

Lawrence Berkeley National Laboratory

Recent Work

Title

LIGHTING RESEARCH PROGRAM

Permalink

<https://escholarship.org/uc/item/3530t0rk>

Author

Berman, S.

Publication Date

1984-02-09

PUB-470
c.1

THE LAWRENCE BERKELEY LABORATORY
APPLIED SCIENCE DIVISION

RECEIVED
LAWRENCE
BERKELEY LABORATORY

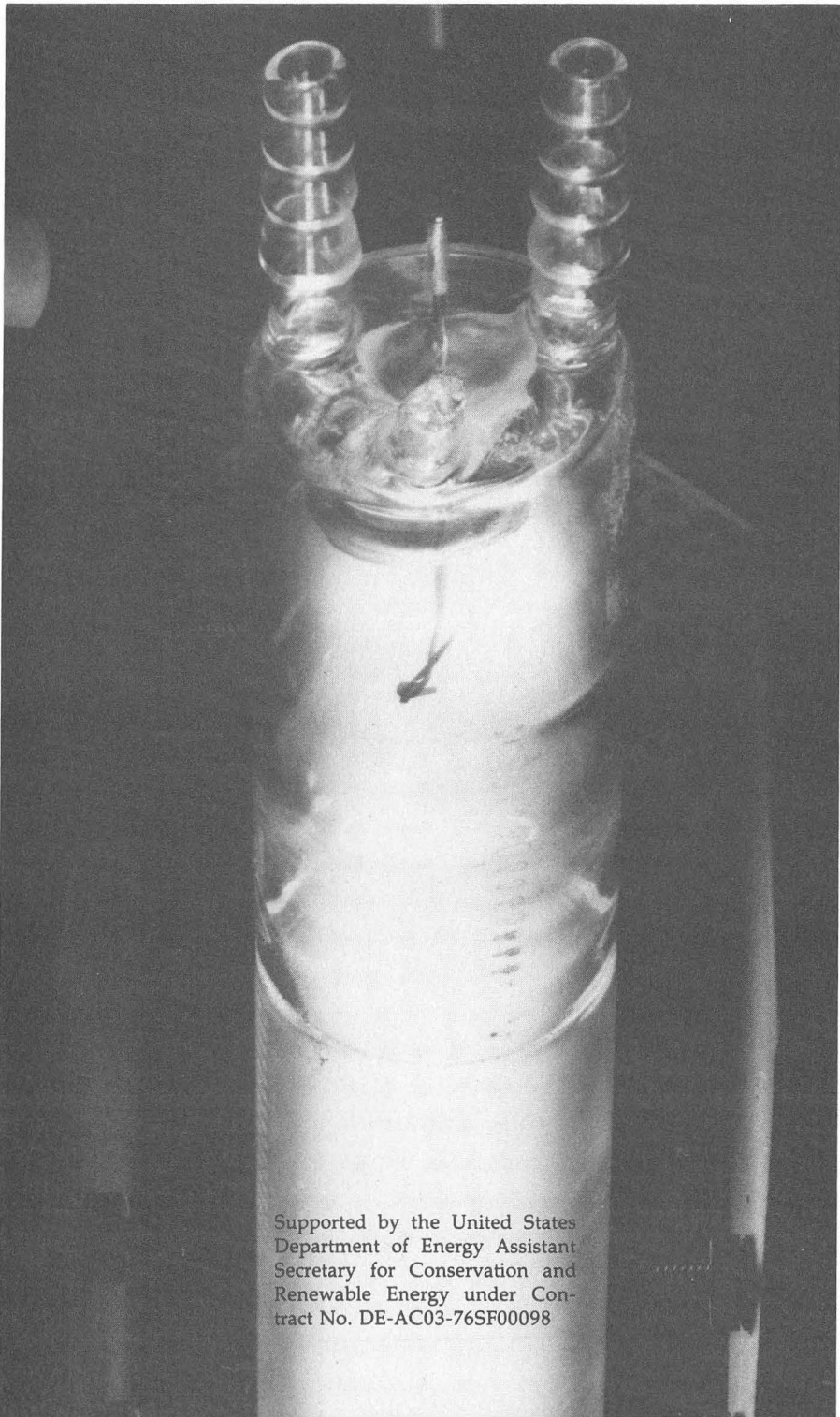
FEB 9 1984

LIBRARY AND
DOCUMENTS SECTION

For Reference

Not to be taken from this room

LIGHTING RESEARCH PROGRAM



Supported by the United States
Department of Energy Assistant
Secretary for Conservation and
Renewable Energy under Contract
No. DE-AC03-76SF00098

