure . . . might bring an action against the Secretary". Initiative is thus in the hand of the general public as well as in the Federal Government. Penalties are also prescribed.

Action may come more quickly than expected in this growing area of biological interaction with radiation. The Secretary of HEW is empowered here also to "conduct . . . research . . . relating to innovative methods, techniques, and approaches for dealing with occupational safety and health problems". The National Institute for Occupational Safety and Health is created by this act "to develop and establish recommended occupational safety and health standards". The Secretary is empowered to "develop and maintain an effective program of collection compilation, and analysis of occupational safety and health statistics", a provision which could place very great burden on radiometric capabilities. One initial effect of this legislation is already apparent in requests from NIOSH for calibration [21].

In addition, NBS as an employer will be expected to "establish and maintain an effective and comprehensive safety and health program".

If the anticipated connection between radiometry and medicine is shown to be as close as present experiments suggest, the indirect statutory obligation that NBS is acquiring will strain the present capability for measurement far beyond its design performance.

Measurements now made with primary concern for great reliability do not lend themselves readily to massive, inexpensive repetition and extension.

(2) Secondary Calibration Laboratory Support

The NBS has not been able to meet all or even most requests for calibration and other technical assistance. Commercial calibration laboratories have been founded to fill the gap. But the performance of these laboratories has not met the requirements of the marketplace. Discrepancies are common [6]. This whole small industry must depend on NBS not only to stay in business but to provide more consistent service. Some sort of direct NBS assistance will be called for. This aid will probably take the form of measurement intercomparison and the dissemination of techniques. NBS will also have to be prepared for a formal request for the establishment of an accreditation procedure [22].

3.2 Technological Issues

Although the recent rapid growth of electro-optics technology was illustrated by a few examples in Section 2, the specifically technical implications of this development should now be examined in more detail. The public interest and finally the commercial implications of this technology will then be examined.

a. New Lamps

In the traditional lamp industry two types of lamps are replacing incandescent lamps: fluorescent lamps for inside use and high intensity discharge lamps for outside use. Fluorescent lamp measurement is not new. Nevertheless, except under special circumstances that cannot economically be extended, the level of measurement agreement among lamp companies, 5-22%, is presently intolerable [23]. High intensity discharge lamps are so much more difficult that NBS is not in a position to measure them at all.

One source of this difficulty lies in the greatly differing spectral distribution of discharge lamps both from each other and from incandescent lamps. Typical spectral power distributions were illustrated in Plate 1. The photometric system had performed barely satisfactorily for incandescent lamps, whose spectral distribution could be roughly matched with one another by adjustment of the filament power. This flexibility is no longer possible for discharge lamps. In addition, differences in shapes and in sensitivity to operating temperature sensitivity, as well as other factors, also cause fluorescent lamps to strain the traditional photometric system [8]. The resulting disagreement is an order of magnitude larger for fluorescent lamps than that for incandescent lamps [23]. High intensity discharge lamps, whose spectra consists largely of spectral lines, now strain the system to the point that routine measurements have not even been attempted at NBS. The difficulty arises here primarily because of the dominant spectral lines and high levels. So many different lamp types are now on the market [8] that a full set of direct substitution standards is no longer feasible.

The higher UV output of these lamps is an additional new factor in their measurement. Moreover the potential public health influence of this output, as described later, is expected to lead to increasingly tight Federal regulation, either under the legislation just described or by new laws.

Light emitting diodes present problems similar in character to those of the high intensity discharge lamps: spectral distribution and level. The level involved here, however, is not higher but lower than normal [3-7; app. A]. As noted before, these diodes promise to replace all low level signal lights, a potentially very great usage.

b. New Detectors

Until recently most light detectors have been so unstable both in spectral sensitivity and in total response that they could be used only as comparative devices. That is, they could compare reliably only similar sources. Moreover, measurements had to be made in rapid succession. With many new types of detectors these limitations are now becoming less confining however. The spectral sensitivity of new solid state detectors is now sufficiently stable to make worthwhile reliable measurement with accuracy and precision [7,9]. Silicon diodes are being widely used in the visible and near infrared. A wide variety of new diodes is being used throughout the infrared, where technology is moving very rapidly. New vacuum diodes and multipliers with photocathodes of III - V compounds such as galium arsenide are highly sensitive and display a relatively flat spectral response in the visible, an exciting development [10].

This new technology presents new demands on NBS for characterization and measurement. But these developments also provide new opportunities for new technical solutions to radiometric problems.

c. New Instrumentation

Optical instrumentation is also developing very rapidly. Beyond the obvious problems associated with the fidelity of color TV as presently produced, for example, new technology for TV picture reproduction is on the horizon and will require new techniques. Liquid crystals are one promising approach [19]. Thin film electroluminescent surfaces are another [24]. The development of low level imaging tubes has outstripped the ability to measure their gain accurately. A measurement capability is now desirable; it will become necessary [25-26]. Recent developments in the film and camera technology are leading to requirements for 1% measurements [27], and new radiometric standards [2,18,28].

With recent technical advances, then, better standards are indeed required to support continued technical growth [2]. Recent developments in all of these fields also make possible new solutions to radiometric problems, but their effective utilization will require a major new effort.

3.3 Public Issues

a. Public Health

(1) Phototherapy

The relationship of radiometry to health has been noted by George Zissis, Chairman of the NAS-NRC Radiometry and Photometry Evaluation Panel [29]. A review of a number of biological effects of lighting has appeared in the MIT Reports on Research for April 1970 [30]. The jaundice that occurs in 10-20% of premature infants [31], if allowed to persist, can cause permanent neurological brain damage [32]. It is treated now by phototherapy [33]. The herpes virus infections that cause cold sores and the genital area infections that often precede cancer of the cervix are also responding to such treatment [34]. Another direct effect of light is seen in calcium absorption in elderly men. The amount of absorption has been shown to be a function of the lighting environment [35-36].

Indirect effects are also observed. A number of neuroendocrine functions both by humans and animals have been shown to be so controlled. For example, the effect of illumination level and duration on gonadal size has been shown [37-39]. The working ability of school children has been shown to be affected by the spectral distribution of room illumination [40].

Wurtman and Neer have editorialized in the New England Journal of Medicine: "perhaps it is not too early to suggest than an appropriate Federal body give thought to the ultimate necessity of regulating the spectral composition of commercially available light sources . . . It seems safe to state that, whether we like it or not, light is another thing that physicians must worry about" [41].

NBS now has no geometrically total flux standards or techniques in the spectral region probably of greatest importance in biological activity 200-400 nm.

(2) Clinical Analysis

A separate medical issue is the increasing interest in spectrofluorescence as a new tool in clinical analysis. Professor G. A. Crosby stated in a recent symposium at NBS that he had received over 500 requests for a recent unquantitative article of his on quantum yields in fluorescence. Most of these requests were from hospitals, with which he had had virtually no previous contact. The development of this promising chemical analysis field, in contrast to transmittance or reflectance measurements, will depend on accurate radiometric standards.

The Task Group for Industrial Activity of the National Academy of Engineering feels that: "Standards for and acceptance of uniform clinical evaluation procedures required for successful development and marketing of biomedical products have not been achieved [42].

b. Public Safety

Three general areas of increasing importance will depend on new capability in radiometry.

(1) Atmospheric Transmission of Ultraviolet Light

"It has been suggested that the emission of oxides of nitrogen and possibly water vapor [by the SST] may reduce the ozone content of the stratosphere. Since ozone plays a vital role in screening undesirable ultraviolet radiation from the sun, any significant reduction in ozone is viewed with concern. Indeed, several alarming estimates of increased skin cancer have already been made public" [43]. Accurate measurement of this radiation thus assumes great importance.

(2) Biomedical Engineering

The regulation of germicidal, sun, and ozone-producing lamps under the Federal Hazardous Substances Act has been noted above. In addition, the Task Group for Industrial Activity of the National Academy of Engineering has listed a number of questions that imply a strong probability for future governmental activity involving radiometry. This Group notes that "the question of medical device safety and efficacy has been repeatedly posed. The high possibility of device safety legislation being passed in the near future . . . causes industry to be very concerned about this topic. That an appropriate type of governmental regulation and control is needed is not challenged by responsible industrial leaders . . . The Task Group recognizes these valid concerns of industry. Because of the critical nature of many products in direct contact with the patient or used in the diagnosis of diseases, however, there must be greater assurances than that currently available that adequate protection is given to persons exposed directly or indirectly to biomedical products or services . . . There is an urgent need to develop a rational program that includes procedures for the development of standards" [42].

Not only the National Academy of Engineering but, at the operational level, secondary calibration laboratories are already feeling the pressure of biomedical problems [7].

(3) Transportation

The increasing public concern for safety in transportation and particularly for highway safety has led to the transfer of safety monitoring from the states to the Federal Government.

This transfer is leading to the instigation of new highway lighting research and to new regulation, e.g. for headlights [44]. These will replace the flexible Society of Automotive Engineers (SAE) agreements. At one research institute research is in progress on optimum automobile illumination, both for a driver's own car and for those he meets on a highway. These measurements are being taken with a single instrument and without reference to NBS standards. Thus equipment made to comply with the new Federal regulation based on these experiments may not duplicate the optimum lighting conditions actually found.

This particular issue is an example of a requirement for photometric standardization that is not recognized as a problem even by those responsible for it. More generally, this is an important aspect of the increasing Federal activity in regulation. Those with new measurement responsibility do not always recognize the severity and complexity of the measurement and standardization problems. Without NBS cognizance, new regulations can be written that bear very little resemblance to the research data on which they are in principle based. Such regulations could be a danger to public safety, not its protector. Surely, if the potential hazards were not severe, no regulation would have been required in the first place.

