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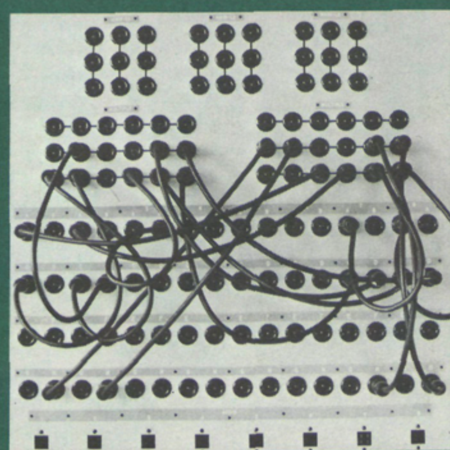

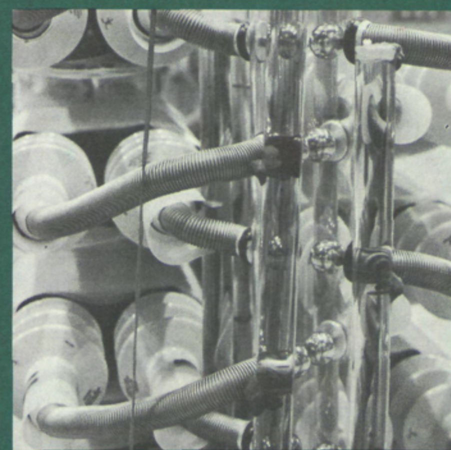

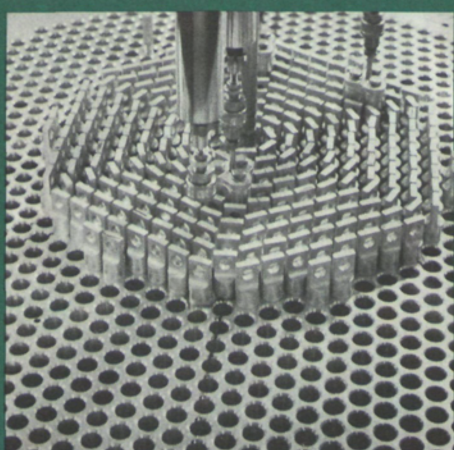

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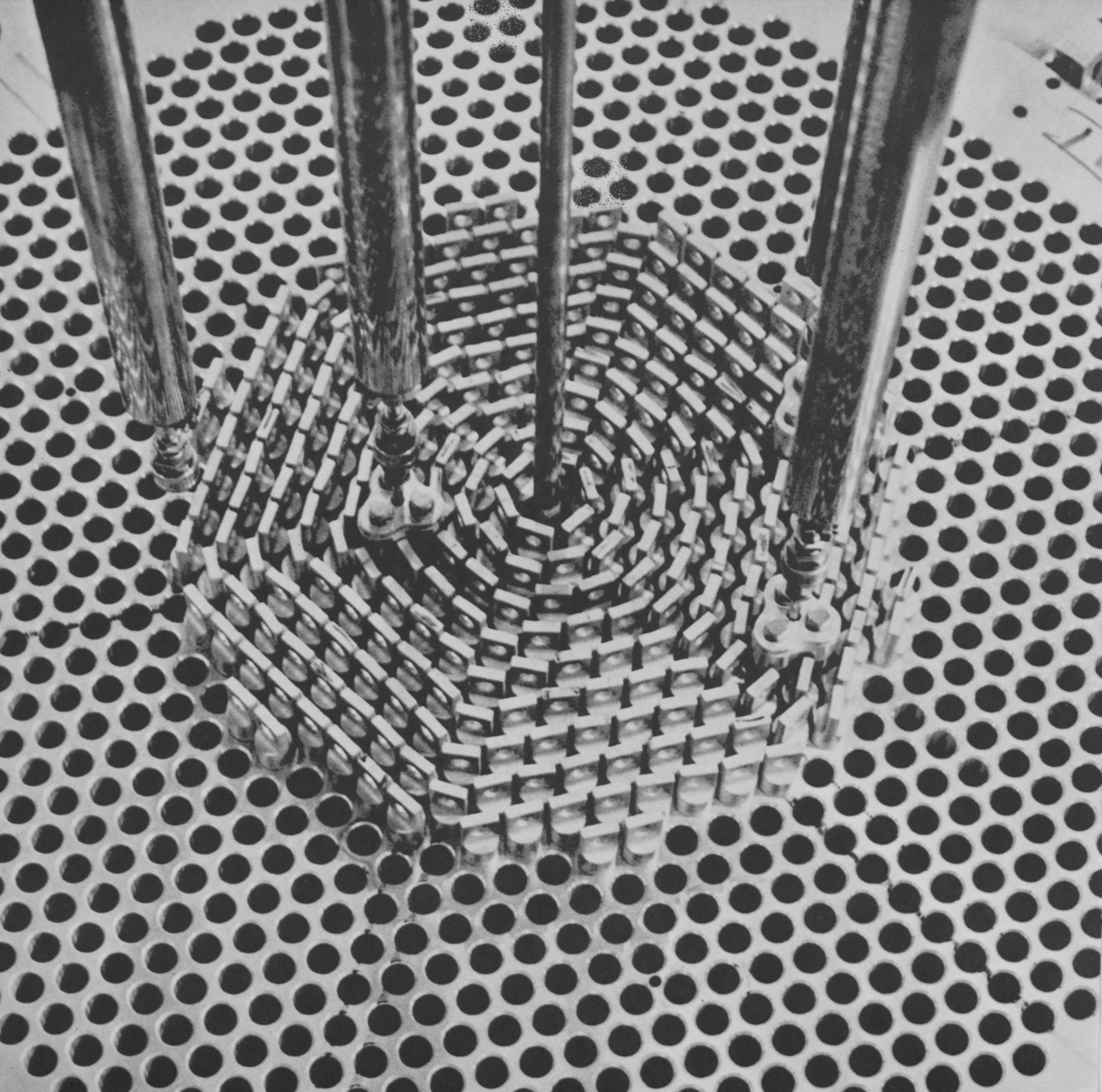
ELECTRICAL
POWER
PROSPECTS



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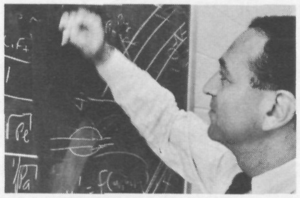

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Opposite: A closeup of the loading end of the unique Cornell zero power reactor (ZPR), used for basic studies in reactor physics and dynamics.

THE POWER INDUSTRY LOOKS AHEAD

By Philip Sporn

The future prospects of the electric power industry through the year 1980 have been the subject of several extensive studies; being a period of only twelve and a half years, its technical-economic outlines may be readily projected. It is a period in which there will be major changes in the sources of electrical energy generation. What these changes will mean, mainly for energy generation but also for transmission and distribution, will be discussed here.

GENERATION

Growth in the Recent Past

In the period 1960–66, the average annual rate of growth of electrical energy consumption in the United States was 7.24 percent. Except for the recession year 1961, when the increase was 5.5 percent, the annual increase in electrical energy consumption in each year exceeded 7 percent, and in 1966 was just short of 9 percent. During 1967, energy consumption exceeded that of 1966 by 7 percent.

Growth in noncoincident peak load in the same period was generally comparable to growth in energy consumption. For the period as a whole, the average annual increase was 7.34 percent, with a high of 9.15 percent occurring in 1966. The lowest growth periods were 1961 with 5.79 percent, 1963 with 6.6 percent, and 1965 with 6.5 percent.

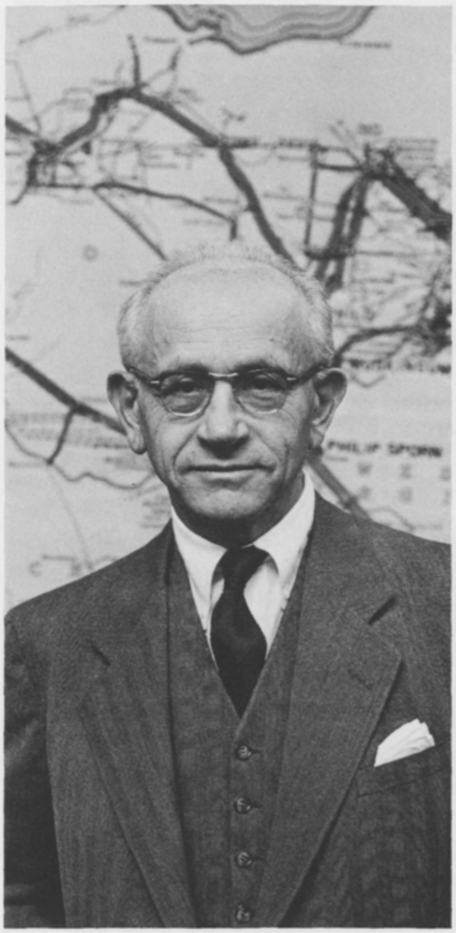
In 1967, the generating capacity which was added to that already available amounted to 19,471,000 kilowatts (kw), of which 3,044,000 kw was hydro power, 14,588,000 kw was conventional thermal power, 1,793,000 kw was gas turbine and diesel power, and 46,000 kw was nuclear power. This additional amount, which increased the generating capacity of the nation's utilities by 7.9 percent, brought the country's total capacity to 268,000,000 kw.

Growth Projections to 1980

Experience has clearly shown the danger of carrying out any important planning in electric power on any basis other than long-term trends in the use of energy. The essential quantity in electric use is energy use; in a final showdown, demand, load factor, and capacity factor can all be adjusted, and the necessary work of any industrial society can be successfully executed, if the requisite inanimate energy, usually electrical energy, is available.

The graphs on pages 4 and 5 show a projection of electrical energy generation and capacity through 1980. They and Table 1 give some very important information about the development of the electric power industry in the next thirteen years:

1. Growth will continue to be dynamic, although by the end of 1980, it will have slowed to an annual rate of 6.0 percent.
2. Total electrical energy generation will, by 1980, reach an annual figure of 2,820 billion kilowatt hours (kwh), and the total installed capacity will reach 575 million kw.
3. By 1980, installed nuclear capacity will have reached 130 million kw, almost 25 percent of the projected national total.
4. Total annual capacity installed during the 1975–80 period will amount to approximately 25 million kw, of which half will be



nuclear. The remaining half will be 2 to 3 million kw of hydro power with the rest provided by fossil fuel.

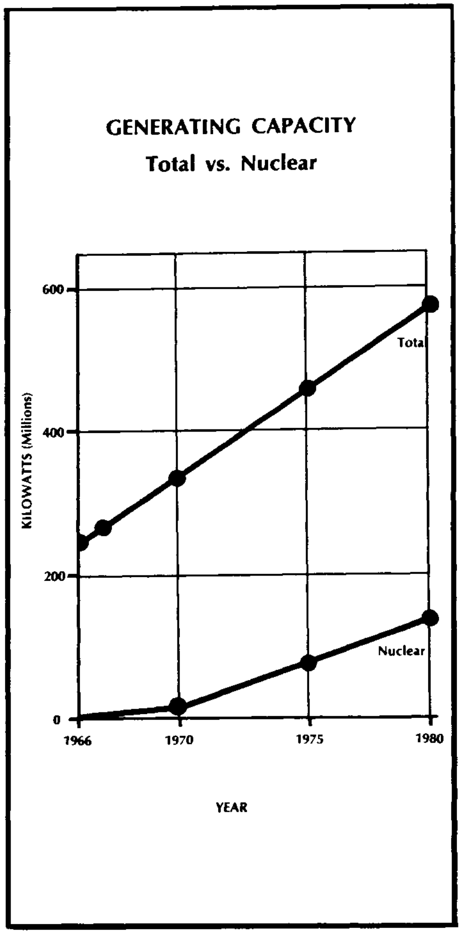
Size of Units

One of the effective steps that the electric power industry has taken to combat rising costs has been to increase unit sizes. A study of the prospects for further size increases shows several interesting factors.

Fossil-fueled Generation (Cross-Compound)

Utilization of an integrated steam system to drive separate high-pressure and low-pressure turbo-alternators (cross-compounding) has made possible significant increases in installation sizes. The Tennessee Valley Authority's Bull Run Unit No. 1, just outside Knoxville, is the largest installation of this type in the United States. The high-pressure turbine drives an alternating-current generator (alternator) at 3,600 revolutions per minute (rpm). The low-pressure turbo-alternator turns at 1,800 rpm. Steam terminal conditions are 3,500 pounds per square inch (psi) with 1,000°/1,000° reheat. Net output of the unit is 914 megawatts (Mw), and with a wide-open throttle, the total output would be approximately 5 percent higher, or 960 Mw. The stationary windings (stator) of the 3,600 rpm alternator are water cooled with gap-pickup hydrogen cooling on the rotating windings (rotor). The 1,800 rpm alternator is also water cooled on the stator but with straight hydrogen cooling on the rotor. The boiler consists of two separate units which are connected like Siamese twins.

TVA's new Cumberland plant, located on that river slightly upstream from Paducah, will consist of two Brown-Boveri generating units which are cross-compound at 3,500 psi with 1,000°/1,000° reheat. Each component will have essentially the same generating capacity, and there will be duplicate alternators, a water cooled one on the stator and a hydrogen cooled one on the rotor. The single-shell boilers will have divided furnaces and three separate cavities.



Fossil-fueled Generation (Tandem Compound)

A number of large tandem-compound turbo-alternators are now in operation. Each of these units consists of a reheat steam turbine driving a single alternator. The largest tandem units now in service have generating capacities of approximately 600 to 640 Mw. In the case of the Cardinal Plant at Brilliant, Ohio, two 3,600 rpm, 615 Mw tandem units are in operation at steam terminal conditions of 3,500 psi, 1,000°, with double reheat at 1,025° and 1,050°. Other similar single reheat units operate at 1,000°/1,000° reheat. Tandem compound alternators are water cooled on the stator, and gap-pickup hydrogen-cooled on the rotor. On the American Electric Power Company system, five 800 Mw single-shaft, 3,500 psi units with double reheat are now under construction, four of them by the General Electric Company, and one by the Westinghouse Electric Corporation. These, when they go into operation within the next three years, will be the largest single-shaft machines operating in the United States.