PUB-470
c.1

Principal Investigator: Samuel Berman

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

The work described in this pamphlet was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Building Equipment Division, and the Energy Conservation Equipment Branch of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Program Highlights

Concerns and Goals

Past Efforts

- High-Frequency Solid-State Ballasts

- Energy-Efficient Replacements for the Incandescent Lamp

- Lighting Controls Demonstration at the World Trade Center

Current Research

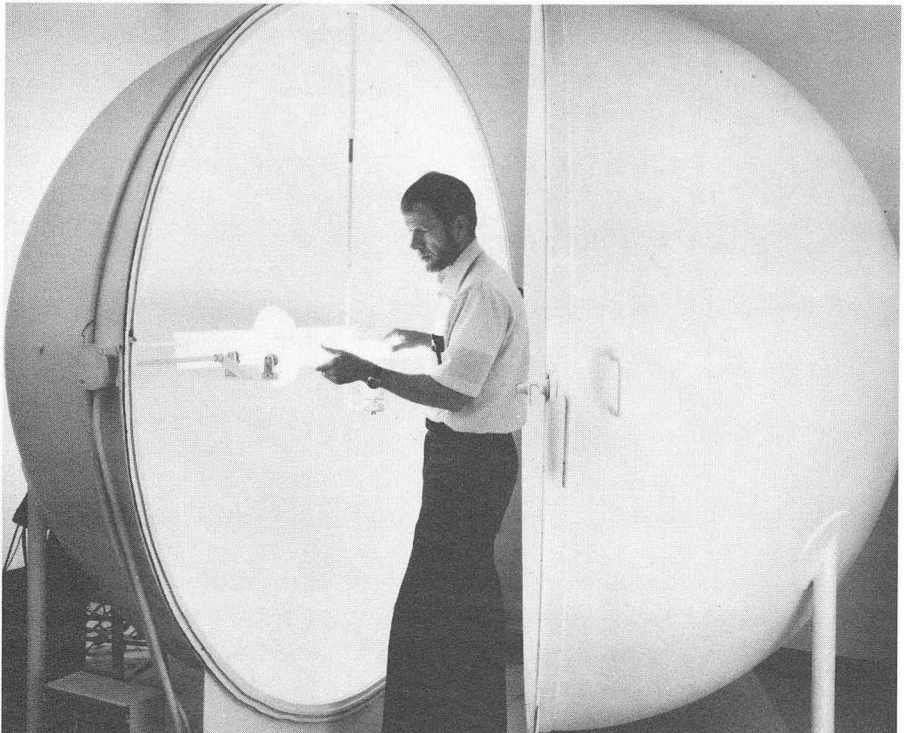
- Researching Lamps of the Future

- Electromagnetic Compatibility of High-Frequency Lighting

- Understanding Impacts of New Lighting Technologies on

- Productivity and Health

Lighting Program Principals



Integrating sphere. A fluorescent lamp is placed in the lighting laboratory's integrating sphere. Here its total light flux, color temperature, and spectral distribution in the visible region are determined.

THE LAWRENCE BERKELEY LABORATORY
APPLIED SCIENCE DIVISION
LIGHTING RESEARCH PROGRAM

Concerns and Goals

We estimate that approximately 50% of the electrical energy consumed by lighting, or about 12% of total national electrical energy sales, could be saved by gradually replacing existing lighting with energy-efficient lighting. This would amount to a yearly savings of some 220 billion kilowatt-hours of electricity.

The objective of the Lawrence Berkeley Laboratory (LBL) Lighting Program, sponsored by the U.S. Department of Energy, is to work in concert with and assist the lighting community (manufacturers, designers, and users) to achieve a more efficient lighting economy. The program at LBL exemplifies a new kind of partnership between a national laboratory/university complex and industry, facilitating technical advances and strengthening industry capabilities.