The shift in responsibility from the SAE to a Federal agency implies two future trends. It foretells a tightening of the specifications. It also will mean the first monitoring for conformance of production to specifications. Partially in response to this movement, industry is developing new photometric capability [45]. This capability will create new demands for measurement.

As noted in Section 2 photometric problems in transportation have been aggravated not only by regulation, but also by the new technology itself. One example is the development of new red plastic signal light covers that differ substantially in character (spectral transmission) from the former glass covers. This difference makes obsolete the formerly satisfactory techniques of color monitoring used when only one type was available. To support this new safety-related technology, far more sophisticated techniques will be required [16].

Low level signal lighting measurements are related to other widely recognized safety problems. One consequence of such problems is the expensive rejection of a major fraction of signal panels for aircraft cockpits because these parts fail to conform to present tolerances [46], tolerances that are believed to cause difficulty in aircraft guidance. Dark adaption of the pilot must be protected so that he can see external objects; he must also see the inside panels distinctly.

c. The Energy Crisis

The rapid and increasing growth in the use of energy in this country is now front page news [47]. It has also been well documented [48-50]. Our per capita rate of consumption of energy is increasing at a time when the availability of sources of power is becoming questionable [51]. The Chairman of the Atomic Energy Commission has predicted the probable eventual rationing of electricity [47]. The efficiency of utilization of available power is thus now a matter of great importance.

Approximately one quarter of our electricity consumption is used for lighting [51]. It is here that precise light measurement becomes significant. The efficiency of lighting has increased from 15 lumens per input watt for standard incandescent lamps to 50 lumens per watt for early fluorescent lamps to 75 lumens per watt for typical modern fluorescent lamps and more than 100 lumens per watt for the most efficient "high intensity discharge" lamps. Some of this progress has occurred in steps, with the introduction of new lmap types. But the 50% increase in efficiency of fluorescent lamps and advancement in other lamp types has occurred in small steps over a long period of time [52-53]. The technical ability to evaluate such improvement depends strongly on the stability of reference standards. Not only an industrial standard is involved. Stability is required in all standards to which reference is made.

In addition to the necessity to detect reliably small increases in luminous flux, the absolute total luminous flux of different new types of lamps must now be intercompared on a common basis if the superiority of advanced types is to be demonstrated reliably. This capability does not now exist. The issue here is not narrowly commercial, although it has commercial implications that will be examined later. The strong balance of payments implications of improved lighting efficiency will also be explored later.

d. Meteorology

Meteorology [29] is more limited by present radiometric capability than probably any other technical field. Conversely, it can make proportionally great progress with better radiometric measurements. Radiometric information with an accuracy of 1%, but with a long-term precision for the detection of changes of 0.1%, is being requested. Both of these requests are now beyond the state of the art [13] although not beyond achievement within a modest period of time given the appropriate determination to do so.

Ten percent discrepancies are apparent, for example, between Japanese and American atmospheric profile measurements [54]. Such discrepancies and the even more serious lack of global data have caused the World Meteorology Organization to take action [55]. New international attention through the Global Atmospheric Radiometric Program (GARP) has been focused on the physical collection of the proper amount and distribution of data now unavailable.

Even within the U.S. serious discrepancies in data from the pyranometric network remain [56-58]. The projected requirements can be achieved only by very few institutions such as NBS with a proper variety of technical resources to make the necessary progress.

Three areas of meteorology will be affected by improved radiometric capability. First, short-term weather forecasting depends on radiometry for atmospheric temperature profiles and indirectly to check mathematical models of the atmosphere. The validity of a short-term forecast depends on the sophistication of the mathematical model used and also on the reliability of the measured temperature profiles of the atmosphere. That is, the more accurately the temperature distribution is measured, the more accurately the local weather can be predicted [58]. Such measurements were not feasible on a broad enough scale to make a substantial impact before the advent of weather satellites. But these satellites present revolutionary opportunities for large scale sophisticated measurements such as the temperature profiles. These measurements in turn will lead to more reliable models. Before this promise is realized, however, new technical problems will have to be solved. Calibration in flight will have to be consistent with ground-based observation. Accuracy is involved here and not mere stability or precision.

In contrast to short-term weather forecasting, long-term weather projection depends on the global heat balance, i.e. the amount of heat incident on, absorbed by, and radiated from the earth. It is the heat absorbed by the atmosphere that "drives" the weather. Thus measurements by satellites must be accurately correlated with ground observations to provide a meaningful measurement. Long-term drifts cannot be tolerated.

An issue closely related to natural long-term heat balance changes is the influence of pollutants. To detect such an influence, reproducible measurements over a period of years are required. Time is running out for the initiation of such measurements. This question is critical at the 0.1% level because of the lead time for effects to become manifest. Time is required also for controls to be instituted.

NBS has completed the initial phase of work applicable to this goal. However, much more remains to be done. The value of this work has been noted by Robert White of NOAA [55].

e. Pollution Monitoring

The field of pollution is so large and moreover so rapidly changing that a quantitative definition of future requirements is much more difficult than in other fields. Nevertheless, the potential payoff for a development of radiometry here is so great that it is worthwhile to examine [29,59]. Although interrelated, air and water pollution may be separated here for this analysis.

Air pollution at the top of the atmosphere has been indicated to be of significance because of its potential for long-range climate modification [60]. In addition, pollution introduced at the bottom of the atmosphere may have a short-range immediate effect, both in space and in time. Although work in this field is just beginning, crude radiometric and photometric techniques are already being used [61]. These will have to be made more precise and accurate. They will have to be placed on a continuing basis and provision made for rapid response levels that suddenly become hazardous. Such an evolution is technically possible. Pollution experiments on aerosol monitoring are already taking place in Boulder in a joint NOAA-NCAR effort [62].

The influence on the upper atmosphere chemistry of potential supersonic transportation was examined by Harold Johnston recently [63]. The implications of the changes produced in transmitted solar energy on life were so great [43] that a National Academy of Sciences panel was convened to examine the subject. This panel observed that "the importance of obtaining base line data [of the solar ultraviolet flux] in advance of any era of substantial pollution needs to be strongly emphasized" [64]. The technological challenge to radiometry both quantitatively and qualitatively is enormous. Primary work in this area is now being proposed by NOAA. NBS has been asked to be of assistance: "NBS calibration assistance is vital to a successful endeavor" [43].

Water pollution is another large area of concern. Thermal pollution particularly is susceptible to radiometric monitoring [6,51,65], but the challenge is increased by relatively high levels of atmospheric humidity. Other types of pollution are also susceptible to monitoring [66] through their characteristic spectra. The opportunity that space observation offers in this area is large. The corresponding challenges to radiometry will be great.

f. Remote Sensing

The field of remote sensing is a technological tool applicable to a wide variety of ultimate social uses. Some of these were covered in the preceding sections on meteorology and pollution monitoring. Remote sensing involving optical radiation promises to transform these fields. In addition, however, other uses are also foreseen [29]. These potential applications are collectively so important that the Panel on Science and Technology held a review of this field in January 1972 before the House Committee on Science and Astronautics. The paper of Thiel and C. D. Graves prepared for this Congressional review is included here [67]. Thiel and Graves note that by the most conservative calculation the benefit from remote sensing will be $59 billion. About half of this will accrue to agriculture in stress analysis, meaning for example, crop disease, infestation, and meteorological influences on agriculture. The other half is distributed among human disease, agricultrual inventory, fishing, animal disease, natural disaster, solid waste disposal, resource management, mapping, tax assessment, search and rescue, geophysics, water pollution, forestry, nautical charting, ship routing, and air pollution. The savings in the last field at $1 million are the smallest of those mentioned.

Performance specifications of current NASA earth resources observational components have not been determined by the quality of the data that would be effectively utilized by these various fields, however. It is limited by the necessary constraints placed by the state of the art of radiation measurement [68]. This is a case in which the limitations presented by the state of the art are indeed costing a substantial, but as yet undetermined, amount.

The launching of the first Earth Resources Technology Satellites (ERTS) this spring will provide the second NASA earth observation system. The data produced by the first system, the "Michigan Scanner", will then be comparable directly with other NASA data for the first time [69]. Initial comparison will present an interesting test of the degree of correlation of remote sensing data produced by equipment that has seen minimal laboratory calibration.

The specific limitations of this data for use by the Department of Interior and the Department of Agriculture will probably become evident only after several such platforms are in operation. Private concerns operating from airplanes over a long period of time are already suffering from the lack of standards and have requested general assistance from NBS [66].

This field is still in its infancy. Its growth is widely believed to be hindered by its ability to demonstrate economic accomplishment. This in turn is very likely limited by the performance of the systems themselves. These in turn are limited by the state of the art of practical radiation measurement [68].

One of the most promising techniques in much of the accessible spectral region, the infrared, is Fourier spectroscopy. The application of this technique to remote sensing is probably only a question of time. Development of this field presents an opportunity for NBS to work at measurement frontiers of immediate utility.

g. Crime Prevention

The issue of crime is relatively straightforward: there seems to be a direct correlation between effect of street lighting and the incidence of crime [70]. A variety of statistics indicate that crime has decreased 30-40% in streets where new more intense street lights have been installed. The new highly efficient lamps are of a type that NBS is not now able to measure reliably. Inauguration of manufacture of these lamps by several companies produces commercial incentives for measurements as well as the social and technical ones.

h. Botany

The small, but presently growing interest among botanists in the influence of light parallels the growing interest of the medical profession and photobiologists [71]. This new interest in the influence of light on plant growth will indirectly create a demand, not only for new lamps and their measurement, but also for simple but reliable spectroradiometers and their calibration.