Nuclear-fueled Generation

The advent of the nuclear reactor as a primary source of energy is perhaps the most important factor in the trend toward larger generating units. The average electrical output of nuclear-fueled turbo-alternators now on order is approximately 800 Mw as compared with the 600-640 Mw units previously described. These large, single-shaft, tandem-compound machines are designed to operate at steam conditions which are far less extreme than those of conventional thermal units. All, without exception, utilize relatively low pressures and low temperatures. Their turbines operate at throttle pressures ranging from 695 pounds per square inch gauge (psig) to 900 psig, and the most typical terminal temperature is 540°F. Thus, they operate at close to saturation temperature, possibly as high as 30° to 35° superheat.

Of the reactors on order as of December 31, 1967, nine General Electric units and seven Westinghouse units have a rating of 1,000 Mw or above. The largest General Electric reactor has a rating of 1,130 Mw, and the largest Westinghouse unit has a rating of 1,100 Mw. There is every indication that larger-sized conventional and nuclear units will be called for in the immediate future and will certainly be called for before the end of 1980. For conventional units, ratings as high as 1,500 Mw may be called for but will not be exceeded in single-shaft design units. The size of atomic power machines, where size may offer a greater capital savings dividend than is possible to obtain with coal-fired high-pressure boilers, may reach as much as 1,650 Mw. From every indication, unit sizes between now and 1980 will fall within the following limits:

Conventional 3,600 rpm, cross-compound, maximum size: 1,650 Mw

Conventional 3,600 rpm, tandem-compound, maximum size: 1,350 Mw

Nuclear tandem, 1,800 rpm, maximum size: 1,650 Mw

These predictions are based on the economic logic that no plant is a good one if it consists of but a single unit. Many factors, such as system, steam, and electric, support this judgment. Probably the best number of units for a single plant is three. A plant of 4,000 Mw would consist of three 1,350 Mw units; a plant of 5,000 Mw would consist of three 1,650 Mw units. At $125 per kw of installed capacity, the 4,000 Mw plant would represent an investment of $500 million, and the 5,000 Mw plant would represent an investment of $625 million. There are very few industrial complexes anywhere in the world today, in the steel, automotive, chemical, or oil refining industries, where more than $500 million has been invested at a single site, and, indeed, economic conservatism militates against investment of a greater amount at one

POWER GENERATION
(Kilowatt Hours)

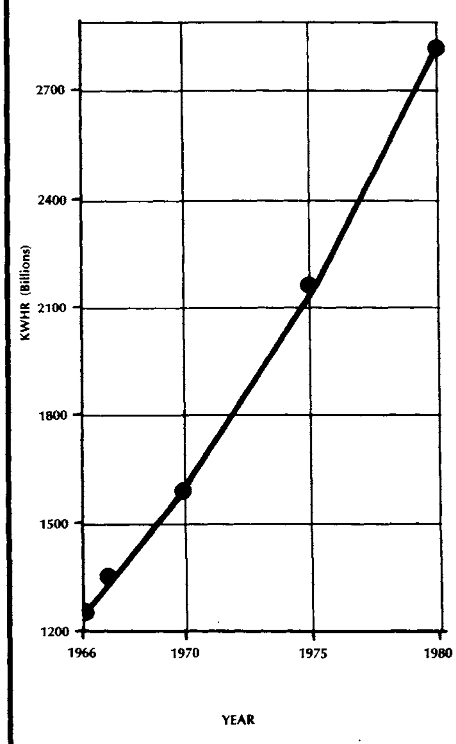


TABLE 1
Projections of Commissioned Electrical Energy Capacity

Year	Increment in Energy Consumption	Commissioned Total Capacity (thousands kw)	Commissioned Nuclear Capacity (thousands kw)
1966	9.0%		
1967	7.0%	21,000	430
1970	6.5%	24,000	2,750
1970-1975	6.3%*	23,000*	12,000*
1975-1980	6.0%*	24,000*	12,000*

*Average per year for each of the years shown.

location. Considering economics and other factors such as pollution control, the optimal size of the plant of the future will probably range from 4,000 Mw to 5,000 Mw, and the maximum size of its units will range from 1,350 Mw to 1,650 Mw.

TECHNICAL TRENDS

The technical trends relating to conventional plants can be gathered from a study of the characteristics of the plants ordered during the past year. Of the 103 conventional thermal units of 10 Mw or more reported by the manufacturers between May 1, 1966, and June 30, 1967, forty were larger than 500 Mw. Of these forty, twenty-five were supercritical at 3,500 psig. In the case of two units, double reheat is employed with temperatures of 1,000°/1,025°/1,050°. In the other twenty-three, there is only single reheat at 1,000°/1,000°. The sixty-three units under 500 Mw use subcritical steam conditions with either 2,400 psig, 1,000°/1,000°, or 1,800 psig, 1,000°/1,000° reheat. Of the 103 units, eighteen were single casing, eighty-one were tandem-compound, and four were cross-compound.

All thirty-six nuclear units studied operate at 1,800 rpm, with throttle pressures ranging from 695 to 950 psig. The most frequent pressure is 950 psig, with thirteen out of thirty-six units at this pressure. (Three units were as low as 695 psig, one unit was at 900 psig, and six were at 885 psig.) The most representative terminal temperature is 540°, with thirteen units out of thirty-six having this temperature. In each case, 540° accompanied 950 psig. The highest temperature used was 566°, and this was in combination with 885 psig and, in one case, 900 psig. Eighteen units utilize single reheat and eighteen use no reheat. Reheat temperatures ranged from 379° accompanying 765 psig and 513° initial temperature to 541° reheat with 885 psig and 566° initial temperature.

LOCATION OF FUTURE POWER PLANTS

As might be expected, current thinking about the location of power plants, especially nuclear power plants, has been greatly influenced by the experience gained in siting conventional power plants during the past eight decades.

The first power company systems in the United States developed in such cities as Boston, New York, Philadelphia, Cleveland, Toledo, Chicago, Pittsburgh, St. Louis, Los Angeles, and San Francisco. All of these cities had original Edison systems, in which the power plant was located at the center of the load area. Because of the low electric grid voltage—230 volts—the load area for each plant in this system was necessarily limited to a few square blocks.

This system design had considerable influence on plant location in the early days of the industry, and it also affected the industry's philosophy with regard to service and service areas. At a famous conference held some twenty-five years after the beginning of Edison service in New York in 1883, some of the bright young people in the industry argued successfully for a rate-making theory which reserved the lowest rates for urban areas and sharply increased the rates for areas just a short distance from the high-density community center. Consequently, many of the original large city systems neglected to develop service beyond the city limits and thus lost the opportunity not only to serve these potentially attractive areas, but also to locate their plants outside city limits. As a result, they didn't master the technique of bringing in a major power supply from these areas by transmission. In the 1890's, the transmission voltages for such blocks ranged from 12,000 to 25,000 volts and today range up to 765,000 volts. A new power supply system in which the principal transmission for delivering power from outside the city is at 750,000 volts is being planned for Paris by the Électricité de France.

Some large cities are now bedeviled by the difficulties of adhering to the old practice of locating generators close to the load because of the pollutants that are produced mainly by the burning of sulphur, either in coal-fired or oil-fired generation. Because of the utilities companies' past failure to develop the necessary transmission systems, they find it difficult to establish themselves outside city limits where the populations are less dense, and where conventionally fueled plants would not contribute more filth to the already polluted city air.

A number of utilities in some of our very large cities are solving the pollution problem by turning to nuclear rather than to fossil fuel. Some, notably the Consolidated Edison Company of New York, have actually announced the building of their last conventional fossil-fuel plants.

The change to nuclear generation to reduce pollution has created problems that may be equally hard to solve. Because utilities have had only limited experience in operating nuclear plants, the regulatory agencies have so far not approved their construction in highly populated areas. Nuclear plants, therefore, may continue to be located thirty to fifty miles from urban load centers. The problem of transmitting power to urban load areas remains.

Table 2 lists the sites chosen by several utilities companies for their nuclear plants. Note that the average population within a five-mile radius of the nuclear plants is less than 12,000, and that the average population within a ten-mile

"It would appear that not until after 1980 will a major reactor be developed on a site within or close to a major metropolitan center."

radius is scarcely more than 50,000.

Yet a number of large metropolitan utilities have attempted urban construction. Consolidated Edison of New York and the Boston Edison Company each proposed to the Atomic Energy Commission several years ago that units be installed within the cities. Consolidated Edison proposed to build a nuclear plant at their Ravenswood plant site in the borough of Queens, almost directly across the East River from the United Nations building. Boston Edison announced that it had placed an order with General Electric to build a plant within the city limits of Boston. After several months in which objections were vigorously presented in New York, Consolidated Edison withdrew its application for a construction permit. In Boston, General Electric and Boston Edison decided to postpone their construction plans, so Boston Edison did not go through the proceedings necessary to obtain a construction permit.

Despite these setbacks, the utilities industry continues to press the problem of urban siting with the Commission. But both parties require further experience with nuclear power before the Commission can permit urban siting.

That experience is now being gained in the installation of some 60,000 Mw of atomic reactors that have been ordered within the last two and a half years by the utility systems of the country. But until a substantial part, if not all, of this reactor capacity has been operated, there can be no solid basis for eliminating the restriction on urban siting.

Thus, it would appear that not until after 1980 will a major reactor be developed on a site within or close to a major metropolitan center. The nuclear power plants now being developed to serve these communities will be located in the less populous surrounding areas, as much as twenty to thirty miles or more away from the load centers. The generation capacity thus developed will have to be brought to the load centers by the best transmission methods available. Alternating current is the most likely, but direct current remains a possibility.

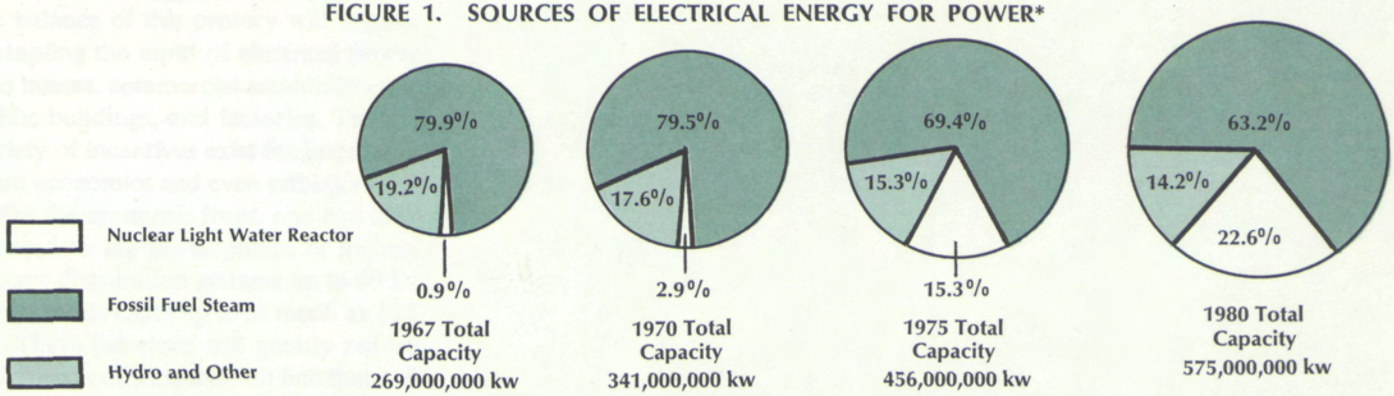
FUTURE MIX OF GENERATING CAPACITY

A question frequently asked is: What will be the energy mix among fossil-fuel steam, nuclear light water, nuclear fast breeder, hydro, and other sources? Projected answers are presented in Figure 1. A particularly intriguing question concerns the role of the fast-breeder reactor (FBR). As Figure 1 shows, by 1980 there will be no FBR commercial capacity of any significance, but it is likely that breeder reactors will be successfully developed in the 1980's. Then large amounts of plutonium will have been accumulated as a result of the operation of the light-water reactors (LWR) that have been ordered in the last two and a half years and reactors that will be ordered between now and 1975–76 for installation by 1980.

The kind of FBR that will first be successful is not certain. Top priority is being given to the development of the sodium-cooled FBR, but its early success is not assured. Below is a "guesstimate" of this reactor's development timetable between now and 1980.

First prototype	1972
First demonstration unit	1976
First commercial unit	1980

FIGURE 1. SOURCES OF ELECTRICAL ENERGY FOR POWER*



*No energy generation is projected from the fast-breeder reactor source before the 1980's.

TRANSMISSION

At the end of World War II, the highest transmission that existed in the United States was 132,000 to 220,000 volts, except for a single line of 287,000 volts which was operating between Boulder Dam and Los Angeles. It was generally thought that the need for additional transmission either at existing or higher voltages had disappeared in the United States. This had some very severe consequences, not the least of which was the abandonment of a number of high-voltage research laboratories at such major institutions for engineering education as Purdue and Stanford Universities. No judgment could possibly have been more wrong.

The War had scarcely ended before a major program of research was undertaken on the American Electric Power Company's system on a voltage range up to 500,000. This study was the basis for the subsequent construction of the first 345 kilovolt (kv) transmission lines and, some years later, for the first 500 kv transmission lines in the world. By the end of 1967, 9,050 miles of 345 kv transmission line were in operation in the United States, plus close to 4,000 miles of 500 kv transmission line. Only fourteen years after the first 345 kv line went into service, there was projected, again on the American Electric Power Company system, a transmission network of over 1,100 miles of 765 kv. The first lines of this network will be operational in 1969, and it will expand to almost 1,700 miles by 1973. Meanwhile, a rapid increase in both 345 kv and 500 kv transmission will take place during the six-year interval between 1968–73, more than doubling the mileage of 345 kv lines to 20,770, and of 500 kv lines to 11,170.