The engineering science component of the LBL program undertakes research and development projects in lamp technology that are both long-range and high-risk. These are projects in which the lighting industry has an interest but is unable to pursue on its own, and from which significant benefits could accrue to both the public and industry if the technical barriers were surmounted.

LBL is also concerned with developing a full technical understanding of the electromagnetic compatibility of high-frequency lighting with the internal functions of a building, including machinery, computers, and other electrical and electronic systems. The impacts component of the program examines relationships between workers and the physical lighting environment, in particular to assure that new energy-efficient technologies contribute positively to human productivity and health. These efforts are interdisciplinary, involving engineering, optometry, and medicine.

Since its inception in 1976, the LBL Lighting Program has produced more than 75 reports and publications available to the public and documenting research on subjects such as solid-state ballasts, operation of gas-discharge lamps at high frequency, daylight availability and computer programs, energy-efficient fixtures, lighting control systems, and visibility and human productivity. The internationally recognized staff is drawn from the fields of engineering, physics, architecture, optometry, and medicine and participates in a variety of professional, technical, and in-government activities.

The Lighting Program combines the facilities and faculties of LBL with those of the University of California College of Environmental Design, School of Optometry, and School of Medicine. It is a unique program in the United States, with its results directed toward enhancing the capabilities and long-term viability of the lighting industry and toward providing the design profession and general public with needed information.

Past Efforts

High-Frequency Solid-State Ballasts

All gas-discharge lamps (e.g., fluorescent, mercury vapor, high- and low-pressure sodium, and metal halide) require ballasts to maintain stable electrical operation. The ballast provides the required starting voltage and limits the lamp current to a constant prescribed value. In normal operation, typical electromagnetic ballasts can undergo energy losses amounting to 25 to 35% of the overall lamp/ballast system. The advent of solid-state electronics provided the impetus for creating ballasts that experience much lower energy losses and allowed lamps to be operated at high frequencies—in the 30,000 cycle range where the intrinsic efficiencies of the low-pressure lamps are 10 to 15% greater than at 60 cycles. LBL, working with two small engineering firms, developed a cost-effective, high-frequency, solid-state ballast that is 20 to 25% more efficient than the typical electromagnetic ballast. Demonstrations conducted by LBL in occupied buildings measured actual savings achieved by the new ballasts and convinced the lighting community of their viability and effectiveness.

After the small engineering firms successfully developed engineering prototypes, they were purchased separately by different major ballast manufacturers, who will now introduce the ballasts to the market. The technical knowledge that LBL brought to the solid-state ballast field has stimulated the entire industry to examine the general usefulness of high-frequency lighting. Lighting systems reaching the market today are beginning to use the new ballasts, which should become commonplace within the next few years.

Table 1. Comparison of energy performances of standard magnetic ballasts, energy-efficient magnetic ballasts, and solid-state ballasts with a standard F40, cool-white fluorescent lamp and with two types of energy-efficient, "lite-white" phosphored lamps.

Ballast/Lamp System Efficacy			
Ballast/Lamp System	Input Power (watts)	Rated Light Output (lumens*)	Efficacy (lumens/watt)
St-F40	100	6300	63
St-Br	100	6900	69
St-35	91	6100	67
EC-F40	91	6300	69
EC-Br	82	6900	76
EC-35	79	6100	74
SS-F40	79	6300	80
SS-Br	79	6900	87
SS-35	71	6100	86

St Standard two-lamp, F40 magnetic ballast.

EC Efficient core two-lamp, F40 magnetic ballast.

SS Solid-state two-lamp, F40 ballast.

F40 F40 T-12, rapid-start, cool-white lamp (argon-filled).

Br F40 T-12, rapid-start, lite-white lamp (argon-filled).

35 35-watt F40 T-12, rapid-start, lite-white lamp (krypton-filled).

* Lumens measure the quantity of the luminous flux of light.

Energy-Efficient Replacements for the Incandescent Lamp

Nearly 90% of energy applied to an incandescent filament lamp is dissipated as heat. An energy-efficient replacement for this kind of lamp is an acknowledged need and the focus of much research. Low cost, ease of use, and good color quality are all concerns that must be addressed in developing an efficient substitute.

Working with the lamp industry, LBL in 1979 began a program to accelerate development of a wide variety of energy-efficient replacements for the incandescent lamp. The concepts considered have included slimmed-down fluorescents (compact fluorescents) that are small enough to use in current incandescent configurations. To satisfy individual preferences, the phosphor coating the inner wall of the lamp can be tuned to provide the color typical of an incandescent lamp or to simulate daylight.