3.4 Economic Issues

The economic issues that derive from optical radiation measurement are first of all questions of productivity: unit cost, quality control, product improvement, and product innovation. These, however, in turn bear also on equity in domestic trade in a manner that affects the consumer's ability to make intelligent choices. Foreign trade and the balance of payments also will be strongly affected.

a. Unit Production Cost

Unit production cost is a basic industrial concern. Indeed this issue probably more than any other is immediately responsible for the great industrial concern recently for improved optical radiation measurement. A lamp industry technological forecast notes: "Growth stimuli in the market will include . . . improved lighting economics" [72]. A product testing group is currently looking at its own program activity within the framework of the widely disseminated internal slogan, "Best Buy Our No. 1 Goal" [73]. The lamp industry in fact sells efficiency, as illustrated 22 February 1972 in the Wall Street Journal [74]. Such a marketing approach is demonstrably not in vain. Special 96" fluorescent lamps with a 10% greater efficiency than normal production for one manufacturer are sold by him for an approximately 10% higher price than that for his conventional lamps.

Productivity or efficiency, in turn, is greatly affected by present measurement techniques. In general, insufficient and discrepant measurements may add hours to a given measurement [4]. The absence of confidence between the lamp industry and other producers who incorporate lamps into their own products is now so pronounced that a number of these lamp-buying producers are installing new acceptance testing laboratories at great expense. This expense is, of course, paid indirectly by the purchaser of the end product [76]. Moreover, this solution has aggravated another problem in efficiency: the maintenance of several different unit sizes. For example, a Kodak lumen may differ from a Xerox lumen [8]. Both must be maintained by suppliers at added expense. In addition, purchasers of lamps will pay indirectly for the extra costs of a supplier whose production is rejected by another purchaser. A similar problem of even greater magnitude is that faced by LED manufacturers in their rapid growth stage [4,6]. The LED problem is part of a more general low-level problem [app. C]. Productivity problems traceable to measurement are being faced by the laser industry as well. Photodetector production costs also depend on measurements [6,18]. In addition the cost of complete radiometers, a growing industry, is being affected by current measurement problems [app. A].

b. Quality Control

An issue closely related to unit product cost is quality control. Some of the major components of the electro-optics industry both individually and together have testified that present quality control in the industry is being affected by the state of optical radiation measurement. The photographic industry is being adversely affected [14,18; app. A]. The laser industry is also affected [77].

c. Product Improvement

Reference has already been made in the section on the energy crisis to the fact that improvement in the efficiency of lamps has come in small steps [52,53]. It was shown in that section that improved capability in measurement is of great significance here and bears directly on improvement throughout the industry. Improvement in radiation measurement techniques will also influence photodetector development [10].

d. Innovation

The rapid growth of the electro-optics industry described in Section 3 is based primarily on innovation. But in addition to the technical implications of this growth already discussed, the commercial value of innovation should be noted also. This value determines commercial consequences of the related measurement problems. The rapid growth and commercial promise in light emitting diodes, for example, has been cited [3-5; app. A]. The influence of measurement on the commercial development of the rapidly innovating infrared industry has been noted [6]. The connection between innovation and measurement precision in the photographic industry, particularly in connection with camera automation, has been noted in conversations between NBS and the Physikalisch Technische Bundesanstalt [78]. The commercial importance of new discharge lamps has been observed [74] as well as of new detectors [10].

e. Equity in Trade

Equity in trade, a dominant issue with those who turn to NBS for assistance in optical radiation measurement, involves three separate factors.

(1) The Consumer's Concern with Technical Data

The consumer can be the "little old lady" comparison-shopping in the supermarket, the "commercial and industrial" purchaser, or the "original equipment manufacturer" [8]. These last two groups account for 60% of the market in the lamp industry. They are exceedingly cost-conscious. The consumer, primarily large but also small, currently has technical problems of three types derived from measurements. He has problems of equipment compatibility. He has the efficiency problem of dealing with various manufacturers employing discrepant units [8; app. D, app. E]. In addition, he sometimes needs to compare a commercially derived number with a natural or more purely scientific one. An example is a comparison of artificial illumination with natural light [5]. Commercial optical radiation measurement must be more firmly based than at present to be comparable with other measurements. Measurement problems are particularly severe in the ultraviolet.

(2) Government Purchasing

GSA purchasing of light bulbs is of importance not only to economy in government. Government purchasing is substantial enough to affect the lamp industries themselves [52]. The leverage that it exerts affects the entire market, particularly the purchases of other governmental agencies, state and local governments.

(3) An Orderly Market

The issue of an orderly market in lamps, photodetectors, or other instruments is different from that in a government regulated market such as gas-flow or electrical-power meters. With the diversity of the electro-optics industry, an important question is, "are competing values comparable?" Manufacturers both large and small in the lamp industry feel that they are not [8,52]. Rather than seeing a potential commercial hazard in new measurement capability, the industry is looking to NBS for assistance [app. E].

This remarkable industry interest in greater activity by the NBS in part stems from actual experience in that the lamp companies have had, in some cases, to derive independently their own luminous flux assignments. The result on the market is deplored by all concerned.

With the development of new high intensity discharge lamps, the absence both of NBS standards and of accepted procedures necessarily lead to a separate discharge lamp lumen for each manufacturer.

The thrust of industry concern here is not: U.S. Government, stay away; but rather, NBS please help! [app. E].

f. The Balance of Payments

The present adverse balance of payments is widely recognized. Secretary Stans pointed out in his testimony before the Subcommittee on Science on 27 July 1971: "The major element which we can influence decisively for the long run is the level of technological development. It may be our only hope of maintaining a future trade position adequate to support our balance of trade payments in years to come" [79].

But the Secretary noted also: "From 1950-1965 our productivity growth rate trailed Europe by 35% and Japan by 60%. The trend since 1965 shows an even more rapid relative decline: United States rates trailed Europe by 60% and Japan by 84%" [79].

The high technology electro-optics industry is growing very rapidly in this country and abroad [1]. As demonstrated above, American productivity is affected by measurement capability through unit product cost, quality control, product improvement, and innovation.

The instrumentation industry as a whole is concerned with foreign trade expansion. "There will certainly be an unfavorable foreign trade impact if electro-optical devices of U.S. manufacture cannot be relied upon to yield uniform NBS traceable quantities. The cost impact in this area can easily run into millions of dollars" [4]. A working group of the Council for Optical Radiation Measurement has also noted: "discrepancies on an international basis, which have occurred, result in lost sales and decreased exports" [app. A].

The light detector industry is also involved. "We expect . . . to measurably enhance our position in both domestic and foreign markets. The latter is an area where our competitors, largely nondomestic, have made serious inroads . . . Recent developments in the international monetary scheme are a great assist, also, and your efforts in resolving the problems outlined above will help solidify our international position of leadership" [10].

A working group of the Council for Optical Radiation Measurement notes "the lack of standardization of calibration methods and standards among manufacturers and users of light emitting diodes and displays". It cites as an important concern the "very large market domestically and internationally" [app. A].

The photographic industry is likewise concerned: "Lamps are calibrated for our associated companies throughout the world" [80]. "International trade depends on the worldwide acceptability of such measurement" [14].

The working group on total flux measurement of the Council for Optical Radiation Measurement with representatives of the lamp industry notes that "many purchases are made on the basis of promised performance. A difference of one or more percentage points in promised performance will, therefore, determine the business to be done, either domestic or foreign, by a given manufacturer or even by an industry. This can run into millions of dollars" [app. E].

"One company in the lamp industry, at least, has run into the fact that their lumen levels, for some, if not all lamp types, are different by several percent as compared to this country. Sales of our industry off-shore have been slowed down because the European lamp manufacturers are talking loudly about the inflated lumen level of the United States products. Under such conditions, especially in a competitive business, it is very difficult to grow much of a market at least in Europe where a considerable effort has been expended" [8]. "If we are to export lamps, our foreign customers must again know that Boston lumens are the same as Paris, London, Tokyo, or Istanbul lumens" [52].

The lamp industry is sufficiently concerned enough about international measurement agreement as it expands its markets abroad to be sending its measurement people abroad after its sales ads [81-82].

3.5 Scientific Issues

a. An Opportunity

The rapid technological development already described leads to scientific opportunities that did not previously exist. The promise of Fourier spectroscopy, for example, has only begun to be realized in science as a whole. It has not yet been applied to quantitative radiometric measurement of scientific interest. It is much faster, more sensitive, and less noisy than other techniques. It also averages entire spectra simultaneously, a great advantage in drifting and fluctuating systems.

Every object radiates: this is useful information for material characterization, always about the state of the surface and usually about the internal state of the systems as well. The opportunity to acquire and evaluate this knowledge rapidly and with much less noise than previously will permit realization of new opportunities. If it is to be exploited fully for material characterization it must be evaluated quantitatively. Remote sensing of the earth is one area of immediate application.

b. "One-shot" Experiments

One area of opportunity to which radiometry is of great importance because few other tools exist is astronomy. This field has been transformed by the utilization of satellites outside the earth's atmosphere. But calibration problems have been intensified. Satellite measurements made by the Smithsonian Observatory differ by a factor of three from those made by the Naval Research Laboratory [83]. Evaluation of the solar and other stellar spectra in the UV will be held up until such uncertainties are clarified. Large amounts of money are already being spent on such programs and the scientific payoff will be far greater, with relatively little increase in cost, with more sophisticated radiometry.

c. Atomic Physics

In addition to the new spectacular space spectroscopy, cross section data in atomic physics is still being limited by the accuracy of radiometry [84]. Relatively large amounts of time are now being spent on reducing the uncertainties in radiometric measurement to the level of other limiting parameters in these measurements.

Conventional astronomy and earth-bound stellar astrophysics are sufficiently concerned about the status of radiometry that a recent symposium on astronomy devoted nearly one quarter of its time to a review of recent developments in radiometry [85]. This concern reflects both the limiting nature of the present state of the art and great interest in its advancement.