This progress comes about as a result of the trend of American power systems to double in power output every ten years; it is also a result of a belated recognition of the important function of extra-high voltage transmission not only to furnish the mechanism for bulk energy transportation but also to integrate and coordinate power systems. The drive to bring about these important technological improvements in power systems performance is further supported by the fact that it produces great economic advantages. Thus, in going from 345 kv to 765 kv, the capacity per circuit on a typical system rises from 500 Mw to 2,500 Mw, and the specific cost of transmission is cut by about 45 percent.

Power systems are going to grow at substantially the present rate for at least the balance of the century. It is fortunate, therefore, that a great deal of research and experimental work on voltages over 760 kv is being done. What these voltages are going to be has not yet been determined. The first increase will most probably be to 1,050 kv or above, perhaps to as high as 1,150 kv or 1,300 kv; it may, however, be as high as 1,500 kv.

DISTRIBUTION

Distribution is usually thought to be a prosaic part of an electric utility system plant to which no imagination and no ingenuity—in other words, no engineering—can be brought. But this is to forget not only that distribution is generally the one item of the system plant involving the largest investment, but

TABLE 2. NUCLEAR PLANT SITES AND SURROUNDING POPULATION DENSITIES

Site	Plant Capacity (Mw)	Population			Date of Population Census
		0-5 mi. radius	0-10 mi. radius	0-30 mi. radius	
Browns Ferry, Alabama	3,248	20,000	31,000	214,000	1960
Zion, Illinois	2,200	56,160	193,360	927,910	1965*
Diablo Canyon, California	1,065	12	1,572	87,610	1960
Dresden, Illinois	1,818	2,600	22,600	350,000*	1960
D. C. Cook, Michigan	2,200	7,100	46,000	503,000	1965
Oyster Creek, New Jersey	640	39,000	102,000	———	1960
Turkey Point, Florida	1,442	0	42,400	828,200	1960
Surry, Virginia	1,600	800	40,000	504,000	1960
Palisades, Michigan	821	4,600	20,000	202,000	1960
Peach Bottom, Pennsylvania	2,130	6,150	40,000*	———	1960
Total	17,164	119,222	518,932		
Average		11,922	56,893	*Estimated	

also that the energy needs projected for the balance of this century will involve sextupling the input of electrical power into homes, commercial establishments, public buildings, and factories. Thus, a variety of incentives exist for improving plant economics and even esthetics.

On the economic front, one can look forward to the development of higher-voltage distribution systems up to 69 kv and in many cases up to as much as 132 kv. These increases will greatly reduce the amount of transmission line that will have to be spread over the country and will aid the industry in eventually placing the distribution system underground. Much technical ingenuity will be required to bring this about. Fortunately, the main technical problems—such as insulation, overvoltages, and switching and clearing—in dealing with the distribution of these high voltages have been fairly well solved during the many decades when all these higher voltages served a transmission function. But the use of these voltages in distribution will certainly create many new problems and will, without question, present new challenges to engineers and technologists of the future.

Philip Sporn, a director and consultant to the American Electric Power Company, earned the degree of Electrical Engineer in 1917 from Columbia University and did graduate work there in 1917–18. He has been the recipient of honorary doctoral degrees from more than a dozen colleges and universities including Stevens Institute of Technology, Illinois Institute of Technology, the Polytechnic Institute of Brooklyn, The Ohio State University, Columbia University, the University of Grenoble in France, Technion–Israel Institute of Technology in Haifa, and Rensselaer Polytechnic Institute.

Mr. Sporn began his distinguished career with the American Electric Power Company in 1920. From 1934 to 1945, he was vice president and chief engineer, becoming executive vice president in 1945. He was named president and a director of the twenty companies in the American Electric Power Company system in 1947. In 1961, having reached retirement age, he became chairman of the Company's newly created System Development Committee while continuing as a director and a member of the Executive Committee. In 1967 he assumed his present duties. He has served as president and director of the Ohio Valley Electric Corporation from 1952 to 1967; chairman of the Research and Development Committee, East Central Nuclear Group, from 1958 to 1967; chairman of the Atomic Energy Commission's ad hoc advisory committee on cooperation between the utility industry and the Commission in 1949; member of the United States Delegation to the Geneva Conference for Peaceful Uses of Atomic Energy in 1955 and of the National Commission on Technology, Automation and Economic Progress in 1965–66; chairman of the Sea-Water Conversion Commission of Israel from 1959 to the present; member of the United States Department of Commerce's technical advisory board on electrically powered vehicles in 1967; member of the advisory council of Cornell's College of Engineering.

A fellow and honorary member of the American Society of Mechanical Engineers and the Institute of Electrical and Electronics Engineers, Mr. Sporn is also a fellow of the American Society of Civil Engineers and a member of the National Academy of Sciences and the National Academy of Engineering. Last July, he was elected honorary fellow of the Institution of Mechanical Engineers of Great Britain. He has been the recipient of numerous awards and honors including the Chevalier of the French Legion of Honor; the Edison Medal of the Institute of Electrical and Electronics Engineers; the John Fritz Medal of the founder engineering societies; and the American Society of Mechanical Engineers' own medal.

Recently, the Philip Sporn Professorship of Energy Processing was established at M.I.T. by electric utilities and electrical equipment companies throughout the country. Another chair named for Mr. Sporn is the Philip Sporn Professorship of Electric Power Systems Engineering at Rensselaer Polytechnic Institute.

PROSPECTS FOR CONTROLLED FUSION

By Peter L. Auer

It is inevitable that the world's electric power requirements will be furnished primarily by nuclear energy. There are already signs that the days of conventional fossil fuel-fired steam plants are numbered. In certain sections of the country, especially the Northeast, nearly all orders for new generating plants are for nuclear units. The reason for this conversion is primarily economic; in many areas it has become cheaper to erect and operate nuclear plants than conventional ones. Yet two major questions are still unanswered: Will future power-generating plants be *fission* or *fusion* breeders or a mix of both? And what is the time scale for the transformation to an all-nuclear technology?

Today's nuclear reactors are "converters". To generate energy, they consume more fissionable material than they make. Such converters can hardly qualify as long-term suppliers of electricity, since they would eventually exhaust all available fissionable material. Fortunately it is possible to design reactors that generate energy and at the same time produce more fissionable material than they consume. Known as "breeder" reactors, their primary fuel is the virtually inexhaustible supply of naturally occurring uranium or thorium.

The feasibility of fission breeder reactors was demonstrated several years ago. Because breeder reactor technology is still in its infancy, however, many years of development work still lie ahead before breeders can compete with converters. There is no urgent need for acceleration in our breeder development programs; there is a sufficient supply of fissionable material on hand to fuel converters for the foreseeable future. Neither has there been urgency pushing the converter development of the past two decades; fossil fuel is as plentiful today as it was then. In other words, research and development in new forms of energy production must be stimulated by a policy of vision which can foresee the benefits well before the actual need arises.

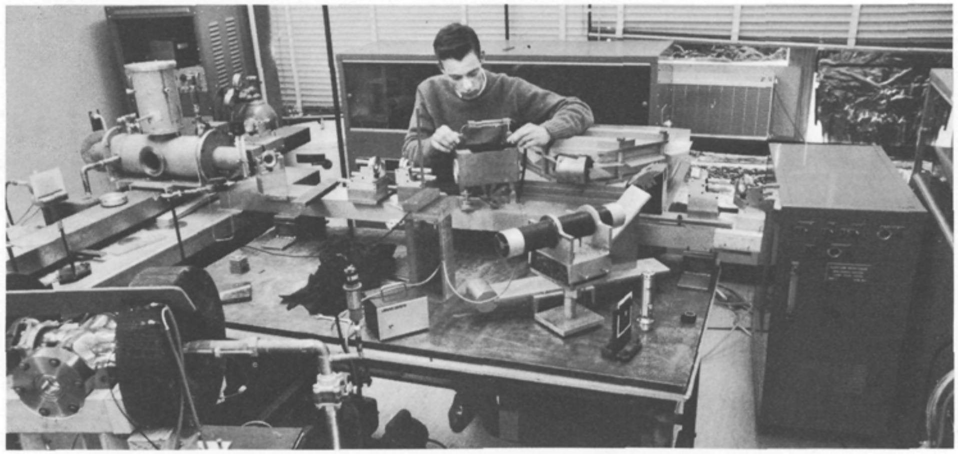
WHY FUSION?

Although the principle of fusion (the reactions resulting from the rearrangement of certain light elements, with subsequent energy release) was discovered several years before that of fission, no one has yet demonstrated the feasibility of a self-sustaining fusion reactor. Why then, you may ask, is it necessary to be concerned with fusion power when fission reactors have a considerable lead in development and can supply all our foreseeable energy requirements.

In the first place neither alternative, fission or fusion, has been clearly proved the better. It is far too early to make a final choice and put all our money on either horse. Furthermore, fusion reactors will produce few if any long-lived radioactive products. They are also likely to be inherently safe, avoiding problems and risks of nuclear runaway accidents. There is even a chance that pure deuterium burners may generate electricity directly, thereby eliminating the extra complication of heat exchangers and associated equipment common to steam cycles.

Perhaps an overriding argument in favor of the pursuit of fusion research is that it has captured the imagination of many highly talented scientists and engineers throughout the world. But there are even political implications to consider in the fission versus fusion contest. The issue of nuclear proliferation is very much with us today. Unfortunately a fission reactor industry contains almost all the elements required to produce nuclear weapons. How do we en-

The dynamical behavior of full-ionized plasmas is studied under conditions where ordinary collisions are not important and where collective plasma effects dominate. The plasma wind tunnel produces neutral plasma streams at speeds of 10^7 cm / sec or more over a time interval of 10^{-3} sec.



force a code designed to keep nuclear weapons from proliferating once the tools for fabricating these weapons become readily available? This is not to imply that a fusion reactor cannot be diverted to produce clandestine weapons material. But there are significant qualitative differences between the two, and it should be easier to monitor fusion reactors to guard against infractions.

A FUSION PRIMER

A variety of nuclear rearrangement reactions involving light elements result in the release of energy. All may be termed "fusion," but the ones of interest to the controlled thermonuclear program involve the three isotopes of hydrogen—hydrogen (H^1), deuterium (H^2), and tritium (H^3)—as well as the two isotopes of helium (He^3 and He^4) and the neutron (n). The reactions of interest are expressed in the following equations.

(1) $H^2 + H^2 = H^3\ (1.0) + H^1\ (3.0) + 4.0\ \text{MeV}$

(2) $H^2 + H^2 = He^3\ (0.8) + n(2.5) + 3.3\ \text{MeV}$

(3) $H^2 + He^3 = He^4\ (3.7) + H^1\ (14.7) + 18.4\ \text{MeV}$

(4) $H^2 + H^3 = He^4\ (3.5) + n(14.1) + 17.6\ \text{MeV}$

In each equation the last number indicates the amount of energy released measured in units of millions of electron volts. The figures in parentheses indicate how much of this energy shows up in each of the reaction products.

Reactions similar to those expressed above are responsible for the production of energy in the sun and the other stars in our universe. On earth we have mastered the uncontrolled release of this power through the hydrogen bomb. Our task now is to tame this power and put it to peaceful use.

Deuterium occurs in nature in the ratio of 1 part to 6,000 parts of ordinary hydrogen. It is found wherever water exists. Through the chain of reactions expressed above, 1 gallon of sea water could produce as much energy as 350 gallons of gasoline. The cost of recovering the deuterium from the sea water would be about 4¢ in this example. If we assume that power demands will

"The stuff stars are made of, our sun included, is plasma."

Opposite page and left: A giant Q-spoiled laser can be focused to produce small "fireballs" of very dense and hot plasma with initial expansion velocities greater than 10^7 cm / sec. Professors Peter L. Auer, director of the Laboratory of Plasma Studies, and P. C. Tobias de Boer of aerospace engineering head work in this general area of collision-free plasmadynamics.

continue to increase according to present trends, it would take some ten billion years to exhaust the supply of deuterium contained in the oceans.

Tritium, however, is radioactive and decays so rapidly that it does not occur in nature significantly. It may be created by nuclear reaction from lithium, a more plentiful, naturally occurring element. So even in the initial phases, fusion reactors need "rocks" to the same extent that fission breeders do, uranium, thorium, and lithium all being found in the earth's mantle.