Also considered as a possible replacement is an electrodeless fluorescent lamp in which the discharge is excited magnetically at very high frequencies (13.56 megacycles) and maintained in a glass tube shaped much like the classic incandescent lamp. Still another possibility is to cover the inside of the incandescent lamp with a very thin selective coating that transmits visible light but reflects infrared radiation. The radiation reflected back to the filament reduces its power requirement and increases efficacy. Another concept is a small metal halide lamp operated at high pressure, but

with a very small arc length to provide the light output characteristic of an incandescent lamp rather than the high lumen output typical of metal halide lamps.

These lamps have improved efficacies ranging from two to four times that of the incandescent lamp. Some of them can last longer than 10 years (10,000 hours), compared to less than one year (750 hours) for the incandescent lamp. Although first costs may be higher, the longer lifetime and lower operating costs provide a lower life-cycle cost than for an incandescent lamp. The consumer will soon find many possibilities for converting to more energy-efficient household lighting.

Table 2. Technical and economic characteristics of energy-efficient replacements for incandescent lamps.

CHARACTERISTIC	LONG-TERM GOALS					INITIAL PERFORMANCE			
	Incandescent (75-watt)	ENERGY-EFFICIENT LAMPS		Coated Filament	Electrodeless Fluorescent	COMPACT FLUORESCENT			High-Intensity Discharge
		Filament	Gas-Discharge			High Light	Medium Light	Low Light	
Input Voltage (volts)	0-120	0-120	120	0-120	120	120	120	120	120
Frequency (hertz)	60	60	60	60	60	60	60	60	60
Power Factor (%)	100	100	50	71.1	59 ± 0.5	75 ± 1	62 ± 0.3	61 ± 0.2	59 ± 0.6
Initial Light (lumens—lm)	1210	1000-2200	1000-2200	1550 ± 68	1665 ± 110	1700 ± 60	1020 ± 10	490 ± 70	2410 ± 160
Power (watts—W)	75	---	---	54 ± 1	32 ± 1	34 ± 0.5	18 ± 0.2	16 ± 0.5	51 ± 2
System Efficacy (lm/W)	16	34	50	29 ± 1	53 ± 3	50 ± 2	56 ± 1	32 ± 5	43 ± 2
Burning Position	any	any	any	any	any	any	any	any	base down
Life (hr)	750	2500	10,000	2500*	10,000*	8000*	6500*	10,000*	6500*
Weight (oz)	1	6	16	4.1	9.6	22.7	7.4	5.9	4.5
Size (length × diameter)	4.5 × 2.38	5 × 2.5	7.5 × 4	5.1 × 3.3	7.2 × 3.1	9.7 × 3.4	7.2 × 2.8	8.3 × 2.4	5.7 × 2.5
Retail Cost (\$)	0.70	5.00*	15.00	5*	15*	17*	15*	10*	10*
Total Cost/10 ⁶ lm/hr (\$) @ \$0.07/kWh	5.27	<5.27	<5.27	3.71*	2.23*	2.64*	3.52*	4.26*	2.27*
Number of Units Tested				9	10	10	6	5	19
Color Rendering Index	93	90	70	90 ± 3	16 ± 2	82 ± 2	81 ± 0.4	39 ± 6	65 ± 2
Color Temperature (°K)	2800	3000 ± 200	3000 ± 200	2940 ± 60	4815 ± 111	2620 ± 70	2790 ± 70	4507 ± 240	3020 ± 150

*Estimate.



Examples of energy-efficient lamps. Visual and electrical properties are evaluated in LBL's Physical Lighting Laboratory.

Lighting Controls Demonstration at the World Trade Center

Many approaches have been considered for saving lighting energy in commercial buildings. Techniques such as having the lights turn off and on according to predetermined schedules, removing overhead bulbs in little-used areas, and taking advantage of available daylight have been discussed theoretically. To quantify the actual energy saved by introducing an energy-saving lighting management system to a realistic environment, LBL conducted a demonstration on the 58th floor of the World Trade Center in New York City. The tests were designed to determine:

1. which control functions have the greatest impact and why,
2. what are the economic tradeoffs between control cost and savings potential,
3. how acceptable controls are to occupants, and
4. how reliable control systems are.