4. ALTERNATE SOLUTIONS

These are the impact areas of optical radiation measurement and some of its implications. The question now is, "Why not leave the solutions to those who are most affected?" There are both technical and nontechnical reasons for not doing so.

4.1 Technical Factors

Each radiometric measurement is extremely complex. There are in fact, four sets of parameters to be controlled or evaluated: spectral, spatial, temporal, and polarization. To understand and control these four parameters the radiometrist must be highly trained in optics and heat transfer. He must also be experienced in these and other fields. An exhaustive examination of each of these parameters even by an expert is expensive and time-consuming. At some point, of course, even the most careful worker must make a compromise. If this compromise does not occur in the initial measurements then it will reduce either repetition or the systematic variation of all parameters. But even the simplest measurement requires intelligent compromise. The technical difficulty is further complicated by the lack of commercial instruments available to evaluate many parameters. Ultimately the development of technology in this area will make a new generation of instruments possible.

A large investment in time and effort is thus now required in order to make independent measurements that are reliable and comparable with other independent measurements at the 1-10% level. For example, one must select and characterize his detector for these four parameters. He must select and characterize his electronics. He must select and characterize his sources and then his optical system. Since generally accepted techniques and highly accurate commercial equipment is rarely available, he must usually develop or evaluate these himself. Moreover, he will also have to attenuate either the beam to be measured or that from a standard; his attenuation techniques will have to be characterized as well.

In short, the independent worker is left to work without any comprehensive assistance either in equipment or techniques. The independent development of comprehensive expertise in every laboratory making photometric and radiometric measurements is an impossibility for most companies in this industry. It is an uneconomic solution even for the large ones.

4.2 Nontechnical Factors

Large companies are not reluctant to spend considerable sums in the optical standards area. Indeed they are doing so through automation in this field. But they are not making so much of an investment in technical development. -- Why?

Being right is not enough in the highly competitive field of optical radiation measurement. The really important question is, "Does my measurement agree with another institution's?" If I am selling, "Does it agree with that of the purchaser?" If I am buying, "Does it agree with that of the seller?" If I am being regulated, "Does it agree with that of the regulatory agency?" In a bilateral situation, agreement based on an adjustment can generally be made. But the typical market and its regulation involves many different agencies.

The development of a complex system of bilateral agreements among companies to enable them to deal with the real market situation has been forced, but it is uneconomical. It is uneconomical in terms of the number of measurements required. It is uneconomical in the maintenance required of separate units of varying size. It is uneconomical in the effort required for identification of sources of the differences in measurements. The cost even of rejected purchases is borne by other purchasers who come along later. It is uneconomical in productivity. The international consequences of this reduced productivity are both more evident and more severe than the domestic ones.

There is also the legal question. In all photometry and in all radiometric areas contingent on Federal activity, the basic legal question is not, "Is it right?", but rather, "Does it agree with NBS?" This necessity for agreement means that norms must be selected and values adjusted to them. Particularly when a complex system of bilateral arrangements is illegal, industrial investment in expensive competence will not purchase legality.

Thus even the largest companies will not be inclined to make a major investment or expenditure where agreement with the next fellow is paramount.

4.3 Other Agencies

The coordination of other Federal Agencies with NBS is really a part of the preceding consideration -- agreeing with others. In photometry, legal measurement must always be coupled with NBS. But for radiometry in government purchasing and for regulation through HEW and DOL, an identification with NBS measurement is also highly desirable. In order to preserve Federal measurement credibility, it is essential that Federal agencies have coordinated measurement facilities. Without a proper NBS system, a GSA lumen or a DOT candela will necessarily come into existence.

4.4 Synopsis

To recapitulate, therefore, both technical complexity of optical radiation measurement and the need for comparability and interchangeability dictate a unified solution to the presently severe optical radiation measurement problems.

5. THE ROLE OF NBS

5.1 What Needs to be Done

A nationally centralized competence in optical radiation measurement is highly desirable for two purposes. First it would provide for the most economical solution to problems in the characterization of complex optical radiation components and systems. Secondly, it could also provide a framework for the achievement of uniformity in such measurements on a national basis.

a. The Characterization Required: Research

The research endeavor implicit in the foregoing review of the issues involves three separate problem areas: 1) source characterization, 2) detector characterization, and 3) the characterization of certain general problems in radiometric technique.

The first two problem areas involve the following separate steps:

(a) Realization of a scale

(b) Transfer of the scale to secondary standards

(c) Development of techniques for the extension of these standards to dissimilar measurement objects.

The output of the first two steps includes both hardware and software. That is, it includes the derivation and characterization of objects. It also includes the development of techniques. The output of the third step is almost exclusively software. This software is the description of new techniques associated not with the generation of standards but with their utilization for other purposes.

The third separate problem area focuses on the optics employed both with sources and with detectors. It includes general spectral techniques, diffraction, and attenuation.

(1) Source Characterization

(a) Realization of Scales

The realization of scales in both radiometry and photometry is widely recognized as basic to the NBS mission. In addition, new strong industry desire for the rigid coupling of photometry and radiometry is now evident [6-7,13,18,20].

(b) Transfer to Secondary Standards

(i) Characterization of Present Standards

"Firm uncertainty information is extremely important to us" [11]. "The necessity to provide an estimate of the precision/accuracy/uncertainty for both color temperature and luminous intensity of the individual stages of calibrations as well as an accumulative value" has been considered to be paramount [80; cf. 13]. Once the size of the present uncertainties is recognized in these and other areas, requests follow for a reduction in size.

(ii) Improvement of Present Standards

In the few cases where the uncertainty is already established, the immediate requirement is for its reduction [10]. "The need is that of more accurate radiance and irradiance measurements. The need is for one percent or better standards" [18]. "There is a pressing need for increased accuracy in the N.B.S. maintained (and transferred) standards of spectral radiance and irradiance" [13]. "A standard of spectral irradiance accurate to 1 percent" is desirable [20].

(iii) Description of Procedures for Present Standards

A recent request of one of the working groups of the Council for Optical Radiation Measurement states a widely held desire for, "Provision by NBS of detailed, written description of the methods and techniques through which NBS calibrates standards of spectral radiance, spectral irradiance, luminous intensity, color temperature, etc." [app. F; cf. 13, 86].

Such descriptions are now being initiated by NBS where procedures are already established and preparation of the description is straightforward. However, when a change in standards or procedures is desirable, time spent in preparing detailed descriptions must be weighed against the benefit to be gained from a more immediate improvement of the standards instead.

New types of information are being requested explicitly. One is the influence of the environment on the measurement process [app. B]. A widespread desire [6,8,13,87] for help in the selection of lamps for calibration is evident. This request is particularly crucial with the phasing out of industrial standard lamps manufactured by the main U.S. supplier [7,18].

(c) Extension of Present Standards

The need for a general description of techniques and methods has been recognized: "Because of differences in methods of measurement, a standards handbook would give the basic setup for measurement of radiance and irradiance in the UV, visible, and I.R. range . . . A tutorial treatise should complement the handbook" [18]. Moreover, "NBS should take the steps necessary to provide easy access to existing written descriptions of techniques and methods" [app. F].

Extension in level is of great concern. Extension of irradiance to lower levels has been requested [7,86,88; app. A]. It is stimulated by the advent of light emitting diodes, the general increase in use of low level devices, and the increasing attraction of photon counting as an absolute standard. Conversely, higher intensities are increasingly important as Underwriters Laboratories begins writing specifications for lamps used in photography [15]. Optical system calibration is presenting similar requirements [20]. As lamps become more efficient higher total fluxes are also being generated and must be measured reliably by lamp manufacturers [5].

Extension to new spectral regions and improved standards at the present extremes have also been requested. Infrared is one area where progress is being made but new problems are anticipated. One example is "Extension of blackbody sources to operating temperatures down to 77 K (mainly for the purpose of calibrating detectors employed in the far infrared region)" [13]. "Many problems will develop that are not now recognized [in the infrared]" [6]. Extension of the range to 25 μm has been requested [app. B].

In the other direction, the importance of extending geometrically total flux measurements into the ultraviolet has been noted [5]. This desire will increase as the biological effects of this radiation become more widely recognized.

In addition to work in relatively uncharted spectral ranges, the measurement of light with a nonconventional spectral distribution is a rapidly increasing problem [7,20,87]. Sources with a spectrum similar to daylight have been requested by a working group of the Council for Optical Radiation Measurement [app. A]. Light emitting diode measurement problems are traceable to their new spectral distribution as well as to their low level. High intensity discharge lamps are breaking a total flux measurement system already strained by fluorescent lamps [8]. The problem of spectral lines as well as new measurements outside of the visible are involved. High priority has been requested for the development of spectroradiometric techniques [89].

In addition to the extension of present measurements in level and spectrum a spatial problem has arisen in the infrared. Extended sources need to be evaluated both theoretically and experimentally [app. B; 90].

And finally, the development of new source measurements in the time domain is being requested. Pulsed irradiance and illuminance measurements are required [7,20,87]. Total flux pulsed measurements are also required [app. A].

(2) Detector Characterization

Detectors can be usefully divided into three subgroups: electrically calibrated, thermal but nonelectrically calibrated, and quantum.

(a) Realization of the Scale: Electrically Calibrated Detectors

It is recognized that a series of electrically calibrated detectors is basic. Both because of their self calibration and because of their relative freedom from wavelength dependence they are essential to a detector characterization program [13; app. B, app. D].

(b) Thermal, Nonelectrically Calibrated Detectors

Dependence on many detectors as transfer devices has been hindered by the absence of reliable characterization techniques. An electrically calibrated detector can in principle be used not only as an absolute standard, but as a tool to characterize gray detectors for spectral response. Such a capability is badly needed both for conventional radiometry [6,11; app. A] and for laser measurement [app. G].