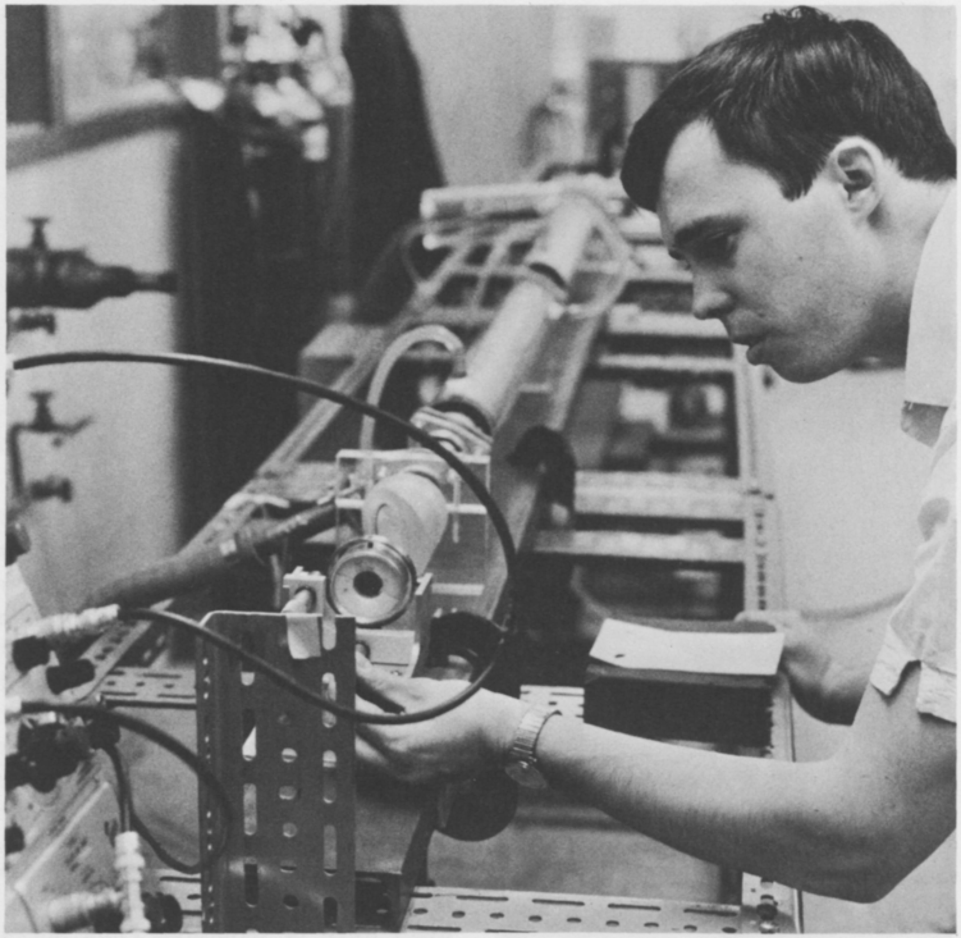
You may ask why fusion energy seems so much more difficult to generate than fission energy. Nature has been kinder to fission, having provided a neutral catalyst, the neutron, to activate the nuclear chain reaction. Since fission reactions involve neutral reactants, they can proceed readily at room temperature. The rearrangement reactions of fusion, however, involve *charged* nuclei of hydrogen and helium isotopes. Each has a positive charge, so the reaction tends to be inhibited by the coulomb force of repulsion. Only nuclei traveling at high speed can surmount the coulomb barrier. High speeds imply high temperatures; in fact it is estimated that a temperature of 400 million degrees will be required to "ignite" a self-sustaining deuterium reactor.

The deuterium-tritium reaction (equation 3 above) proceeds somewhat more readily than one involving deuterium alone, and it is estimated that a temperature of 50 million degrees would be sufficient to ignite it. Largely because of the lower heat requirement, it would seem that deuterium-tritium reactors will be the first fusion units to be made commercially available. Tritium, however, must be generated, and some means must be provided to accomplish this. As is indicated by equation 4 above, neutrons are produced in the deuterium-tritium reaction; these neutrons can be captured in a blanket containing lithium to produce additional tritium. Thus, the deuterium-tritium reactor will in fact be a breeder.

THE PROBLEMS

The two major problems in fusion research today are (1) to find the means of heating reactants to these extremely high temperatures and, having found them, (2) to contain the reactants at these temperatures long enough for fusion to produce a net gain in energy output. Of the two problems, the latter appears to be the more difficult to solve.

In the sun the large mass provides enough gravitational attraction to contain the plasmas of hot gases. The weight of the material is sufficient to compress inner regions to high temperature. On the earth the only feasible way to contain extremely hot reactants for reaction times at least on



Professors Chung L. Tang and George J. Wolga of electrical engineering head research work in nonlinear optics and rare gas lasers. Nonlinear optics work at the Laboratory of Plasma Studies involves studies of the optical parametric process in nonlinear optical crystals and the interaction of light waves with phonons in liquids and solids. Ionized rare gas lasers study includes calculations of approximate wave functions, lifetimes, and transition probabilities for all the laser states in the important rare gas ion lasers. Detailed experimental measurements of excited state population densities are being made under various conditions to determine the nature of the excitation and relaxation mechanisms in these lasers.

the order of seconds is by means of magnetic fields. At these high reaction temperatures, the electrons in hydrogen and similar materials of low atomic weight are stripped from the atom. This stripping produces a fully ionized gas, consisting of equal numbers of free electrons and residual positive ions.

Electrically charged particles spiral about magnetic field lines and can be localized in space. This characteristic permits the guiding of the motion of particles in such high energy accelerators as cyclotrons and synchrotrons. By suitably designing a magnetic field, it is possible to construct a kind of magnetic "bottle" that will hold low concentrations of electrons and ions for extremely long periods. An example of such a bottle is the Van Allen radiation belt which contains charged particles trapped in the earth's magnetic field.

ENTER PLASMA PHYSICS

Ionized gases are popularly referred to as plasmas. Any macroscopic collection of electrons and positive ions with an overall charge of zero and with prop-

"Research and development in new forms of energy production must be stimulated by a policy of vision which can foresee the benefits well before the actual need arises."

erties which are appreciably different from what would be expected of individual particle behavior may be considered plasmas. For example the motion of individual electrons and ions in applied electric and magnetic fields can be computed with considerable accuracy. From such computations we can construct schemes for speeding up the motion of charged particles to high energies, and these schemes are employed in linear and circular particle accelerators. But once there is a sufficient concentration of both electrons and ions, rather different "collective" properties dominate. Thus, a plasma will tend to screen out external electric and magnetic fields from its bulk; it is this phenomenon that occurs when radio waves bounce off the ionosphere and permit trans-Atlantic broadcasts.

For the most part our universe consists of plasma. The stuff stars are made of, our sun included, is plasma. The space between the stars contains little matter, but what there is of it is mostly plasma. A few miles above the surface of the earth, our atmosphere turns into a plasma to become the ionosphere and, beyond that, the magnetosphere. Only a few tiny specks of cold spots, such as the earth and similar planets or moons, contain regions free of naturally occurring plasma.

Plasmas are, in fact, the fourth state of matter. The application of heat to a solid will produce a liquid after the melting point has been reached; further heating will cause the liquid to boil and produce a gas. If we continue to add energy to ordinary gas and raise its temperature, the gas becomes ionized as the electrons are stripped away from their parent atoms and molecules. This condition represents the fourth state of matter, a plasma.

Irving Langmuir coined the term plasma in the 1920's when he found that ionized gases could support oscillation in a manner akin to gelatinous substances. In 1951 the first organized research thrust in the United States was begun on controlled nuclear fusion by the Atomic Energy Commission under the code name Project Sherwood. The Soviet Union began similar work at about the same time and so did Great Britain. All these efforts were tightly cloaked in secrecy until the summer of 1958, when every aspect of controlled thermonuclear research became declassified by mutual agreement. Since that time periodic meetings among parties to the agreement have been held under the auspices of the International Atomic Energy Agency.

Since 1958, most European countries (both western and eastern), Australia, and Japan, among others, have begun vigorous programs in plasma physics. This "population explosion" is certainly not due just to a scientific interest in fusion power. There are applications to space research; and certain schemes for energy conversion and a variety of military research projects require the use of plasmas somewhere in realizing their objectives.

Interest in plasma physics has also been generated within the various professional societies. For example, the annual meeting of the Plasma Physics Division of the American Physical Society now has an attendance of 500 or more. Even more impressive is the growth of interest within the academic community; there are now about seventy-five universities with plasma physicists on their faculties. Up until the last few years plasma physics teaching and research were conducted largely by converts who had been attracted to this new activity through their own research programs. Now universities are beginning to add faculty with graduate training in plasma physics itself rather than in related areas. Several of these men have spent some of their formative years on Project Sherwood or programs closely allied with it.

Cornell University's Laboratory of Plasma Studies was established just a year ago, and now some twenty faculty members—chemists, physicists, applied physicists, and men in several engineering disciplines—are affiliated with its programs. Of these, five engineering faculty members have been added within the last two years, all of them specializing in plasma physics.

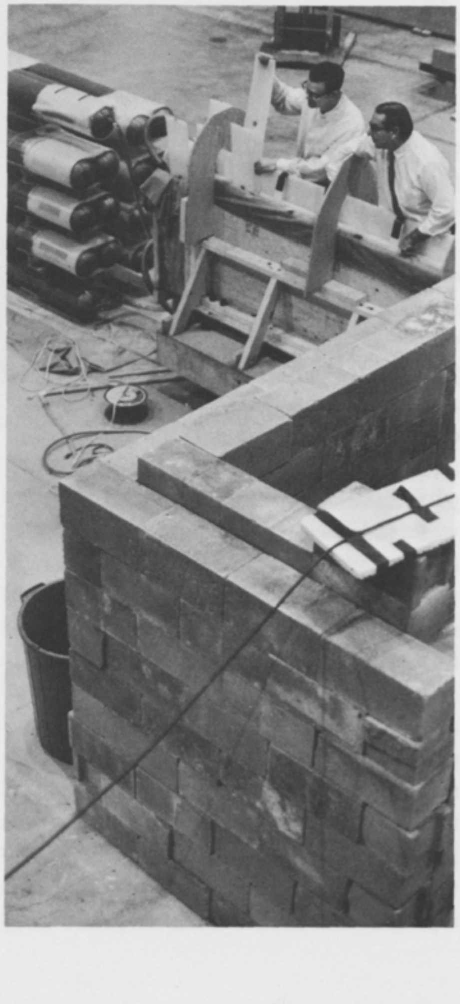
PROGRESS IN FUSION RESEARCH

Let us recall the two principal technical problems in fusion research: high temperature and containment. In the early stages of research a number of schemes for heating appeared equally attractive; it was obvious, however, that magnetic fields were the best means of containment.

There are two basic geometries employed in containment experiments, open-ended and closed. The open-ended configurations are axially symmetric; radial confinement is provided by the axial magnetic field. Escape through the ends is controlled usually by a "mirror effect" which reflects most escaping particles back into the plasma mass. End losses can be eliminated by closed configurations; in these cases the plasma volume fills a torus which may or may not resemble a doughnut and the geometry of the container need not have axial symmetry. Closed systems lead to more complications in designing the magnetic field, however, and in performing detailed experimental work.

Variations in duration of confinement also figure in experiments on plasma containment. Long-duration confinement schemes are essentially steady state and involve working with low-density plasmas, 10^{14} particles/cc

1



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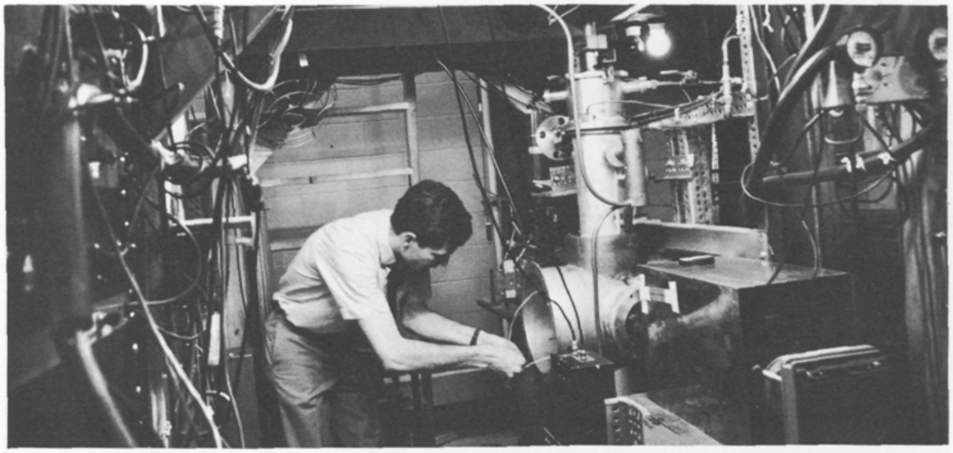


1. A team completing construction of a high-voltage pulse transmission line technically known as the "Blumlein." This apparatus produces large bursts of relativistic electrons over short intervals. The electrons are injected into partially evacuated drift tubes and allowed to stream freely over long distances (50 feet or more). In addition to the self-generated magnetic field of the electron stream, externally generated magnetic fields can be applied to the drift tube to guide the electron flow.

2. This 20 kw radio frequency heater provides a plasma over a pressure range of 0.1 mm Hg to atmosphere, with temperatures up to 20,000°K. A navy cannon is used to shoot nylon projectiles through this plasma at speeds up to 6,000 ft / sec. Through this kind of study in magnetohydrodynamics, such phenomena as forward facing waves and wakes, channel flows, body flows, the Hall effect, space charge effects, and non-equilibrium effects have been discovered. Professors Edwin L. Resler and Donald L. Turcotte of aerospace engineering head groups using this facility at Cornell.

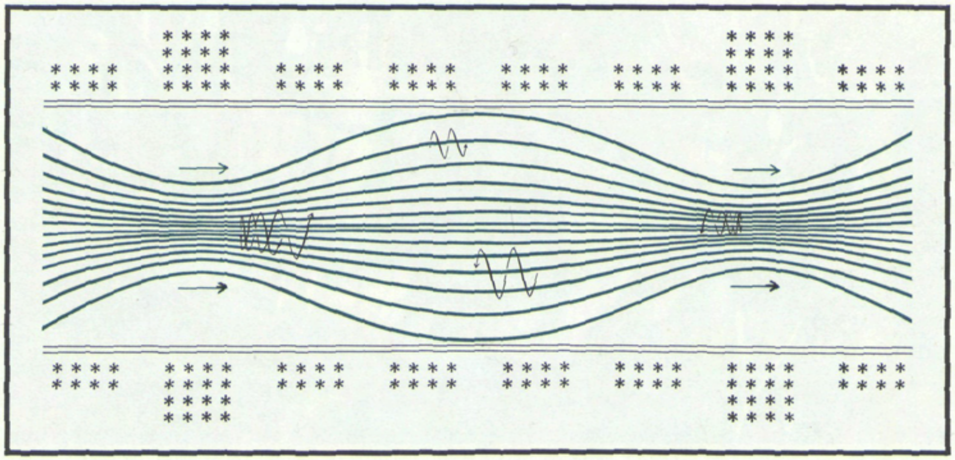
or less, for periods which should last about a second. Pulsed confinement schemes, on the other hand, are designed to operate for short durations on a repetitive basis; here the plasma densities approach 10^{18} particles/ cc and plasma lifetimes are a millionth of a second. To date, pulsed schemes have come the closest to demonstrating feasibility or approaching the so-called "figure of merit" criterion required for a self-sustaining reaction. This figure, a product of plasma density and confinement time, has been approached within a factor of 500 of the target value 10^{14} with plasma temperatures as high as 50 million degrees.