To provide the monitoring necessary to evaluate a wide range of strategies, a relay was attached to every ballast on the 58th floor of the building. By selectively switching relays, it was possible to make any of the 6-lamp, 3-ballast fixtures go to 1/3, 2/3, full "ON," or "OFF."

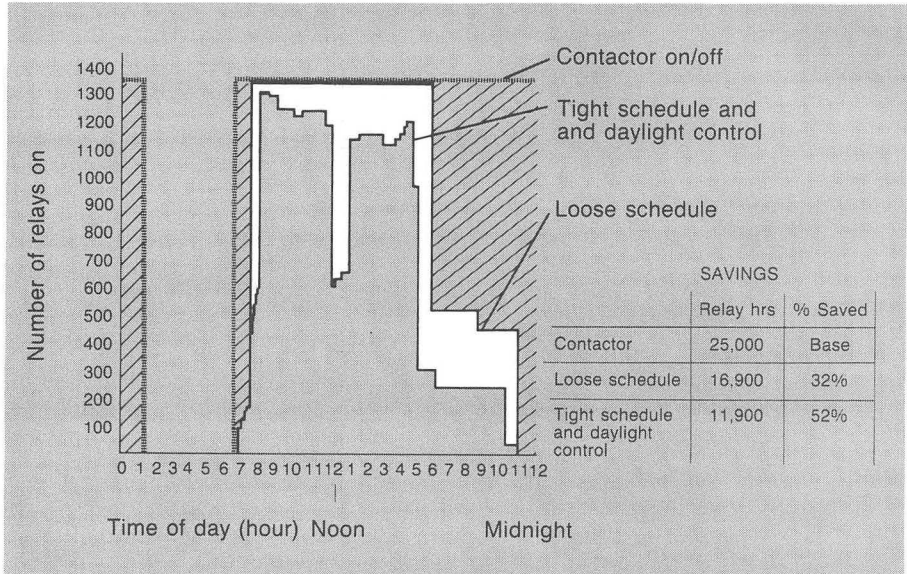
The 1350 relays were operated by a computer-programmed lighting control system that allowed independent scheduling of each relay, monitoring of daylighting thresholds to provide a constant level of illumination, and manual override of the lighting by occupants via existing desk phones. In addition, all relay activity could be stored on tape to provide a record of consumption in response to various strategies.

A series of one- to two-week tests focused on finding the most effective ways to schedule lighting levels to match tasks, take advantage of daylight, and provide occupancy-based control. Variables affecting each of these functions were manipulated to determine their impact on the extent to which that strategy could be used.

The most significant conclusions of this demonstration were:

1. Lighting controls can have a significant and positive impact on energy consumption: a maximum reduction of 52% was achieved in this test.
2. The payback on relay-based lighting control for new construction is extremely attractive.
3. Relay-based automatic lighting controls are acceptable to occupants, are very reliable, and provide significant energy savings, but continuous dimming is preferable.

The value of the tests was not only the 52% savings achieved, but also the insight gained into why certain strategies were successful, how strategies interact, the relationship a strategy to the purpose of a space, occupants' response to the techniques, and the importance of providing individual overrides to ensure positive reactions to the system.



Profile of the instantaneous power used during a 24-hour period at the World Trade Center before and after installation of the lighting control system. The major control strategies tested were scheduling according to occupancy and taking advantage of available daylight.

Current Research

Researching Lamps of the Future

Today's fluorescent lamp has a luminous efficacy of approximately 80 lumens of light output per watt of electrical power input. Although this efficiency is nearly four times that of an incandescent lamp, much greater efficacies are possible. White light can, theoretically, be produced at almost 350 lumens per watt. The lamp research program at LBL is devoted to attempting to reach that efficiency within the next few years.

Two important loss mechanisms must be changed before more efficient fluorescent lamps can become a reality. These are, first, reducing the self-absorption of the ultraviolet (UV) radiation within the lamp plasma before it strikes the phosphor-covered inner lamp wall, and second, developing a more efficient phosphor that will convert one energetic UV photon into two visible photons. Reductions in self-absorption could provide a 30% improvement, while a two-photon phosphor could double a lamp's efficacy.