(c) Quantum Detectors

Quantum detectors have not yet reached sufficient development to qualify as absolute photon counters. In general they are not gray spectrally either. Nevertheless, the recent development particularly of solid state photodiodes has led to high stability and sensitivity that make them attractive as secondary standards. A new approach to photometric units, based as the units themselves are conceptually on an "idealized" detector approximating human visual response, is particularly attractive in principle. Characterization of promising new photometric detectors has been urged [87-88]. Characterization of spectral response is particularly desirable [7,13, app. D]. Temperature sensitivity is another area for attention [app. D]. The evaluation of linearity and performance at low levels is basic [app. D]. And finally, the examination of time response and utilization of detectors for pulsed measurements has been urged [app. D].

(3) Characterization of Certain General Problems

Finally, the evaluation of certain techniques used to make comparative measurements is highly desired. Attenuation techniques are requested very frequently [6-7; app. A, app. C]. Other optical system components that have become the foci of questions are the use of diffusers and integrating spheres in general [7].

A special very important area of general concern is the characterization of spectral techniques not only for spectral irradiance measurements [18] but particularly for use with flux measurements [5,89].

b. Dissemination and Verification

Until the standards and techniques developed by the research program have been applied not only to the internal generation of standards but also to the verification of measurements made in a variety of laboratories, the maximum benefit will not have been realized. A proper research program will lead to economical measurement. But the full practical utilization of this research program will become evident only after the compatibility of measurements has been actually demonstrated among users [11].

The Radiometric and Photometric Calibration Program has been greatly expanded, and twenty-five regularly scheduled calibrations are now routinely available to the public. In addition to the scheduled items, special calibrations are also available to satisfy special needs.

But "of equal importance is standardization of technique for transferring these standards from NBS to the user, regardless of whether an intermediary is used" [10]. Reliable transfer will involve a "method of supplying and checking secondary laboratories issuing standards and calibratee sources", in other words, a "method of specifying NBS traceability" [13]. Such desires almost certainly imply "Determination of suitable intercomparison techniques at the various laboratories, and evaluation of the issued product", that is, "Participation of issuing laboratories in intercomparison" [13]. "Another recommendation would be to periodically have round-robin measurement comparisons between laboratories" [app. C]. "When NBS is unable to provide full calibration services, they should provide some method of guaranteeing that commercial standards labs are providing measurements on the NBS scale . . . Small scale, simple interlaboratory intercomparisons utilizing NBS techniques . . . with NBS acting as referee, would be desirable . . . [app. F]. "Secondary standards laboratories will build detectors and participate inperiodic round-robin calibration exercises with NBS" [app. D].

5.2 Why NBS?

a. Fractionated Market

Two reasons for a centralized national competence in optical radiation measurement were stated in the previous section. The first of these was the diversified nature of the industry involved. Only very few of the companies in this market are large enough to fund the complex research and development required to make competent measurements in this field. The Director has suggested that NBS might "explore ways of aggregating the research and development capabilities of many companies vying for a fractionated market" [91]. Another aspect of such problems in infrared has been described: "In the component area, the documentation procured during the development contract is frequently inadequate to support the procurement of spares later" [12].

b. Agreement Rather than Accuracy

The second issue addressed in the previous section is the need for agreement of measurements in various laboratories. Since being right is less immediately important than agreeing with the fellow with whom one is doing business, a centralized focus for achieving this end has been widely requested.

c. NBS Mission

In addition to these issues which point merely to the designation of the single national laboratory, certain aspects of the Bureau's mission and program lead specifically to its desirability as the proper national laboratory.

The first of these is the statutory obligation of NBS covered in Section 3. The specific NBS obligation with respect to photometric units (visible light) was noted as an important addition to the more general mission cited in the Organic Act. Indirect statutory obligation was also anticipated through increased reliance on optical radiation measurement by other Federal agencies.

In addition, however, other aspects of the general NBS mission, apart from its standards function, are increasingly the focus of attention. The specific impact of strengthening the photon measurement capability on a variety of public issues was covered in Section 2. Most of these bear directly on the overall NBS goal "to strengthen and advance the Nation's Science and Technology and to facilitate their effective application for public benefit" [92].

More specifically, improvement in optical radiation measurement bears directly on the various subdividions of this goal. The general necessity for "promotion of accurate, meaningful, and compatible scientific measurement" has been demonstrated by the number of requests for improvement in the agreement of optical radiation measurements reviewed in the previous sections and included in virtually every letter in the Appendices. Moreover "the more effective use of science and technology" has been called for implicitly both in these letters and in the working group reports of the Council for Optical Radiation Measurement. "The promotion of strength in the economy and equity for the buyer and seller in trade" [92] has been reviewed in detail in Section 3. The impact of such equity on foreign trade balance was noted specifically. This impact follows directly from several other factors that bear on domestic trade as well as in the entire electro-optics industry. "The provision of standards and test methods for protection of the public from specific hazards" is already important in view of the demonstrated effects of ultraviolet radiation and will grow in public concern as this field develops.

The "provision of technical information services" not only through the technical journals but through the new "Optical Radiation News" column of the NBS Technical News Bulletin has drawn a flood of requests for inclusion on the mailing list.

The growth of problems in optical radiation measurement that act as a "barrier to effective use of technology" has been cited by most recent industrial respondents. They are concerned with the application of optical technology both to problems of domestic impact and those of foreign trade. The influence of measurement on this rapidly growing high technology domestic industry is of recognized importance.

The "[promotion of] economic growth through product improvement and [the promotion of] equity in the market place" [29] have been cited in Section 3.3.

d. Past Accomplishment

Does NBS have the competence to perform the needed job?

Its accomplishment in this field is widely known. NBS is the only laboratory in the world that furnishes spectral radiance standards accurate to one percent. It is one of two laboratories that generates its own spectral irradiance laboratory standards. Indeed, many other national laboratories are dependent on these standards for their own work. NBS achievement in the development of electrically calibrated detectors has been widely recognized also [55].

There is abundant testimony to NBS competence: "the state-of-the-art measurements accuracies achievably by NBS" have been recognized [77]. "Ideally, highest echelon standards would be available from a completely objective, impartial source that enjoys the respect of the entire technical community: i.e. NBS" [88].

In addition to acknowledged radiometric competence, the recognized application of sophisticated statistical techniques by NBS permits maximum effective utilization of its technical expertise. "NBS application of sophisticated statistical techniques to the calibration of standards has been a welcome addition to its endeavors" [52], "the work reported in NBS Technical Note 559, 'Spectroradiometry and Conventional Photometry, An Interlaboratory Comparison' [is] a splendid start" [88].

e. Organizational Contacts

The position of NBS on international standards committees places it in the unique position to work for the solution of international problems that concern American industry in this technical area. Its reputation for accomplishment places it in a position moreover to exercise leadership that is very greatly needed internationally.

In addition, the close contact of NBS with DOD technical problems and solutions in this area puts it in a position to secure the application of relatively unknown work to new problems of nondefense interest. This opportunity will be of great importance in the application of IR technology, developed largely by DOD, to a growing civilian activity.

f. Industrial Desire for NBS Activity

In a period of wide industrial concern about the effect of Federal activity, it is clearly remarkable that industry is turning actively to NBS for assistance in research and development in this area: "We look to NBS" [77]. "A U.S. Government-operated laboratory is in the best position . . . and it would again seem that NBS has the best facility to do this work" [52]. "NBS should provide the national focus . . . Industry would much prefer to get this kind of help from NBS" [14].

The enthusiasm for NBS activity extends particularly to the desire for verification, the question of "traceability". NBS has been urged by industry even to inspect its commercial facilities periodically [4]. However, this is an area of expansion that will have to be closely examined before action is taken.

In still another area of its program, NBS has been urged to continue its activity to anticipate future needs: "It is imperative that NBS work with aerospace, medical, agricultural, and other industries to keep abreast of these problems as they occur" [6].

And finally, industry has "voted" with its feet. On 10 February 1972, sixty representatives of industry and government met at NBS to consult with one another and establish a a position for future action. They formed the Council for Optical Radiation Measurement to coordinate the definition of needs, to discuss alternative approaches, to coordinate technical projects, to ask NBS for assistance, and to coordinate activity with other organizations [93].

g. Future Savings

Another factor indicating the desirability for NBS to mount a comprehensive program now in optical radiation measurement is in the influence that this program will have ultimately on savings both in NBS expenditure and in costs to those served by the program. If the present partial gage system of interrelated standards were to be expanded to meet present needs, the impact on future budgets would be increasingly severe. A systematic approach leading to a general solution of measurement problems in this area by application of modern technology will ultimately lead to a more economic solution.

5.3 Present Program

In the absence of increased resources, the program at NBS for the next year or two will be devoted largely to realizing and improving the radiometric and photometric scales required. Only a few of the extensions and characterizations called for in Section 5.1 will be possible.

5.4 Other NBS Resources to be Applied

One resource available to NBS in the development of its program in this area not previously cited is the Optical Physics Division effort in the vacuum ultraviolet. Cross fertilization between these two programs is already taking place. In addition, the presence of a strong statistics competence has been noted; it is a highly valued additional resource. Without it, in fact, a viable program for traceability could not be effectively built.

5.5 Non-Monetary Support

Non-monetary support is present in the form of an industrial research accociate provided by the lamp industry through the Lamp Testing Engineers Conference via the Electrical Testing Laboratories. With the increased development of an NBS program in this area and the demonstration of its competence it is entirely possible that other components of the electro-optics industry will provide similar assistance.

In addition, several companies have already offered to perform parallel experiments and to check new procedures in their laboratories. The use of major equipment not available at NBS has also been offered.

6. RECAPITULATION

Serious measurement discrepancies universally plague quantitative measurement in the electro-optics industry.