Plasma heating in pulsed devices is straightforward. A strong induced shock can raise the plasma to at least 10 million degrees, and additional heating takes place when magnetic forces compress the plasma. Similar phenomena take place in the outer reaches of the earth's atmosphere when the solar wind comes in contact with the geomagnetic field.

In open-ended configurations hot plasmas are produced indirectly. Positive ions are accelerated to modest energy levels in an external facility, converted to energetic neutral particles, and injected into the magnetic container. Upon crossing magnetic field lines, these high velocity particles respond to the electric field in proportion to their speed and local magnetic field strength. This provides a mechanism for ionization; additional ionization takes place when the neutral particles collide with plasma already trapped in the container. Such a method requires the employment of the most advanced high-vacuum techniques.

There are some interesting heating problems associated with toroidal experiments. The volume of plasma required is comparatively large and difficult to fill by injection from external sources. Once the plasma is inside the torus, electric current induced in the plasma produces resistive heating. Since the resistivity of a plasma drops rapidly with increasing temperature, however, this method fails above the million degree level. So-called plasma guns have been used to inject plasmas of a few million degrees in temperature into the

Figure 1



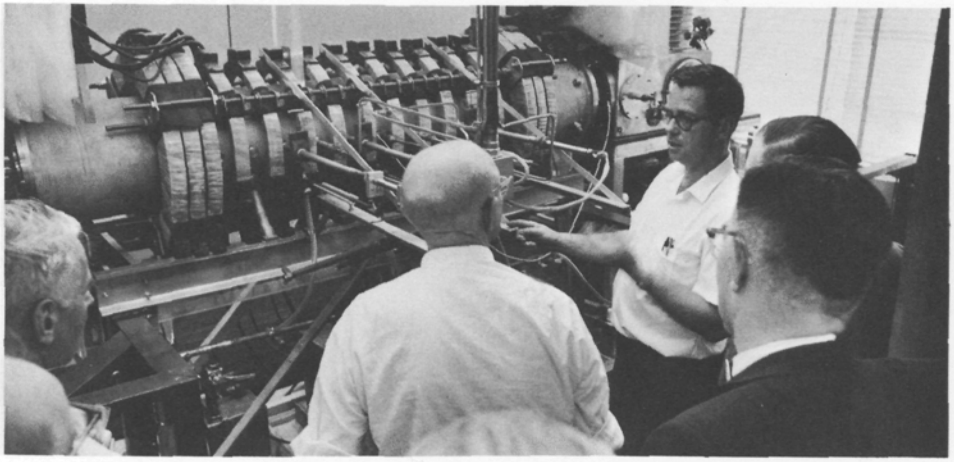
Above: Schematic view of "magnetic mirror bottle." The stronger magnetic field at each end of the container shown opposite bends the path of an approaching particle exerting a force which reflects it away from the ends of the bottle.

Opposite Page: A new facility for studying the mechanism of turbulent heating in fully ionized plasmas has been installed in the Laboratory. This device uses a "magnetic mirror bottle" as the container and is filled with plasma from two guns situated at opposite ends of the machine. Turbulence is induced by application of short pulses of high voltage across the plasma. A principal diagnostic technique utilizes the scattering of millimeter and sub-millimeter electromagnetic radiation off the turbulent plasmas. Professor Charles B. Wharton of electrical engineering explains the container to a group of reunion alumni.

torus, but controlling impurities becomes a serious problem in using this technique.

Only the limitations of our knowledge of instabilities stand in the path to success in fusion research. To illustrate one aspect of instability, let us consider a tumbler filled with water. The pressure of the water is exactly balanced by the pressure of the air at the water-air interface, regardless of whether the tumbler is upright or inverted. Why, then, does the water leave the tumbler if it is inverted? Gravity, you say? Well, yes, but the answer is not that simple. Before the water surface "breaks," some perturbation will ripple the surface. If the tumbler is upright, the ripple will die out and the water will stay put. When the tumbler is inverted, this ripple grows and lets air in to take the place of the water. This demonstrates the theorem that a light fluid cannot support a dense fluid *stably* against gravity.

An analogous relationship finds plasma as the dense fluid and a magnetic field as the light fluid, the curvature of the field playing the role of grav-



ity. The simple mirror machine has an unstable configuration: the curvature is in the wrong direction. This was troublesome until ingenious research solved the problem. (See Figure 1.) Another instability is brought about by the plasma distribution and configuration which is appreciably different from what would exist in thermodynamic equilibrium. This difference produces reservoirs of energy which feed the instabilities. How these and other instabilities can be controlled or overcome is proving an exceedingly difficult and equally engrossing subject for plasma physicists.

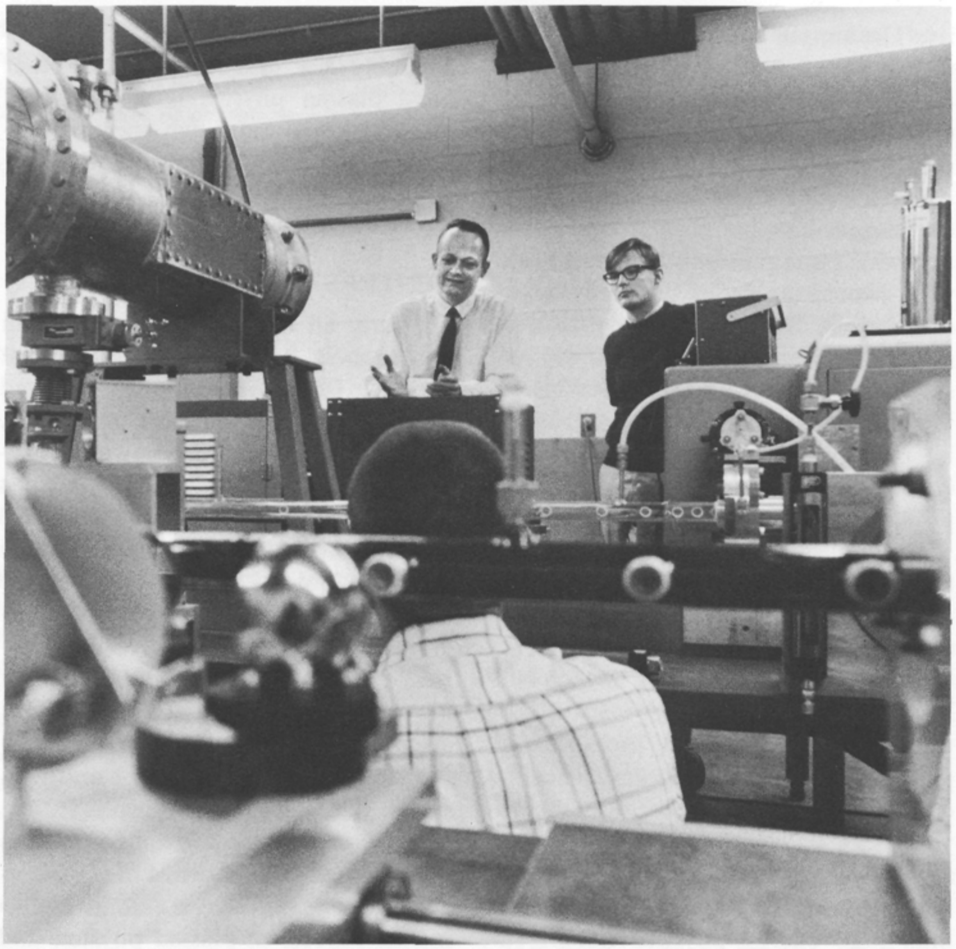
Controlled thermonuclear research today is just one of the more interesting areas of plasma physics. The overall thrust is not merely in the development of fusion reactors. Workers in the field have realized that first they must come to grips with the baffling mysteries of plasma physics. These days, socio-economic scales are the fashionable yardsticks by which research is measured. Given this standard, plasma physics is considerably less fundamental than high energy physics. Compared to nuclear reactor engineering, it is considerably less practical. On the other hand plasma physics is a good deal more practical than high energy physics and far more fundamental than reactor engineering.

PLASMA PHYSICS RESEARCH CENTERS

Nearly all major research efforts in this country have been undertaken at national laboratories. Four, operated by the Atomic Energy Commission, conduct fusion research: Lawrence Radiation Laboratory, Los Alamos Scientific Laboratory, Oak Ridge National Laboratory, and the Princeton Plasma Physics Laboratory. There are a few major confinement research programs outside of the captive laboratories, among them one at The University of Wisconsin and one at Gulf General Atomic, Incorporated.

Once the appropriate staff and necessary funding become available, we hope to develop major confinement experiments at Cornell. Most of our activities at present concern certain fundamental aspects of plasma physics, and

"Only the limitations in our knowledge of instabilities stand in the path to success in fusion research."



Investigations using molecular and chemical lasers include those of Professor Terrill A. Cool of mechanical engineering and his group on the measurement of vibrational relaxation times in CO_2 in high speed flows utilizing rapid mixing techniques.

we are in the process of forming a theoretical group whose major occupation will be with the problems of controlled fusion.

THE FUTURE

It is evident that there will continue to be wide interest within the technical community in enhancing our knowledge of plasma physics and increasing the prospects of controlled thermonuclear reactors. At the same time there is a growing demand to measure the potential benefits of systems yet to be invented in order to determine whether or not it is economically desirable to make the invention. In the hands of the "properly enlightened," such economic forecasting or system analysis may provide relevant information for use in setting long-range research plans. The problem in the proper interpretation of these studies, of course, is to safeguard against throwing out the baby with the wash.

While it is quite obvious that our concept of future fusion reactors is based on conjecture, one can conceive engineering designs which are quite plausible and realistic and potentially competitive with other energy sources. Yet it is not just economic advantages which motivate this effort but also the vision of limitless benefits. In fusion we have the prospects for cheap, abundant power which could make the deserts bloom with water from desalination plants, which could enable us to synthesize valuable chemicals from natural resources, extract metals from abundant low-grade ores, purify the air over our polluted cities, and so on.

In short we're not talking just about a better way to generate electricity; we're talking about the possibilities of a very new way of life.

Professor Peter L. Auer of the Graduate School of Aerospace Engineering came to Cornell in 1966 from the Advanced Research Projects Agency of the Department of Defense, where he was deputy director for Ballistic Missile Defense. Earlier he had been head of the Plasma Physics Department of the Sperry Rand Research Center at Sudbury, Massachusetts, from 1962 to 1964; physicist with the General Electric Company Research Laboratory in Schnectady, New York, from 1954 to 1962; and chemist with the California Research and Development Company in Livermore, California, from 1950 to 1954.

Professor Auer received the Bachelor of Arts degree in chemistry from Cornell in 1947 and the doctorate in chemical physics from the California Institute of Technology in 1951. During 1960–61 he was a Guggenheim Fellow at the Laboratorio Gas Ionizzati in Frascati, Italy, where he did research and helped to supervise graduate student programs in plasma physics.

The director of Cornell's newly established Laboratory of Plasma Studies, Professor Auer administers an interdisciplinary research effort in plasma physics and laser physics which involves twenty faculty members and forty graduate students, post-doctoral fellows, and supporting staff. His own research concerns theory of plasma physics with current emphasis on collision-free shock phenomena.

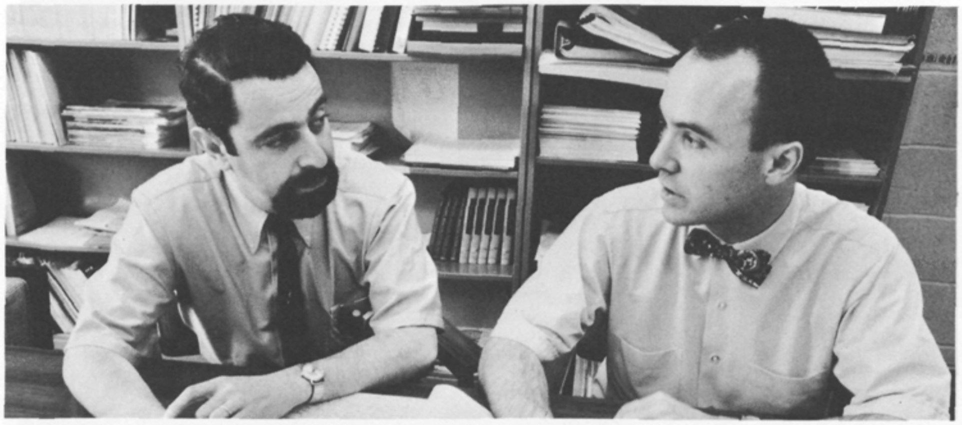
He is a fellow of the American Physical Society, and has served on the Executive Committee of the Society's Division of Plasma Physics. He is a senior member of the Institute of Electrical and Electronics Engineers and a member of Phi Beta Kappa and Sigma Xi.