LBL is studying two principal ways of reducing the UV self-absorption. The first method concerns the naturally occurring isotopes of mercury. There are seven stable isotopes that differ according to their different UV emission spectra. A small subgroup

of isotopes will emit and absorb UV radiation with such a small spread in energy that a nearby subgroup of isotopes is not involved in its radiative transfer. Altering the natural isotope composition can increase the amount of UV radiation reaching the phosphor, thereby improving lamp efficiency.

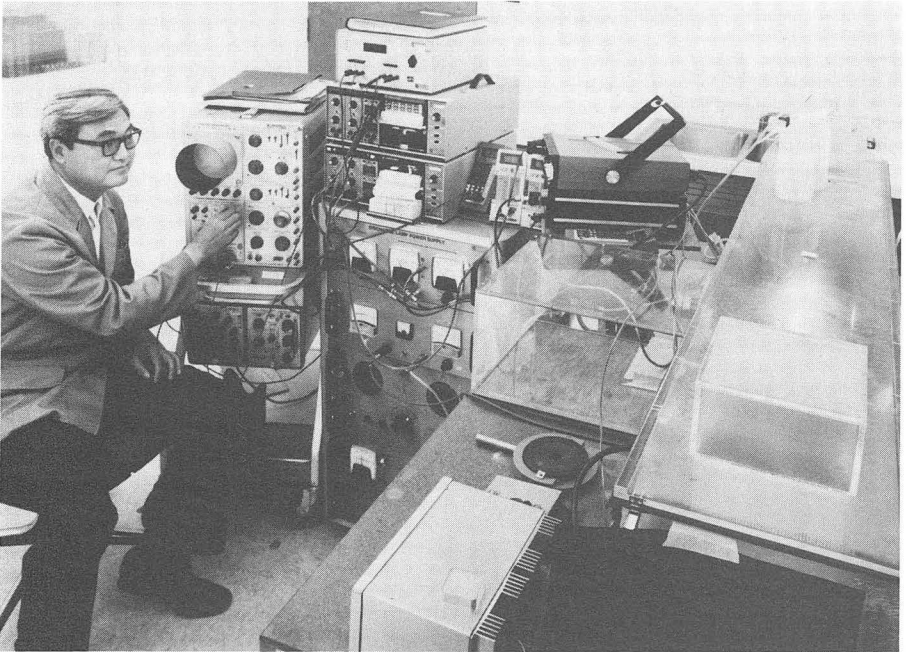
Two possibilities for isotope alteration appear feasible. One of these, enrichment with mercury 196 isotope, is being pursued in a joint effort by LBL and GTE Lighting. The other possibility, enrichment with mercury 201 isotope, is being studied at LBL. Should mercury isotope alterations prove economically successful, modified lamps could enter the market in the near future, as the lamps would simply be loaded with isotopically enriched mercury rather than natural mercury, while all other lamp components would remain the same.

The second method for reducing UV self-absorption was recently discovered at LBL and involves an applied magnetic field that has a direction parallel to the main lamp current. Relatively small magnetic field strengths can increase UV emission by 20%. LBL and major lamp industries are studying practical ways to apply this technique.

The second loss mechanism is that a lamp's phosphor converts each UV photon into only one (at most) visible photon. Improving this conversion rate could greatly increase the efficacy of the low-pressure discharge lamp. Although the energetics are sufficient to permit the cascade conversion of a UV photon into two visible photons, this process must occur very quickly and the intermediate level in the cascade must be tuned carefully to ensure that both emitted photons are in the visible spectrum. Basic studies on phosphor chemistry are being undertaken at LBL to discover whether the two-photon phosphor is feasible. The lamp industry, long aware of this problem but not in a position to make these fundamental investigations, is very interested in the results.

Based on work at LBL, the fluorescent lamp of the future should operate at high frequency and be isotopically enriched, magnetically loaded, and coated with a two-photon phosphor. Such a lamp would have an efficacy of more than 200 lumens per watt, three times that of today's 60-cycle fluorescent.