These problems arise chiefly through the recent explosive expansion of this industry. It triples in dollar volume in a period of nine years. It now represents substantially more than $10 billion in annual sales.

This growth has precipitated a complex development in the variety and accuracy of measurements required. Virtually each measurement is thus a state-of-the-art study. The distress that the resulting disagreement costs the industry as a whole is growing rapidly. At the same time growth in public concerns that have a strong technical base in this industry are just beginning to find a focus for expression. Resulting governmental activity is undergoing a strong expansion.

The impact of these problems falls in many areas. One is the growth of Federal obligation. The levering on technical development by good measurements here has been acknowledged and documented. Public issues encompass public health, public safety, the energy crisis, meteorology, pollution, agriculture, crime prevention, and a variety of opportunities in connection with aerial surveillance. These latter promise savings of $59 billion in the most conservative estimate. The economic lever of improved measurement operates through unit production cost, quality control, product improvement, and innovation to equity in domestic trade and the balance of payments abroad. Basic scientists have a vocal stake in progress here too.

Leadership by NBS in this area is dictated not only by legal authorization. The fundamental problems are too complex to be tackled economically outside of a national laboratory. Moreover, the necessity for measurement agreement requires the assumption of responsibility by a central agency. The opportunity to lever a large market through technical advancement falls squarely within recent conception by NBS of its mission. NBS has the in-house expertise for the job and the required organizational contacts. The electro-optics industry with one voice is calling for NBS leadership.

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8. APPENDICES

Appendix A. Council for Optical Radiation Measurement: Summary of Comments of the Working Group on Classical Radiometry (III), prepared by Michael Mellon, Chairman.

Appendix B. Council for Optical Radiation Measurement: Summary of Comments of the Working Group on Infrared (IV), prepared by Russell Yokley, Secretary.

Appendix C. Council for Optical Radiation Measurement: Summary of Comments of the Working Group on Techniques including Spectrophotometry (VI), prepared by Jack Coulter, Chairman.

Appendix D. Council for Optical Radiation Measurement: Summary of Comments of the Working Group on Detectors, prepared by Richard Leftwich, Chairman.

Appendix E. Council for Optical Radiation Measurement: Summary of Comments of the Working Group on Geometrically Total Flux (I), prepared by Ernest H. Salter, Chairman.

Appendix F. Council for Optical Radiation Measurement: Summary of Comments of the Working Group on Dissemination (VII), prepared by Donald McSparron, Secretary.

Appendix G. Council for Optical Radiation Measurement: Summary of Comments of the Working Group on Laser Measurement (II), prepared by Howard Pinsky, Chairman.

8. Appendices

Appendix A

A. SCOPE OF DISCUSSION

The extent of the subject areas that could possibly be discussed by this Working Group is obviously extremely broad. For example, variables such as the following are inextricably linked together:

a. quantity of interest: irradiance, radiance, intensity, etc.
b. radiometric or photometric calibration standards needed?
c. specific spectral power distribution of source? Monochromatic or broadband?
d. spectral sensitivity of detector used?
e. spectral or total radiation calibration?
f. absolute power levels
g. time-independent or time-dependent (e.g. pulsed) quantity?
h. coherent or non-coherent?
i. accuracy, relative or absolute
j. repeatability (unit-to-unit)
k. methodology: supporting operational techniques/equipment instructions
l. importance and ramifications of work: effects on sales, profits, trade, jobs, etc.

Rather than attempt a full discussion of each of these factors in the very limited amount of time available for discussion on February 10, it was decided that each participating member summarize the problems most familiar to him from his own experience. Individual comments were, of necessity, limited to approximately 20 minutes. Written summaries of individual's comments on these and other topics were encouraged by NBS.

B. STATEMENT OF PROBLEM: Lack of NBS-traceable standards of spectral irradiance and radiance in the 90-250 nM (vacuum UV) spectral region.

PROPOSED SOLUTION: Development of such standards and associated measuring techniques. Need 5% accuracy and/or 2% relative (spectrally).

JUSTIFICATION/APPLICATION: (1) Radiation level measurements in spacecraft and stellar investigations. (2) environmental health studies (e.g. eye damage)

COMMITTEE CONTACT(S): Howard McDevitt, David Sliney

C. STATEMENT OF PROBLEM: Lack of daylight-spectrum sources, needed for applications in photographic film, TV and color-matching fields. Need sources with spectral power distribution matching daylight solar radiation, various CIE defined spectrums, several cm^2 in size and calibrated spectrally at 10 nM intervals from 350 to 700 nM.

PROPOSED SOLUTION: Development of such standards.

JUSTIFICATION/APPLICATION: The economic repercussions of poor quality control for example, in the above industries are clearly very pronounced, particularly when involving consumer markets. Estimated potential losses can be provided by committee contacts.

COMMITTEE CONTACTS: Richard Becherer, Polaroid
William Heaps, Macbeth

D. STATEMENT OF PROBLEM: Lack of availability of current types of lamps for calibration purposes.

PROPOSED SOLUTION:

COMMITTEE CONTACT: J. Gordon Hoffman

E. STATEMENT OF PROBLEM: Better standards and methods of measurement of luminous intensity (candela) of low color temperature are needed for current applications in, for example, aircraft visual display systems (cockpit lighting). Present lack of agreement among parties involved, users and manufacturers.

PROPOSED SOLUTIONS: Development and implementation of such standards.

JUSTIFICATION/APPLICATION: Safety, linked to readability of displays; consequent economic repercussions of disagreements.

COMMITTEE CONTACT: J. Gordon Hoffman

F. STATEMENT OF PROBLEM: Lack of adequate methods for very low illuminance (footcandles) measurement. Needed, for example, in measurements of low reflected power from retro-reflectors used for highway markings etc., which are illuminated by 1 footcandle indident power density and where the reflected radiation is measured at 100 foot ranges and levels are 10^{-6} footcandles. Reflected light is filtered (green, amber, red, etc.)

PROPOSED SOLUTION: Investigate and propose method and/or revision of existing standards of measurement.

JUSTIFICATION: Safety concerned with visibility of highway and other reflectors.

COMMITTEE CONTACT: Pablo Smester

G. STATEMENT OF PROBLEM: Lack of standardization of calibration methods and standards among manufacturers and users of light-emitting diodes and displays.

PROPOSED SOLUTION: A relatively comprehensive statement was made concerning the need for and the implementation of a specialized LED calibration system including standard sources, detectors, procedures, etc. Basic measurement units suggested are radiant intensity (watts/sr), irradiance (watts/cm^2) and radiance. Conversion to photometric units would be performed numerically using spectral radiometric data and photoptic/scotopric conversions. It was suggested that a re-examination of the CIE Standard Observer Curves be undertaken. The general statement was said to represent the consolidated viewpoint of many of the major manufacturers of LED's (perhaps all).

JUSTIFICATION: Typical standardization ramifications. Very large market, domestically and internationally.

COMMITTEE CONTACT: Joseph Horwath

H. STATEMENT OF PROBLEM: Inadequate methods of spectral/total radiometric and photometric measurement of pulsed-type sources such as Xenon flash lamps. Spectral output of these lamps changes as function of duty cycle, percluding extrapolation of CW calibrations. Extrapolation also difficult due to reciprocity failure of photographic films.

PROPOSED SOLUTION: Development and standardization of method and equipment.

JUSTIFICATION: Highly important to quality determination and control in photographic film industry. Also highly important to development and testing of visual warning and identification systems such as stribe lights on aircraft beacons, emergency vehicles, etc. where visibility and safety are prime concerns.

COMMITTEE CONTACT(S): Pablo Smester
Dick Becherer
William Heaps

I. STATEMENT OF PROBLEM: Difficulty of present situation in reliable calibration of laboratory radiometers. Generally speaking, it was felt that the radiometric calibration standards and services of NBS (speaking primarily of incandescent lamp standards) is presently inadequate from several standpoints.

First, there is a notable lack of information from NBS available on exactly what standards are available, precisely what their characteristics are, methods used to calibrate the standards at NBS and recommended operational procedures for their use.

Second, the estimated uncertainties of these standards are not well established either within the industry or apparently within NBS itself.

Third, there is a need for calibration standards of spectral irradiance beyond the present 0.25 to 2.5 micrometer range. In particular, sources other than tungsten-filament lamps are needed (e.g. low and medium temperature balckbody radiators.)

Fourth, it would be desirable to upgrade the accuracy of the present standards to permit better instrumentation accuracy in general.

Fifth, there is a specialized but very widespread need for calibration sources which can be readily used for the calibration of thermal type detectors and radiometers that are equipped with window materials such as fused quartz, KRS-5 etc. The nature of these devices requires such a window, for operation at low levels. The far IR spectral response may frequently not be known with any certainty. What is needed then, is a lamp-filter combination which exhibits a spectral power distribution which is fully included within the range of the window under consideration. The filter must be arranged to eliminate self-emission (i.e. at the detector temperature) which is the problem currently encountered with standards of irradiance, for example. That is, a significant portion of the total radiation is emitted by the envelope of the lamp and is located spectrally in the mid to far IR where the quartz (for example) window does not transmit. This is an immediate need.

JUSTIFICATION: Thermal type radiometers are universally used as calibration (transfer) devices in the field. Improper calibration results in much increased confusion for the users of such instruments. Discrepancies on an international basis, which have occured, result in lost sales and decreased exports. Domestic sales have been affected as well, with consequent effects of employment levels etc. for manufacturers.

COMMITTEE CONTACT: Michael Mellon

J. STATEMENT OF PROBLEM: Need to accurately calibrate "flat" neutral density attenuators with transmission factors as low as 10^{-6}. Spectral range not specified.

PROPOSED SOLUTION:

JUSTIFICATION:

COMMITTEE CONTACT:

K. STATEMENT OF PROBLEM: Measurement of low power lasers for environmental health studies.

JUSTIFICATION: NBS Boulder Calorimeters do not operate at low enough level.