UNIVERSITY RESEARCH IN NUCLEAR POWER

By K. Bingham Cady and Frank Feiner

One reason for the success of nuclear energy programs, both in this country and abroad, is that many scientists and engineers, representing diverse professional interests, have been able to coordinate their efforts successfully in shaping this new technology. The original impetus for this collective application of talent came from university personnel who worked on nuclear projects during World War II.

Just as the collaboration between physical scientists and engineers has fostered the growth of nuclear science and technology in the past quarter of a century, we predict that even broader participation, especially by the biological and social scientists, will characterize the next era. John P. Howe, formerly professor of engineering physics in the College of Engineering at Cornell University and now director of the department of metallurgy at Gulf General Atomic, Incorporated, has advocated that universities consider more seriously the social and environmental aspects of large-scale nuclear power systems in shaping their graduate research programs.



Coauthors Frank Feiner and K. Bingham Cady

EARLY DEVELOPMENTS

The first neutron chain reactor achieved criticality on December 2, 1942, as part of the Manhattan District Project during World War II. Soon, large-scale reactors were built to produce plutonium from natural uranium, and study began on the basic concepts underlying current breeder reactor development.

During the immediate post-war period primary attention was given to collecting detailed reactor and nuclear physics data so that studies could be made on the feasibility of nuclear power for submarine propulsion and electric power generation. Thermal reactors (reactors in which a moderator is used to slow down fission neutrons to thermal energies) offered the best short-term prospects for developing power reactors, but they are primarily burners of low abundance uranium-235 (U^{235}) fissionable material. Reactors which produce more fissionable material than they consume, usually plutonium-239 (Pu^{239}), are "fast" reactors (they employ no moderator, and fast neutrons cause fission in them) and present more difficult operating conditions. An early example of a thermal reactor is the Nautilus prototype (1950); of a fast reactor, the Experimental Breeder Reactor (1951). Both were operated at the National Reactor Testing Station in Idaho.

The Naval Reactor Program subsequently played the leading role in the development of nuclear power. Two reactor coolant materials, pressurized water and liquid sodium, were studied intensively in the early 1950's for use in submarine propulsion. Pressurized water proved highly successful and is now used in all nuclear naval vessels. The liquid sodium coolant, while technically successful, did not offer sufficient advantage to the nuclear naval program to warrant its continued development.

The first nuclear-electric generation station, located at Shippingport, Pennsylvania, employed the pressurized water reactor (PWR) method, and the knowledge gained in the construction and early operation of this plant was made available to commercial interests through the government's civilian application program. Westinghouse Electric Corporation's entry into the commercial nuclear power field was a version of the PWR; the General Electric Company's was a variant of this type, a boiling water reactor (BWR). Both systems are light-water–cooled thermal reactors which employ more or less conventional power conversion equipment (steam to electricity), and while there are minor differences, the two companies have enjoyed about equal success, sharing the lead as suppliers of commercial reactor power plants.

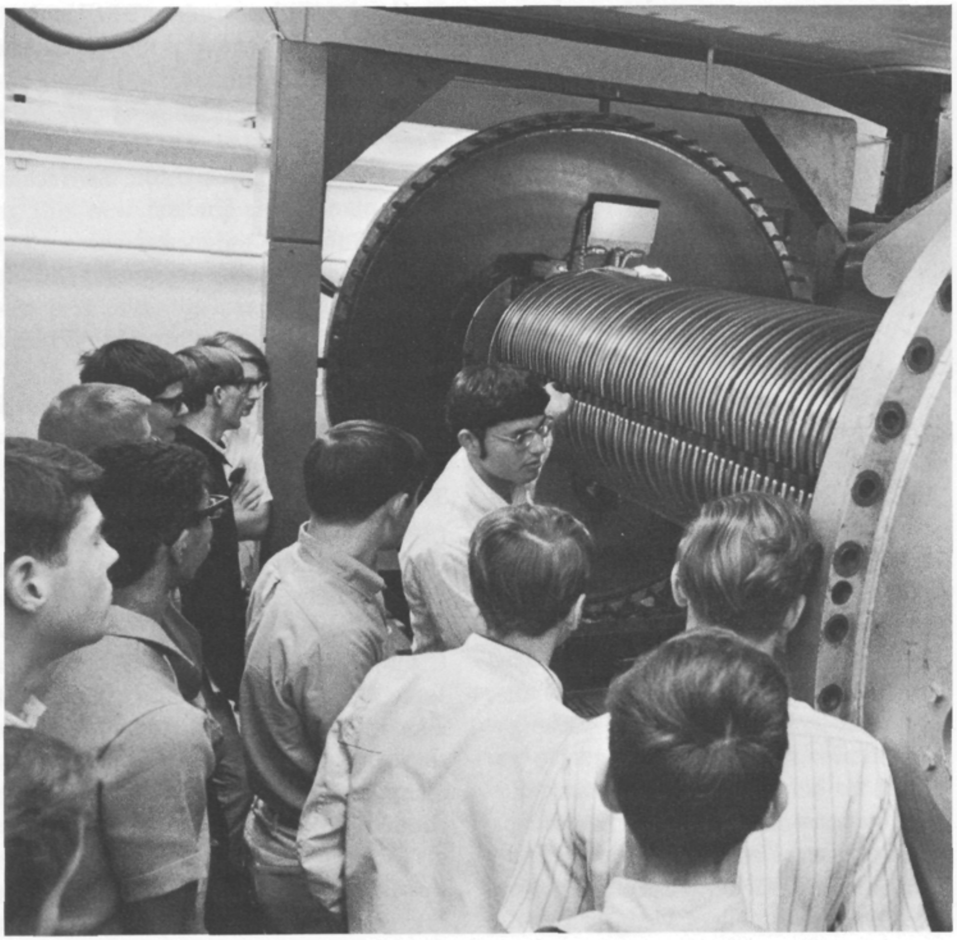
A milestone in the development of economical nuclear power was the Atomic Energy Act of 1954. As the first major modification of national nuclear policy since the original act of 1946, it divorced military from commercial objectives and permitted the leasing of fuel from the Atomic Energy Commission. Major contracts were drawn up between electric power utilities and commercial reactor manufacturers: the Commonwealth Edison Company and General Electric for the Dresden plant near Chicago, a New England utilities group and Westinghouse for the Yankee Atomic plant in western Massachusetts, and the Consolidated Edison Company of New York, Incorporated and the Babcock and Wilcox Company for the Indian Point plant on the Hudson.

After the reactor manufacturers and utilities had gained experience in the operation of these plants, the next major commercial breakthrough occurred in 1963 with the signing of a "turnkey" contract between the Jersey Central Power and Light Company and General Electric for the Oyster Creek plant. The contract provides for a fixed-price plant with warranties on the nuclear fuel costs, and it, together with a similar contract between the Niagara Mohawk Power Corporation and General Electric for a plant at Nine Mile Point on Lake Ontario, marks the beginning of economical nuclear power. In both these instances the utilities chose nuclear power, rather than coal, on its economic merits.

There has been much discussion as to whether the fixed and operating costs quoted in these and similar contracts

Lower left: A graduate student explains the 3 MeV Dynamitron operation to secondary school visitors. This low energy, high current ion accelerator is used for the study of nuclear structure and high intensity radiation damage induced by low energy nuclear reactions.

Right: Setting the fuel geometry for an experiment on the zero power reactor dealing with the analysis of transients and neutron waves.



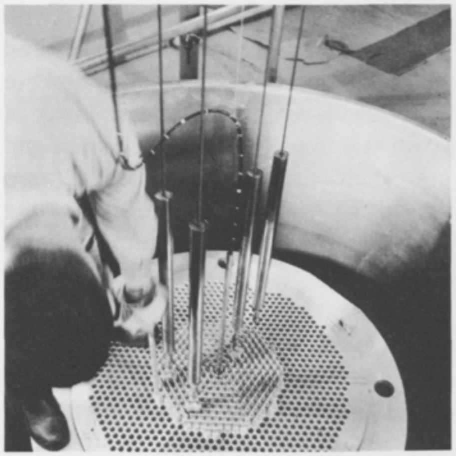
are realistic. At any rate the large electrical manufacturers have opened a major market; since 1966 the nation's utilities have ordered about half of their new generating capacity in nuclear power. Most of the orders have been for plants in the 600 to 1000 megawatts electric (Mwe) range; none of these plants are as yet operational.

This swing to nuclear power is also related to the utilities' concern over air pollution. The nuclear industry, thanks to detailed procedures required for plant licensing, has compiled a remarkable safety record and has contributed much to the understanding and control of environmental pollution.

CURRENT DEVELOPMENT PROBLEMS

For convenience nuclear technology problems can be grouped into three classes: short term, special-purpose reactor applications, and long range. Let us consider each class in turn and assess the role university research can play in each.

Short-term problems are generally associated with improving the present



generation of PWR and BWR plants. Specific goals include

1. increased endurance of fuel elements to reduce fuel costs
2. increased efficiency and size of plants to reduce capital costs
3. greater reliability of reactor components to reduce down time
4. systems analysis to optimize design, construction, and operation
5. better radiological waste treatment to reduce environmental pollution.

In this range of problems, the burden of development lies with the power utilities and the manufacturers of reactor components. Since most of these short-term problems are development-oriented, university research contributions in this area will be small.

Most of the problems in special-purpose reactor applications are not problems of cost. In this area new operating environments require major design changes which necessitate fairly large research and development expenditures, and universities can contribute only in selected areas. Among special-purpose applications are

1. space propulsion reactors, which require high power density and high specific impulse
2. remote-location power plants (such as moon colonies, space vehicles, undersea colonies), which must operate for long periods without refueling and must have long-term maintenance reliability
3. naval ship propulsion, which necessitates great endurance and reliability, high speed, light weight, and low noise in a reactor.

Long-range problems are generally related to breeder reactor developments. Today's nuclear power plants burn U^{235} and convert very little U^{238} to plutonium. There are several incentives for working upon the breeder reactor, among them

1. the need for fuel resource conservation to protect the readily available uranium ore supplies
2. economic incentives because the continued large-scale use of burners will result in the use of lower-grade uranium ores, with associated higher fuel costs
3. social incentives such as increased standard of living as a result of massive low-cost nuclear energy
4. technical changes that low-cost electricity can bring, e.g., extraction of magnesium metal from the ocean at a cost comparable to that of producing aluminum.

There are a number of possible approaches leading ultimately to an efficient breeder reactor system. The liquid metal cooled fast breeder reactor (LMFBR) operates on the U^{238}, Pu^{239} cycle; alternate coolants are steam or helium. A secondary approach is the molten salt thermal reactor, which operates on the thorium-232, uranium-233 cycle.

This country is putting its major effort into the LMFBR. In developing the PWR's and BWR's engineers were familiar with the behavior of the coolant, water, under diverse operating conditions. Liquid metal coolants, generally sodium, offer less familiar ground. As was true in the development of the PWR and BWR technology, the breeder technology will require diverse but coordinated talents of many scientists and engineers in universities, the federal atomic energy laboratories, and the nuclear industry under contract with the Atomic Energy Commission.

THE UNIVERSITY ROLE

There are two products of university research, the graduates themselves and their research achievements. One characteristic of nuclear science and engineering research programs has been the continuum from fundamental science to detailed technology over which researchers have operated. Examples drawn from work at Cornell's Nuclear Reactor Laboratory illustrate this.

Basic Nuclear Structure Physics

Low-energy nuclear physics, both experimental and theoretical, is the cornerstone of nuclear engineering activities. The nuclear isomer research being done at Cornell by Professor David D. Clark and his students is typical. His group is investigating the existence and properties of transient states of the atomic nucleus by means of neutron bombardment of isotopes in a TRIGA reactor. Another group under the direction of Professor Ross McPherson is using the Dynamitron accelerator to study isobaric analog states in light nuclei produced by nuclear reactions.

Basic Reactor Physics

Fundamental to the operation and control of nuclear reactors is a thorough understanding of the physics of the neutron chain reaction. Professor Cady's research group is experimenting with a variety of supercritical, critical, and subcritical fuel configurations to observe their effects on transient responses of chain reactions. This work, carried out in Cornell's unique critical facility (zero power reactor), will contribute to the control and safety program for fast breeder reactors.

Basic Neutron Physics

A neutron chain reaction is initiated and maintained by neutron interaction with the fuel, coolant, and structural materials of the reactor. The probability of neutron reaction occurring, the "cross section," depends on the particular target material, its temperature, and the energy of the bombarding neutrons. Making precise measurements of the cross sections requires expensive facilities which can best be established at government-owned or -supported laboratories. The university, however, has a complementary role through its abilities to evaluate and make theoretical correlations of this basic nuclear data.