Other research on lamps of the future concentrates on high-intensity discharge lamps. These lamps can be made both more efficient and dimmable without color variation if they are operated without electrodes. High-frequency operation is required to excite the lamp plasma in an electrodeless mode. Operation at high frequency may permit lamps to function with just one or two metal halides and without any mercury or sodium. Electrodeless operation would also enable the use of compounds in the discharge that have desirable light output and color, but that are not used today because they attack and harm the electrodes. An electrodeless lamp would be dimmable without a spectrum change and is extremely appealing to lighting designers. It would be an efficient, dimmable point source that could produce any prescribed color.



Isotopically altered lamps are placed in a nitrogen atmosphere and their enhanced ultraviolet emission is measured with the photomultiplier detection system.

Electromagnetic Compatibility of High-Frequency Lighting

The successful development of high-frequency, solid-state ballasts has provided the impetus for adopting high-frequency lighting and control systems in commercial and industrial buildings. Many benefits can be realized by operating at high frequencies: lower starting voltages, increased efficacy, ease of dimming, etc. The electronics industry is also making rapid progress in developing less expensive high-power transistors and amorphous magnetic materials, which are needed to ensure that high-frequency ballasts will be cost-effective and thus enter the market rapidly.

High-frequency lighting, however, can be a source of electromagnetic energy, which could affect sensitive machinery, computers, and electronic systems. The imminent, widespread use of these lighting systems requires studying the possible effects of electromagnetic interference (EMI) on other building operations. LBL is leading the effort to obtain information needed for industry and concerned government agencies. The major technical problem is establishing reliable near-field EMI measurements for lighting systems and relating them to what the Federal Communications Commission requires for far-field radio interference. Furthermore, a methodology must be developed to determine near-field effects on electronic equipment and far-field effects when many EMI-generating systems are in use.

The Federal Communications Commission and National Electrical Manufacturers Association have strongly recommended that LBL

participate in collecting data on the EMI generated by high-frequency lighting systems. The development at LBL of a standard source and measuring method for determining the values of the radiated near fields is essential in order to make convenient and reliable procedures available to industry. Computer models for stray EMI are also being developed at LBL to further study the physical characteristics of external electromagnetic fields generated by high-frequency lighting.

Understanding Impacts of New Lighting Techniques on Productivity and Health

The idea that lighting might negatively affect health has become more prevalent in the lay press in the past few years. Reports are generally subjective, unconfirmed, and anecdotal. Many factors have been implicated, but scientific data are lacking, especially to ascertain whether new energy-efficient technologies have adverse effects on human health and productivity.

Factors that may influence performance and productivity (as well as energy efficiency) may be associated with the lamp, the electronics and associated controls, the fixture, or the geometry and location of the lighting system. These lighting factors are color variations; glare; intensity fluctuations; spectrum variations, including in the ultraviolet region; electromagnetic fields generated by the lamp, ballast, or controls; and flicker, all of which could evoke a variety of human responses. These responses might be behavioral, psychophysical, physiological, or biochemical.