COMMITTEE CONTACT: Dave Sliney.

Appendix B

Recommendations:

(1) Expand NBS calibration temperature range downward (e.g. 170 K - 360 K and extend λ range to say 25 μm and uncertainty to 1%).

(2) Such calibrations to also include effects of source environment.

(3) Need information on the use of extended sources

  (a) goniometric problems (in some cases)

  (b) verification of specifications on such sources

(4) Need application of absolute detector to source calibration

  (a) evaluate such a detector

(5) Since much interest (and emphasis) is in the lower temperatures, what about the development of low temperature freezing point standards (e.g. freezing point of mercury, gallium, etc.).

I. SPECTROPHOTOMETRY

A. Problems

There has been difficulty in the past in checking the transmittance accuracy of conventional spectrophotometers, especially those without integrating spheres. Possible sources of error are (1) non-linearity of photodetectors and/or the pen slidewire, (2) slight wavelength errors in measuring highly wavelength selective samples, (3) spectral stray light and/or geometrically scattered light, (4) beam shift across the non-uniform detector area, (5) unrecognized polarization of the light beam combined with dichroic samples, (6) spatially non-uniform samples, and (7) samples whose reflectance and/or transmittance is a strong function of angle, especially when measured in spectrophotometers of differing F-numbers.

On the whole, T measurements are routinely good to $\pm$ 0.5%, R measurements of specular samples good to $\pm$ 1%, or of diffuse samples $\pm$ 2 to 5%.

B. Impact

Commercial spectrophotometers are employed in an overwhelming majority of analytical laboratories or in any research program studying the optical properties of materials. In fact, the optical behavior of materials can be most readily characterized by their measured reflectance (R) and transmittance (T).

In the vast industrial field of optical thin films, reflectance and/or transmittance are used as the controlling parameters, and in many cases absolute (rather than relative) values of R and T are required.

In the field of temperature control by the absorptive and emissive properties of coated and uncoated surfaces, accurate spectral measurements of R and T are critical in evaluating the various possible materials. In the past intercomparison of the results among various laboratories has been hindered by a lack of suitable reflectance standards. Some examples of the uses of thermal coatings are artificial earth satellites, storage tanks of volatile fluids, and personal dwellings (housepaints).

In addition the lamp industry needs to have good integrating sphere coatings in order to measure the luminance of their sources.

C. Solutions

We need standards of specular transmittance covering the wavelength range 0.20 to 2.5 μm, transmitting 10% to 100% at intervals of $\sim$ 10%, with an accuracy of $\sim \pm$ 0.1%. These specifications would probably have reduced accuracy outside those regions where the sphere coatings used in the measurements are less efficient. These standards should be flat, spatially uniform, stable and durable, isotropic and preferably neutral. These standards would also serve as accurate attenuators. Metal films are probably best because they are most neutral and are more easily controlled during manufacture.

We also need standards of specular reflectance covering the wavelength range 0.2 to 2.5 μm, reflecting about 10%, 50% and 90%, with an accuracy of $\sim \pm$ 0.2%. These samples should also be flat, spatially uniform, stable and durable, isotropic and preferably neutral. Metal films are probably best for higher levels of R and dielectrics at the lower levels.

Again, as an overlap with attenuator requirements, there should be standards of high density transmittance, say 10^{-4} to 10^{-1}, with an accuracy of 1% relative.

In addition standards of diffuse transmittance and reflectance are desirable. However, it is more difficult to specify their behavior because of the broad ranges of angular characteristics that can be described.

One solution would be a standard of perfectly diffuse reflectance (a Lambertian surface) of well-defined total hemispherical reflectance for near-normal incidence, as a function of wavelength, accurate to ± 1%. The wavelength range would again be 0.20 to 2.5 µm. Finally, we need a well-defined, non-cumbersome procedure for producing integrating sphere walls of good diffuseness and high reflectance.

II. ATTENUATION

A. Problems

Many of the absolute radiometric and photometric parameters being measured today differ by orders of magnitude from the nominal values of the standards issued by NBS. Thus in order to make transfer calibrations of lower radiant or luminous power devices some form of attenuation must be employed. It is obvious that if high accuracy is to be obtained in calibrating these lower power working standards reliable and accurate techniques of attenuation must be utilized. The problem of attenuation is one of being able to determine both the absolute magnitude of the attenuation as well as the spectral perturbations introduced by the attenuator. A few examples may better illustrate the problem. Consider first the case of making an illumination calibration. Photometric standards of illumination are typically 500 watt lamps. At 150 centimeters distance these lamps yield on the order of 100 ft candles of illumination. Typical lamps which are calibrated from this standard might be 50 watt, 5 watt lamps etc. having illuminations at 150 centimeters of from .1 to 1 footcandles i.e. 3 orders of magnitude different from the standard. An extreme might be the calibration of low light level light sources commonly used to evaluate image intensifier devices. These devices are calibrated to operate as low as 10^{-7} footcandles, a 10^{9} order of magnitude difference between that of the standard! The problem is further complicated by the requirement that the spectral distribution of the light source be that of a blackbody of a given color temperature (typically 2870 °K) over a spectral region of .4 µ to .9 µ.

Another use of attenuators is to determine linearity of precision measuring instruments, principally the detectors and systems that follow the detectors. Many texts, including Moon and Walsh roughly describe methods of attenuation but it is felt that the Bureau should take the lead in establishing and standardizingmore definitive techniques in attenuation. The current situation is one of each investigator or laboratory employing their own methods and thus giving rise to data correlation difficulties.

B. Impact

The result of not having standardized techniques for attenuation of high light level sources is disagreement in calibration values of low light level sources made by various secondary standards laboratories. The potential impact of disagreement between secondary standards laboratories, i.e. laboratories directly traceable to NBS, is tremendous. A contractor traceable to secondary laboratory A measures the performance of a device to meet specifications of a contractee. The contractee traceable to say laboratory B does acceptance testing of the device and finds it below his specifications and rejects the devices. Many manhours and delay of important developmental programs may be spent to resolve the discrepancy which in the end was found to result from laboratory A employing an attenuation method different from laboratory B.

The above situation is indeed a reality in many of the U.S. Army procurement programs for low light level intensifying devices and the problem is difficult to solve since it requires a significant expenditure of technological resources to determine which is the more theoretically valid method of attenuating a standard source. It is felt that this task more properly falls into the domain of the National Bureau of Standards.

C. Solutions

It is recommended that the Bureau attempt to collect, describe and analyze all methods of attenuation pertinent to photometry, radiometry, spectrophotometry. The Bureau should then make recommendations to industry suggesting which methods are pertinent to different areas of this technology. It is also recommended that these discussions from the Bureau be put in some form that can be distributed to the scientific community. A special NBS technical note or monograph along with the results of the other working groups could be made available to the public. Another recommendation would be to have the results of these analyses and working group discussions presented to the regular international CIE meetings and have international discussions of the results which may be also distributed to the public in the form of NBS technical notes or CIE notes or whatever. Another recommendation would be to periodically have round-robin measurement comparisons between laboratories similar to those which are held for measurements of luminous intensity. For example measurements of low level sources as opposed to sources which are of the magnitude of NBS standards may be compared. Another recommendation is to obviate the use of attenuators by providing to industry standards of luminous intensity and other photometric and radiometric standards which are themselves orders of magnitude lower than those which are currently provided. This relates back to the original discussion of this note: the reason that attenuators are used is that the phenomena being measured are very often different by many orders of magnitude from those of the standards obtained from the Bureau.

Appendix D

The objective of this group is to define and provide for the establishment of a national measurement system for relative and absolute spectral detector response measurements. This will include defining the NBS role in the measurement system and defining the needed accuracy and minimum detectable spectral irradiance as a function of wavelength.

SPECIFIC RECOMMENDATIONS

1.) Cavity receiver, electrically calibrated thermal detector capable of NEI on the order of 1 μ watt/cm^2 for use in relative spectral response calibrations.

2.) NBS should maintain a primary standard in the spectral response area coupled with recommendations for transfer standards and procedures for their use. NBS should encourage industry to go into the business of supplying these transfer standards with calibrations and to set up procedures (such as round-robins) to ensure these calibrations.

3.) A quantum detector should be the transfer standard going down to 0.2 μ. A transfer standard is also needed out to at least 25 μ. This standard need not be a quantum detector.

Studies of the linearity of these transfer standards or procedures for calibrating their linearity.

Studies of the stability of these transfer standards or procedures for calibrating their stability.

SPECIFIC PROBLEM AREAS

1.) Getting down to low irradiance levels.

2.) Correlation of pulsed and steady state measurements (integrated vs. peak). There are no pulse standards.

3.) Specification definitions are not well enough defined to really help the consumer

Areas not defined well enough for D* or responsivity specifications.

4.) Temperature dependence of silicon cells.

JUSTIFICATION

The lack of adequate detector spectral response standards, procedures, and definitions contributes to a disorderly marketplace. The user depends on the detector supplier for spectral response data which too many times is in dispute. Reliable spectral response data is needed for accurate data reduction of user's results. In the case of broad band detectors for example, spectral response is used to establish "effective radiance" characteristics which call for conversion of received radiation to equivalent blackbody temperature. All too often, without reliable spectral response standards the user is now forced to develop effective spectral response results by indirect means.

This group first moved to define its scope; namely, Flux (Luminous, Radiant and Spectral-radiant) needs in the area of measurements of luminous flux (lumens) and spectral-radiant flux (watts/nm) covering sources (incandescent, fluorescent, HID, etc.) of UV, visible and IR radiation.