Basic Materials Research

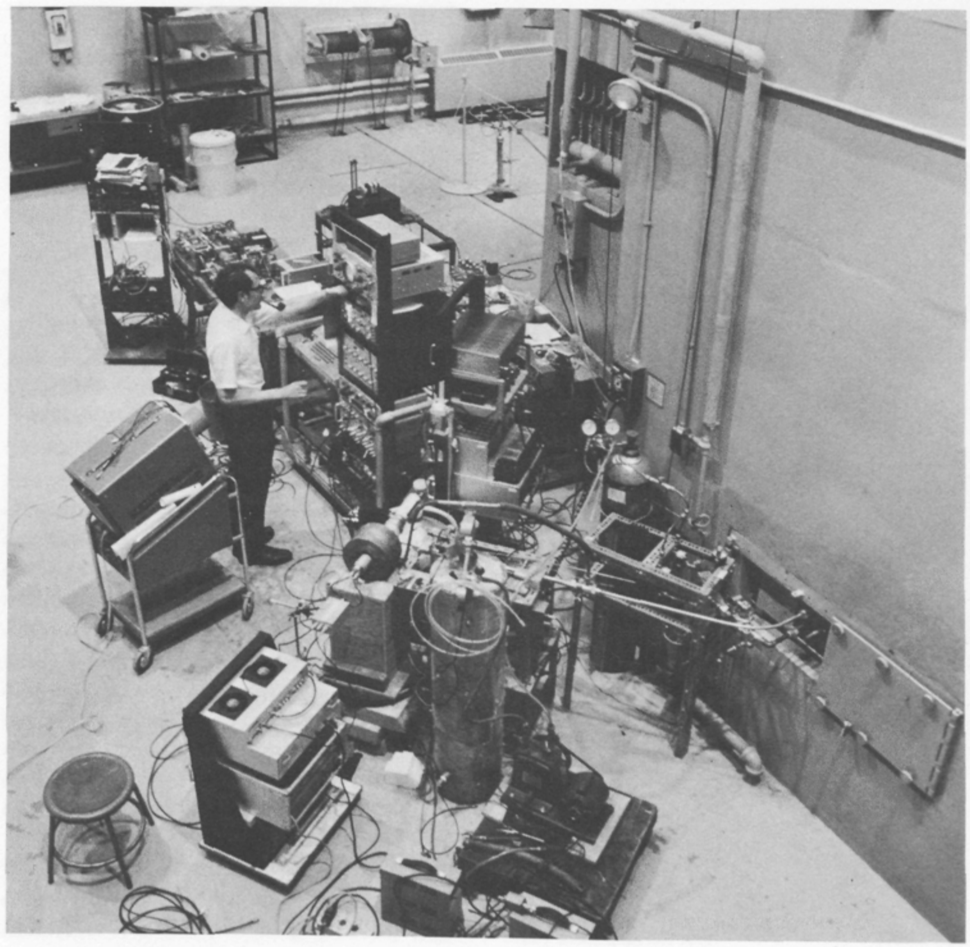
Much of the "engineering" development of reactor materials is best left to the commercial suppliers; however, basic and solid-state physics, as well as the metallurgy of materials, are productive areas for university research. For example, radiation damage in materials can be investigated, with the results leading to better selection of reactor materials with more predictable behavior. A group under Professor Anthony Taylor is studying radiation damage in alkali halides and proton channeling in crystals, making use of the Dynamitron

"The combined efforts of several disciplines could be brought to bear on the problem of environmental changes caused by large-scale power plants . . . from the interaction of . . . the biological and social sciences with physics and engineering."

accelerator. Work in materials is carried out in several areas on the Cornell campus, among them the Laboratory for Atomic and Solid State Physics and the Materials Science Center, as well as the Nuclear Reactor Laboratory.

Nuclear Structural Engineering

High-temperature, gas-cooled reactors are now being developed by Gulf General Atomic. This type of reactor requires a prestressed-concrete reactor vessel to house the primary helium cooling system, the nuclear core, and the steam generators. The design and model testing of such vessels is being investigated by Professors Richard N. White and Peter Gergely of the School of Civil Engineering and their research group in the models laboratory of the Department of Structural Engineering.



Professor David D. Clark employing one of the six beam ports of the TRIGA reactor in his research on nuclear isomers. The TRIGA reactor has a steady state power level of 100 kw and a pulsing capability of up to 250 Mw.

Below: An engineering student "follows" the Cornell lunar rover, which is operating by batteries through remote electronic control. Ultimately, lunar vehicles may require the longer duration power source of nuclear fuel. This project, engineered by Master of Engineering candidates in mechanical and electrical engineering, involved designing, building, and testing a guidance system for a proposed lunar rover. It was funded by the National Aeronautics and Space Administration.

Thermal Engineering

High-performance heat transfer systems will be a basic requirement for high-temperature nuclear reactors on earth and in outer space. Supported by the National Aeronautics and Space Administration's Lewis Research Center, Professor Franklin K. Moore of the Department of Thermal Engineering is investigating the effects of high-temperature, radiative heat transfer on hydrodynamic stability of fluids in order to further the development of high-temperature, gaseous-core nuclear rocket engines.

Nuclear Reactor Systems Design

Another area in which universities can play a vital role is in the preliminary design of new reactor systems. Cornell is promoting meaningful engineering design programs at the Master of Engineering and doctoral levels. One such example is an experimental engineering design program at the Ph.D. level funded by grants from the National Aeronautics and Space Administration and directed by Professor Howard N. McManus, Jr., chairman of the Department of Mechanical Systems and Design. Currently several student fellows are working on the design of an orbiting Jupiter probe including the preliminary design for an auxiliary power system. These students selected this design topic, and now each is working on one phase of it; among them are civil, mechanical, aerospace, and electrical engineering Ph.D. candidates.

FUTURE CONTRIBUTIONS

Probably the most significant gains can come from the interaction of a number of disciplines, particularly the biological and social sciences, with physics and engineering. A brief look at some proposed areas of technological development involving nuclear power immediately reveals why such an association is desirable.

For example, the Atomic Energy Commission is seriously considering the establishment of nuclear industrial complexes. A typical "nuplex" might be a large nuclear power plant which generates electricity by means of back pressure turbines. The electricity generated would be used for the production of nitrates and phosphorus for fertilizers while the turbine exhaust steam would be used to desalt seawater.

The combined efforts of several disciplines could be brought to bear on the problem of environmental changes caused by large-scale power plants, either nuclear or fossil-fueled. Heat and other power-plant byproducts in sufficient quantity can seriously disturb the balance of nature. If we are to avoid a repetition of what happened to our water resources as a result of indiscriminate waste disposal, a concerted effort must be made by industry, government, and the schools. One helpful step might be to develop a reactor which would utilize its waste heat, or part of its electricity, to power waste-treatment plants, thus curbing the flow of pollutants into the environment.

It is clear that tomorrow's nuclear reactors will be more than just a power-generating source. This is why universities need to assume an expanded outlook, not only in their nuclear research programs, but in ensuring that the full promise of nuclear energy is realized.

K. Bingham Cady is associate professor of engineering physics in the College of Engineering at Cornell. His research interests include reactor physics and nuclear engineering.

Professor Cady received the Bachelor of Science degree in naval architecture and marine engineering in 1956 and the Doctor of Philosophy degree in nuclear engineering in 1962, both from the Massachusetts Institute of Technology.

From 1956 to 1959 he was employed by the Shipbuilding Division of the Bethlehem Steel Company at Quincy, Massachusetts, where he worked on preliminary hull design, rotating machinery design and testing, and radiation shielding and nuclear systems design for the U.S.S. Long Beach. While a doctoral candidate, he was employed part-time by Jackson and Moreland International, Incorporated, a consulting engineering firm in Boston, on power plant economics studies and on nuclear systems design for the PM-3A and BONUS reactors.

Mr. Cady is an associate of Advanced Technology Consultants, Incorporated, a consultant to the Knolls Atomic Power Laboratory, and a founding member and past chairman of the Niagara-Finger Lakes Section of the American Nuclear Society.

Frank Feiner is manager for advanced reactor physics at the Knolls Atomic Power Laboratory, a facility operated for the Atomic Energy Commission by the General Electric Company. During the academic year 1967–68, he was a visiting professor of engineering physics in the College of Engineering at Cornell.

Before assuming his present position, Mr. Feiner was manager for advanced experimental physics at the Knolls Laboratory. His research has been concerned with integral and differential cross-section measurement and critical assembly experiments.

He earned the Bachelor of Arts degree from Princeton University in 1950, and the Master of Science and Doctor of Philosophy degrees from the Carnegie Instiute of Technology in 1952 and 1955, respectively.

He is a member of the American Physical Society, the American Nuclear Society and Sigma Xi.

REGISTER

Two men in the College of Engineering have been named professors emeritus by the Cornell University Board of Trustees, effective July 1, 1968. Their biographies follow.

■ Retirement scarcely means leave-taking from professional pursuits for *Nephi Christensen,* professor emeritus of water resources engineering and, from 1948 to 1966, director of the School of Civil Engineering.

Having recently completed thirty months of work as coordinator for several consulting firms that studied water pollution problems in Monroe County, New York, Professor Christensen will continue to be active in this type of work. His research in water resources, which will continue to absorb much of his time, concerns cost analysis of continental water supply systems and of methods for water purification such as desalination and waste-water reclamation. His is the first such effort to consider the continent as a whole in terms of water supply. He also intends to travel by freighter to northern European seaports and take other trips to east Asia, Australia, and South America.

Professor Christensen describes himself as an "opportunist" in that he was never one to stake out a course from which he wouldn't deviate. He took the Bachelor of Science degree in physics and mathematics from Brigham Young University in 1925, and finding university positions in these subjects scarce, he taught high school for a year in Iron County, Utah. From there he went to The University of Wisconsin, where he earned the Bachelor of Science degree in civil engineering. Concurrently, he was a highway engineer with the Wisconsin State Highway Commission. From 1928 to 1933 he was professor of exact sciences at Ricks College in Idaho, where he taught mathematics, physics, botany, geology, and numerous other courses. It was, he notes, a "learning" experience.

From 1933 to 1935 he was an instructor and then special lecturer in civil engineering at the California Institute of Technology. He received the Master of Science degree there in 1934 and the doctorate in 1939. In 1936 he accepted a position as research engineer at the joint California Institute of Technology–United States Soil Conservation Service laboratory at Pasadena, and in 1938 he was named dean of engineering at Colorado State University and director of its engineering experiment station.

While on wartime leave from Colorado State, he served as chief engineer for the Ballistic Research Laboratory and subsequently chief of the Research Branch of the Rocket Research Division, Ordnance Research and Development Center, Aberdeen, Maryland. During this time he and his colleagues did emergency work to develop and test the bazooka, which was introduced in World War II.

Later he served the Atomic Energy Commission and the Brookhaven National Laboratory as a site-feasibility consultant concerned with problems in foundations and cooling for high energy particle accelerators.

Looking back on his twenty-year association with the College of Engineering at Cornell, Professor Christensen

Christensen

notes that the School of Civil Engineering, now predominately a graduate school, twenty years ago had fewer than twenty graduate students. Formerly, there was almost no support for research; today there is about $700,000 a year.

Professor Christensen is a registered professional engineer and land surveyor in New York and Colorado, a member of the American Society of Civil Engineers and the American Geophysical Union, and a former national director of the American Society for Engineering Education. He is a member of Tau Beta Pi, Sigma Xi, Chi Epsilon, and Sigma Tau.

His concern for and commitment to the engineering profession is reflected in *Ethical Problems for Engineers*, the book he wrote with Philip Alger and Sterling P. Olmsted. It particularly stresses the responsibilities of the practicing engineer to all segments of society.

■ *Wilbur E. Meserve,* professor of electrical engineering, emeritus, has retired from teaching at Cornell after 42 years of service. He will remain with the College of Engineering on a part-time basis, however, directing a student project for the development of the control system for an unmanned roving vehicle to be sent to Mars, a project which will be funded by the National Aeronautics and Space Administration.

During his years of teaching, Professor Meserve had a great deal of contact with his students, not only as a teacher but as an adviser. He took particular interest in foreign students, and on two trips around the world he visited many of them, at the same time visiting various universities in Japan, Formosa, Ceylon, Turkey, Lebanon, and parts of Europe.

Mr. Meserve took the Bachelor of Science degree in electrical engineering in 1923 from the University of Maine, then earned the Master of Science in physics there in 1926. Coming to Cornell, he received the Master's degree in electrical engineering in 1929 and the doctorate in physics in 1933. In 1926 he joined the Cornell faculty as an instructor in electrical engineering. He also taught for two years at the University of Maine; was a Fulbright lecturer at the University of Sydney, Australia in 1955; and was visiting professor of electrical engineering at the University of Hawaii during 1961–62 and 1964–65. For the past three years he has been coordinator of graduate studies and Field Representative for the School of Electrical Engineering. He has been on numerous committees in the School and has been chairman of the University Calendar Committee and the College Library Committee.

Mr. Meserve's wide-ranging industrial experience has included work for the Bell Telephone Laboratories, the General Electric Company, the R.C.A. Victor Corporation, the Autonetic Corporation, and the American Brown-Boveri Company. He has been an engineer and consultant for the General Electric Advanced Electronics Center in Ithaca, the Cornell Aeronautical Laboratory, the M.I.T. Lincoln Laboratory, Stromberg-Carlson Radio Corporation, the Associated Universities, Incorporated, and the Seneca Falls Machine Company. From 1950 to 1953 he was director and coordinator of a research program for the development of a self-contained control system that was a part of the North American "dew line" defense warning system. From 1960 to 1963 he served as director of a Cornell research project, funded by the National Science Foundation, that dealt with investigations in discrete control systems. Recently he co-directed a student project funded by the National Aeronautics and Space Administration concerning the development of a guidance system for a lunar roving vehicle. In the future he will likely continue with consulting work.

Meserve

During his association with it, the School of Electrical Engineering has grown from one that awarded very few graduate degrees to one that awarded, in 1967–68, twenty-two Doctor of Philosophy degrees, twenty-five Master of Science degrees, and sixty-five Master of Engineering (Electrical) degrees.

Professor Meserve was a life member of the Institute of Electrical and Electronics Engineers until his election to fellow in 1965. He is a member of the Institute's Committee on Feedback Control Systems, a topic he has treated in several technical articles in recent years. In addition, he is a member of the American Society for Engineering Education, the New York Academy of Science, Sigma Xi, Tau Beta Pi, Eta Kappa Nu, and Phi Kappa Phi. He is listed in *American Men of Science* and *Who's Who in the East* and is a member of Rotary International.

At a breakfast given in honor of Professor Meserve, Herbert J. Carlin, director of the School of Electrical Engineering, presented him with a chair bearing the Cornell seal and with a plaque "to honor a dedicated and respected teacher and adviser." With a bit more leisure time now, Professor Meserve hopes to pursue the study of Pacific history as it parallels the development of America.

FACULTY PUBLICATIONS

The following publications and conference papers by members of the Cornell College of Engineering faculty were published during November and December, 1967, and January, 1968. Names of Cornell faculty are in italics.