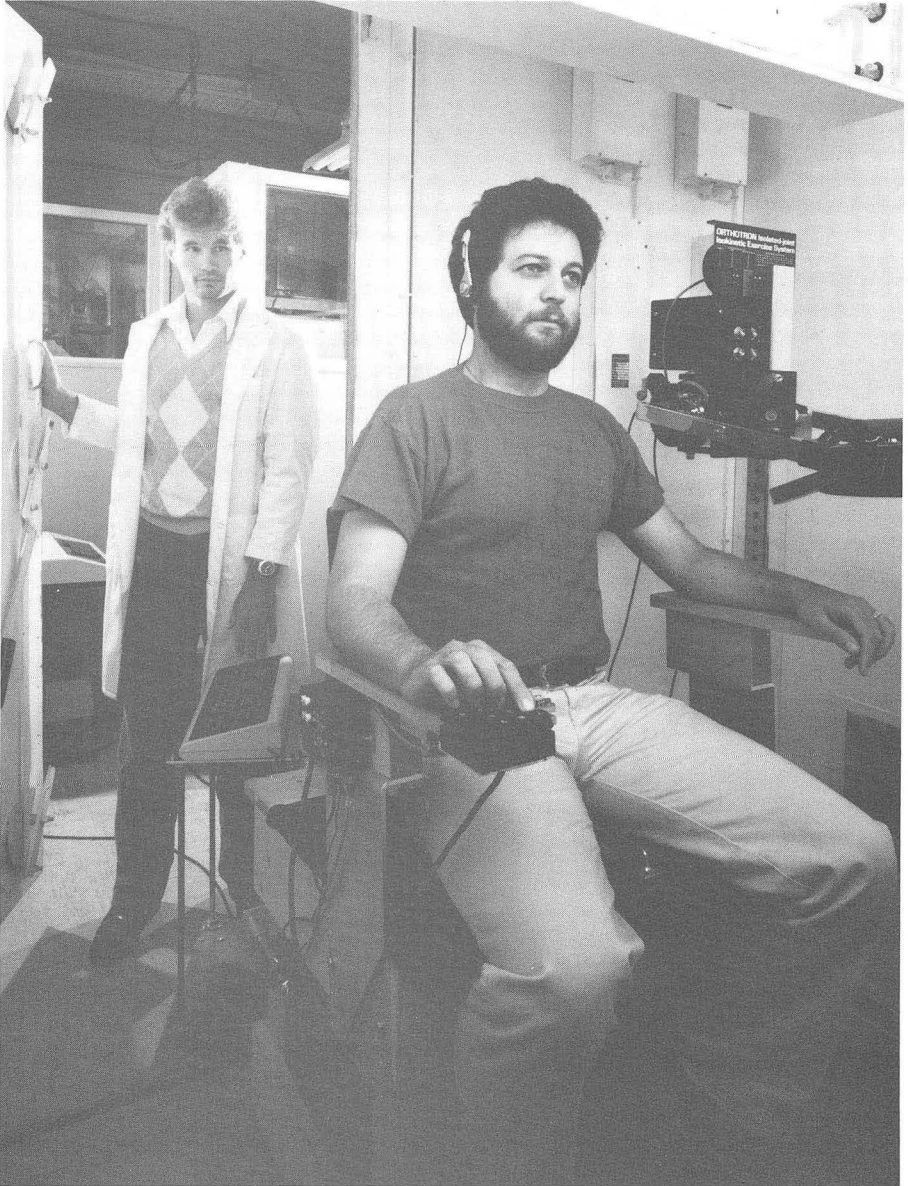
The purpose of our research is to assure that new energy-efficient lighting technologies do not adversely affect human health and productivity. We are investigating whether any aspect of the new technologies can produce responses in humans. If so, the effects will be characterized and any necessary changes to lighting technologies will be identified. Although subjective responses by verbal and written communication with workers can provide some information, such responses are generally muddled by a mix of sociological factors and motivations; the investigations carried out by LBL make intensive use of non-subjective responses in order to establish cause and effect and assure repeatability.

For example, the physiological functions to be tested include muscle strength, muscle fatigue, and factors influenced by autonomic nervous system activation, including heart rate, respiratory

rate, skin resistance, skin temperature, and changes in the diameter of the pupil.

Data-gathering and subject control are all done under the supervision of trained medical personnel. A national technical advisory committee of experts oversees and reviews the project.

Besides these direct effects of lamps on humans, LBL is also examining the question of how lamp characteristics—in particular “invisible” flicker—can affect workers using visual display terminals.



In this chamber, located at the University of California Medical Center, subjects are exposed to different kinds of lighting. Trained medical personnel test for physiological, psychophysical, and biochemical responses.

H. Lighting Program Principals

United States Department of Energy
Washington, D.C.

Building Equipment Division
Mr. Theodore Kapus, Director
(202) 252-9389

Energy Conservation Equipment Branch
Mr. John Ryan, Chief
(202) 252-9130

Lighting
Mr. Robert Boettner, Program Manager
(202) 252-9136

Lawrence Berkeley Laboratory
Applied Science Division
Berkeley, California

Lighting Systems Research
Dr. Samuel Berman, Principal
Investigator
(415) 486-5682

Dr. Rudolph Verderber, Program
Manager
(415) 486-6398

Visibility Research
Dr. Robert Clear, Staff Scientist
(415) 486-4094

Lighting Controls Research
Mr. Francis Rubinstein, Staff Scientist
(415) 486-4096

Health Impacts
Donald Jewett, M.D., dPhil.
University of California Medical
Center
San Francisco, California
(415) 666-5132

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

Lawrence Berkeley Laboratory is an equal opportunity employer

PUB-470/11/83 LAWRENCE BERKELEY LABORATORY