Without particular discussion it was agreed that it was desirable for the Bureau to continue on programs now in progress, such as, the work now underway with Mrs. Burns on incandescent lamp standards, the fundamental definition of the candela, and the work on establishing and improving the derivation of the lumen from intensity, or even spectral irradiance standards goniometrically, then learning to transfer flux standards in spheres and understanding what is happening in spheres. Dr. Schaefer commented that this latter capability will be necessary in any event in order to measure spectral-radiant flux. He questioned if there is not, at least for now, still a necessity to be able to make photometric flux measurements directly with a well characterized detector.

Then came the question, are these needs best met by standards for each of the types of sources or by the development of means for attaining this end through the use of only a very limited number of standards? Up to the present time, photometric laboratories have been existing through the use of standards of luminous flux from NBS for incandescent and certain fluorescent lamps, and color standards for another group of fluorescent lamps. Measurements of luminous flux from lamp types and sizes outside the range of these standards or color assignments beyond the limited group have been made by each laboratory on the basis of its own methods or its own developed standards, usually without direct traceability to NBS.

The development of standardized procedures for the determination of spectral-radiant flux, with a limited number of standards for this characteristic available from NBS, would make it possible for laboratories to determine total luminous or total radiant flux from the results of the spectral-radiant flux measurements. A laboratory equipped to make this spectral determination then would be in a position to transfer flux assignments for a given type and size of lamp to other lamps of this same size and type for use as secondary standards in commercial assignments by substitution methods. A laboratory not equipped to make SED measurements would have to depend on an independent laboratory to supply these needs.

The development and use of the total spectral radiant flux as a means toward total luminous flux determinations has an added advantage in that color appearance and color rendering index both are computable from the results of this measurement. Thus, a standardized procedure for the determination of luminous flux would, at the same time, yield a standardized procedure for color appearance and color rendering index, where standardized procedures presently are available only for a small part of the lamp types and sizes being used.

What would be needed in the way of a range of standards? Lamp measurements now cover the range from 0.01 to 100,000 lumens. The 0.01 lumen is for sub-miniature incandescent lamps and the 100,000 lumens for some of the HID lamps.

If measurement were to be made by spectral-radiant flux determination, what range would be required? Bactericidal and ozone producing lamps would require special techniques for measurements down to 180 nm. It is, therefore, suggested that two sets of equipment and two measurements procedures be developed, one in the range from 180 to 320 nm and the other from 250 to 900 nm.

What is the justification for asking NBS to either furnish standards of all types and sizes or to develop measurements procedures to standardize the determination of spectral-radiant flux? Without lamp standards for the characterisitics or without standardized measurements procedures, determined values may vary from laboratory to laboratory by amounts up to 10 per cent or more. Further, since published performance data for various lamp types are based on the results of measurements in the various manufacturers' laboratories, catalog data will reflect these variations. As a result, there are influences on (a) business; domestic and foreign, (b) health and safety of the public, (c) legal liabilities, and (d) consumer protection.

In business, many purchases are made on the basis of promised performance. A difference of the order of one or more percentage points in promised performance will, therefore, determine the business to be done, either domestic or foreign, by a given manufacturer or even by an industry. This can run into millions of dollars.

In addition, to the unfair competition resulting from such comparative ratings, there is the influence of such catalog data on purchase specifications by state and local governments, GSA, OEM, DOT, FAA, etc.

People live in a radiation environment, natural or artificial. Just as too much sunlight may be harmful, certain elements in artificial light may be harmful. On the other hand, other elements may be beneficial. In other words, there is no doubt but that radiation may have influences on health. BRH no doubt is interested.

Light plays an important part in the safety of our people. Highway and traffic safety depend on light signals. DOT and FAA both are active in specifying performance.

Consumer protection is considered to be of such importance that an agency is set up in government in an effort to provide this protection. One facet of this protection is truth in advertising, facts and not fiction. FTC is interested in this. When a customer replaces a lamp, he expects a similar performance from the replacement. In other words, lamps similarly marked should be interchangeable. With all of this, the manufacturer is subject to possible legal action due to nonfulfillment of contract if lamps do not perform in service as the purchaser was led to believe from catalog data.

With the announced policy of NBS to limit the number of types and sizes of standards to be provided, this group strongly recommends that NBS proceed (1) to continue its present program of calibration of specific lamp types to provide to industry a baseline for these types, (2) to develop methods of extending the calibration of secondary standards from a limited number of standards for a given lamp type, and (3) to develop standard procedures for determining spectral-radiant flux for all types and sizes of lamps. This latter development should provide means for handling different lamp geometries -- bulb shapes, etc.

The working group listed the following items, in order of priority, as the most pressing needs in the area.

1) Provision by NBS of detailed, written descriptions of the methods and techniques through which NBS calibrates standards of spectral radiance, spectral irradiance, luminous intensity, color temperature, etc. Ideally, these descriptions would be duplicated in other laboratories with minimum chance of error.

2) When NBS is unable to provide full calibration services, they should provide some method of guaranteeing that commercial standards labs are providing measurement services on the NBS scale. Various methods of formal and informal certification are under discussion (e.g., NBS calibration reports might include a value predetermined by the customer in addition to the NBS determined value and uncertainty statement).

3) Small-scale, simple interlaboratory intercomparisons utilizing NBS techniques (item 1 above), with NBS acting as referee, would be desirable to determine the level of agreement between interested labs and NBS in selected areas (luminous intensity, total irradiance, color temperature, etc.).

4) NBS should take the steps necessary to provide easy access to existing written descriptions of techniques and methods through bibliographies, subscription information on periodicals, etc.

The committee recognizes a strong need to coordinate closely its future activities with the working group on techniques (working group VI). For the immediate future, the working group on dissemination will direct its efforts toward the preparation of a detailed outline of most useful material to be included in future NBS write ups of techniques and methods.

I. STATEMENT OF PROBLEM

The basic problem with laser energy and power measurement is the large scale discrepancy in calibration of the various energy and power meters that are commerically available. Although manufacturers of these instruments claim traceability to NBS within 5% of absolute, variations of as much as 30% have been seen on several different types of instruments.

The specific problems related to standarization and calibration of laser power and energy monitors are as follows:

1. Lack of standard laser sources stable enough to use as an equivalent to a standard lamp.

2. Lack of readily available standard thermopiles or calorimeters.

3. Unavailability of secondary standards labs to provide a traceable industry-wide calibration service for power and energy meters.

4. Lack of detailed information as to procedures and techniques for use of laser measurement instrumentation.

II. EXISTING STANDARDS AND PROCEDURES

Presently, NBS-Boulder is capable of achieving a 1% accuracy of laser energy measurement with the C-series calorimeter system. In general this is accurate enough for all current laser applications such that a new standard is not needed at this time.

Several NBS documents are available which treat some of the applications of power and energy meters in a standards laboratory setting; however, a generalized descriptive procedure in the form of a handbook is badly needed.

III. CONSENSUS ON NECESSARY NBS ACTION

By consensus of the Laser Committee, the following measures are listed in order of priority:

1. Specification of a generalized class of calorimeters or thermopiles which could be easily calibrated within a 2-3% uncertainty.

2. Appropriate software to support the above chosen class of calorimeters based on laboratory data and containing a broad based procedure and technique for accurate use.

3. Detailed applications note concerning the compounding of errors in laser power and energy measurements to be used as a guide in designing the measurement procedure.

4. Continuation of the calorimeter and thermopile calibration service at NBS with the possible future certification of secondary standards labs who could provide fast accurate calibrations.

IV. JUSTIFICATION FOR NBS ACTION

As previously stated, NBS can achieve a 1% accuracy in measurement of laser energy and power based on the electrical calibration of its C-series calorimeter. The measurement problem therefore exists in the calibration and use of the commercially available measurement devices. As much as 30% error may be found in some instruments due to calibration uncertainty, faulty application techniques and actual instrument instability.

There is a pressing need for increased accuracy by both laser manufacturers and laser users. Laser manufacturers must have accurate measuring instruments in order to guarantee product capability and performance. They must also be assured that their customer's power and energy meters are of the same absolute accuracy such that discrepancies in power level will not be due to the measurement system.

Laser users on the other hand have a significant number of applications which require highly accurate measuring instrumentation. Some of these applications are:

1. Laser damage threshold measurements.

2. Laser material and laser system research and development.

3. Raman scattering.

4. Laser radars and range finders.

5. Laser monitoring in conjunction with the new laser safety standards.

The laser industry is expanding in influence in a multitude of new produce areas. With each new development an increased demand is placed on laser power and energy measurements.

We must rely on NBS to develop new standards and insure that all industry can be supplied with accurate calibrations.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

Serious measurement discrepancies universally plague quantitative measurement in the electro-optics industry. The impact of the resulting problems is reviewed and the role of NBS explored. The measurement discrepancies arise chiefly through the recent explosive expansion of this industry. The growth has precipitated a complex development in the variety and accuracy of measurements required. The impact of problems in optical radiation measurement falls in many areas. One is the increasing Federal responsibility for public life defined in recent legislation. Another is the influence of good optical radiation measurement on the technical development of the electro-optics industry. The impact of these measurements on a number of public issues is reviewed: public health, public safety, the energy crisis, meteorology, pollution, agriculture, crime prevention, and surveillance from air and space. The economic impact of improved measurement both on a fair domestic market and on the balance of payments operates through unit production cost, quality control, product improvement, and innovation. Leadership by NBS has been urged by the industry not only in fulfillment of its legislative responsibility but also to permit the focus of elaborate and impartial resources on the complex problem of optical radiation measurement. In keeping with its mission to help improve industrial technology and the competitiveness of American industry, NBS has an opportunity of major proportions in the electro-optics industry. Leaders of this industry are calling for NBS initiatives to resolve many of the measurement problems now hindering further progress.

17. KEY WORDS (Alphabetical order, separated by semicolons)
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