■ AEROSPACE ENGINEERING

de Boer, P. C. T., "Filling Rate of the Tail of the Velocity Distribution Function," *The Physics of Fluids,* 10:11 (1967), 2485–96.

George, A. R., "Perturbations of Plane and Axisymmetric Entropy Layers," *AIAA Journal,* 5:12 (Dec. 1967), 2155–60.

George, A. R., "Reduction of Sonic Boom by Azimuthal Redistribution of Overpressure," AIAA Paper No. 68–159, 1968.

Shen, S. F., "Parametric Representations of Gas-Surface Interaction Data and the Problem of Slip-Flow Boundary Conditions With Arbitrary Accommodation Coefficients," *Entropie,* No. 18 (Nov.–Dec. 1967), pp. 138–45.

■ AGRICULTURAL ENGINEERING

Bagnall, L. O., *Millier, W. F.*, and *Scott, N. R.*, "Drying of the Alfalfa Stem," Paper No. 67–673, presented at the winter meeting of the ASAE, Detroit, Dec. 1967.

Loehr, R. C., "Aerobic Microbial Degradation of Lipids," final progress report of the Federal Water Pollution Control Administration, Research Project WP–341 (Jan. 1968), 192 pp.

Loehr, R. C., "Cattle Feedlot Waste Water Treatment," second progress report of the Federal Water Pollution Control Administration, Demonstration Project WPD123 (Jan. 1968), 45 pp.

Loehr, R. C., "The Impact of Animal Wastes on Water Resources Activities," presented at the 3rd Annual Conference of the American Water Resources Association, Nov. 1967.

Loehr, R. C., "Preservation of Waste Water Samples Prior to Analysis," *Water Research,* 1 (1967), 577–86.

Loehr, R. C., and Ruf, J. A., "Anaerobic Lagoon Treatment of Milking Parlor Wastes," *Journal of the Water Pollution Control Federation,* 40 (1968), 83–94.

Lorenzen, R. T., "Queuing Techniques in Designing and Operating Livestock Production Facilities," *ASAE Transactions,* 10:4 (1967), 519–22.

Millier, W. F., and *Sooter, C.*, "Improving Emergence of Pelleted Seed," *ASAE Transactions,* 10:5 (1967), 658–66.

Rehkugler, G. E., "Mechanical Harvest of Tender Apple Varieties," presented at the annual meeting of the Maine State Pomological Society, Lewiston, Maine (Jan. 1968), 13 pp.

Rehkugler, G. E., "Screw Conveyors—State of the Art," *ASAE Transactions,* 10:5 (1967), 615–18, 621.

Rehkugler, G. E., and Buchele, W. F., "Biomechanics of Forage Wafering," presented at the winter meeting of the ASAE, Detroit (Dec. 1967), 47 pp.

Rehkugler, G. E., and Buchele, W. F., "Influence of Stems in Alfalfa Forage on the Formation of Wafers," *Journal of Agricultural Engineering Research,* 12:4 (1967), 285–92.

Romig, B. E., and *Millier, W. F.*, "Determination and Simulation of Field Machine Vibrations," *ASAE Transactions,* 10:5 (1967), 697–700.

Spencer, J. W., "An Approach to Planning and Programming Local Road Improvements Based on a Network-Wide Assessment of Economic Consequences," presented at the 47th Annual Meeting of the Highway Research Board, Washington, D.C., Jan. 1968.

■ CHEMICAL ENGINEERING

Edwards, V. H., and Wilke, C. R., "Electronic Sizing and Counting of Bacteria," *Biotechnology and Bioengineering,* 9 (1967), 559–74.

Finn, R. K., "How to Improve Monitoring of CO_2 in Inert Gas," *Chemical Engineering,* 74:11 (1967), 166 ff.

Riggs, J. P., and *Rodriguez, F.,* "Persulfate-Initiated Polymerization of Acrylamide," *Journal of Polymer Science, Pt. A1,* 5 (1967), 3151–65.

Riggs, J. P., and *Rodriguez, F.,* "Polymerization of Acrylamide Initiated by the Persulfate-Thiosulfate Couple," *Journal of Polymer Science, Pt. A1,* 5 (1967), 3167–81.

Scheele, G. F., and Meister, B. J., "Drop Formation at Low Velocities in Liquid-Liquid Systems: Part 1. Prediction of Drop Volume. Part 2. Prediction of Jetting Velocity," *AIChE Journal,* 14 (Jan. 1968), 9–19.

Smith, J. C., "The Electronic Blackboard—a Teaching Experiment," presented at the 2nd Annual Meeting of the Continuing Engineering Studies Division of the American Society for Engineering Education, New Orleans, Nov. 1967.

Smith, J. C., and *Winding, C. C.,* "Thirty Years' Experience With a Five-Year Chemical Engineering Program," presented at the National Meeting of the AIChE, New York City, Nov. 1967.

Winding, C. C., and *Brodsky, P. H.,* "Survey of Polymer Courses," *Society of Plastics Engineers Journal,* 24 (Jan. 1968), 31–34.

■ CIVIL ENGINEERING

Brutsaert, W. H., "Evaporation From a Very Small Water Surface at Ground Level: Three-Dimensional Turbulent Diffusion Without Convection," *Journal of Geophysical Research,* 72:22 (Nov. 1967), 5631–39.

Falkson, L. M., "Water Shortages and Pricing," presented at the 3rd Annual American Water Resources Association Conference," San Francisco, Nov. 1967.

Gates, C. D., "Management of Domestic Wastes," AAAS Publication No. 85, presented at the AAAS Symposium on Quality of Our Environment (Dec. 1967), 367–84.

Ibrahim, H. A., and *Brutsaert, W. H.,* "Intermittent Infiltration Into Soils With Hysteresis," *Proceedings of the ASCE, Journal of Hydraulics Division,* Vol. 94, No. HY1 (Jan. 1968), pp. 113–37.

Sabnis, G. M., and *White, R. N.,* "A Gypsum Mortar for Small-Scale Models," *Journal of ACI,* 64:11 (Nov. 1967), 767–74.

■ COMPUTER SCIENCE

Brown, K. M., "Solution of Simultaneous Non-Linear Equations," *Communications of the ACM* (Nov. 1967), 728–29.

Brown, K. M., and Dennis, J. E., Jr., "On the Convergence of a General Class of Iterative Methods," presented at the 74th Annual Meeting of the American Mathematical Society, San Francisco, Jan. 1968.

Hartmanis, J., "On the Structure of Finite Automata," *Systems and Computer Science,* ed. J. F. Hart and S. Takasu (University of Toronto Press, 1967), pp. 3–13.

Salton, G. "Information Science and Technology," *Encyclopedia Brittanica,* 1968 Yearbook.

Salton, G., and Lesk, M. E., "Computer Evaluation of Indexing and Text Processing," *Journal of the ACM,* 15:1 (Jan. 1968), 8–36.

■ ELECTRICAL ENGINEERING

Abramowitz, I. A., and *Ballantyne, J.M.*, "Evaluation of Hologram Aberrations by Ray Tracing," *Journal of the Optical Society of America,* 57 (Dec. 1967), 1522 ff.

Abrams, R. L., and *Wolga, G. J.*, "Direct Demonstration of the Validity of the Wegner Spin Rule for Helium-Helium Collisions," *Physical Review Letters,* 19:25 (Dec. 1967), 1411–14.

Brice, N. M., "Bulk Motion of the Magnetosphere," *Journal of Geophysical Research,* 72:21 (Dec. 1967), 5193–211.

Carlin, H. J., "On the Existence of a Scattering Representation for Passive Networks," *IEEE Transactions on Circuit Theory,* Vol. CT-14, No. 4 (Dec. 1967), pp. 418–19.

de Boer, P. C. T., and *Grimwood, P. R.*, "Initial Ionization Process Behind a Shock Wave in a Noble Gas," presented at the meeting of the Division of Fluid Dynamics of the APS, Bethlehem, Pa., Nov. 1967.

Farley, D. T., McClure, J. P., Sterling, D. L., and Green, J. L., "Temperature and Composition of the Equatorial Ionosphere," *Journal of Geophysical Research,* 72:23 (Dec. 1967), 5837–51.

Höfflinger, B., "On the Dynamic Constriction of Avalanches in Semiconductors," presented at the Informal Conference on Active Microwave Effects in Bulk Semiconductors, New York City, Jan. 1968.

Huband, F. L., and *Jelinek, F.*, "Practical Sequential Decoding and a Simple Hybrid Scheme," presented at the Hawaii Conference on Systems Theory, Honolulu, Jan. 1968.

Jelinek, F., and Huband, F. L., "Bounds on the Performance of an Economical Sequential Decoder," presented at the Hawaii Conference on Systems Theory, Honolulu, Jan. 1968.

Jelley, D., and *Brice, N.*, "Changes in Van Allen Radiation Associated With Polar Substorms," *Journal of Geophysical Research,* 72:23 (Dec. 1967), 5919–31.

Kennedy, W. K., Jr., Camp, W. O., and *Eastman, L. F.*, "Frequency and Power Scaling of LSA Diodes," presented at the Conference on Active Microwave Effects in Bulk Semiconductors, New York City, Jan. 1968.

Kennedy, W. K., Jr., and *Eastman, L. F.*, "High Power Pulsed LSA Devices," presented at the North East Radio Electronics Meeting, Boston, Nov. 1967 (sponsored by the IEEE).

Kim, M., "On Optimum Control of Distributed Parameter Systems," presented at the Hawaii Conference on Systems Theory, Honolulu, Jan. 1968.

Malmberg, J. H., *Wharton, C. B.*, Gould, R. W., and O'Neil, T. M., "Plasma Wave Echo Experiment," *Physical Review Letters,* 20:3 (Jan. 1968), 95–97.

Rudko, R. I., and *Tang, C. L.*, "Spectroscopic Studies of the Ar^+ Laser," *Journal of Applied Physics,* 38 (Nov. 1967), 4731–39.

Snapp, C. P., and *Höfflinger, B.*, "Some Measurements of the Frequency Response of Negative Resistances in Avalanche Breakdown Devices," presented at the Informal Conference on Active Microwave Effects in Bulk Semiconductors, New York City, Jan. 1968.

Sudan, R. N., Coppi, B., and Rosenbluth, M. N., "Nonlinear Interaction of Positive and Negative Energy Modes," presented at the 9th Annual Meeting of the Division for Plasma Physics of the APS, Austin, Nov. 1967.

Sudan, R. N., Nocentini, A., and Berk, H. L., "Kinetic Theory of the Diochotron Instability," presented at the 9th Annual Meeting of the Division for Plasma Physics of the APS, Austin, Nov. 1967.

Tang, C. L., and Statz, H., "Large-Signal Effects in Self-Locked Lasers," *Journal of Applied Physics,* 39 (Jan. 1968), 31–35.

Wharton, C. B., Malmberg, J. H., and O'Neil, T. M., "Some Non-Linear Effects Associated With Large Amplitude Plasma Waves," Paper No. 6B-9, presented at the 9th Annual Meeting of the Division of Plasma Physics of the APS, Austin, Nov. 1967.

Zimmerman, S. W., "Response of Dielectric Materials to Applied Direct Current Voltages," *1967 Annual Report of the Conference on Electrical Insulation and Dielectric Phenomena,* Publication No. 1578 (1967), pp. 49–52 (sponsored by the National Academy of Science).

■ ENGINEERING PHYSICS

Austin, D. T., Zolotar, B. A., and *Cady, K. B.*, "Comparison of the Waiting-Time Alpha With the Rossi-Alpha," presented at the 1967 Winter Meeting of the American Nuclear Society, Chicago, Nov. 1967. *Transactions of the American Nuclear Society,* 10:2 (1967), 591 ff.

Cady, K. B., and Osias, D., "Investigations of Space-Dependent Values of δ-28 in Light-Water Cores," presented at the 1967 Winter Meeting of the American Nuclear Society, Chicago, Nov. 1967. *Transactions of the American Nuclear Society,* 10:2 (1967), 586 ff.

Fleischman, H. H., "Charge Transfer Scattering in Low-Energy Collisions of Protons With Various Target Gases," presented at the 9th Annual Meeting of the Division of Plasma Physics of the APS, Austin, Nov. 1967.

Golay, M. W., and *Cady, K. B.*, "A Formulation of Neutron Dispersion Relations in Terms of Reactivity," presented at the 1967 Winter Meeting of the American Nuclear Society, Chicago, Nov. 1967. *Transactions of the American Nuclear Society,* 10:2 (1967), 588 ff.

Kawakatsu, H., Vosburgh, K. G., and *Siegel, B. M.,* "Electron-Optical Properties of a Quadrupole Quadruplet Projector Lens," *Journal of Applied Physics,* 39 (Jan. 1968), 245–54.

Kawakatsu, H., Vosburgh, K. G., and *Siegel, B. M.,* "Mechanical Aberrations of a Magnetic Quadrupole Quadruplet Lens," *Journal of Applied Physics,* 39 (Jan. 1968), 255–60.

Nelkin, M., and Ranganathan, S., "Collisionless Sound in Classical Fluids," *Physical Review,* 164:1 (Dec. 1967), 222–27.

Ranganathan, S., and *Nelkin, M.,* "Propagation of Density Disturbances in a Dense Hard-Sphere Gas," *Journal of Chemical Physics,* 47 (Nov. 1967), 4056 ff.

Salpeter, M. M., Bachmann, L., and *Salpeter. E. E.,* "Resolution in Electron Microscope Radioautography," presented at the 7th Annual Meeting of the American Society for Cell Biology, Denver, Nov. 1967.

■ INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

Bechhofer, R. E., "Ranking Multiple-Classified Variances of Normal Populations," presented at the Annual Meeting of the Institute of Mathematical Statistics, Washington, D.C., Dec. 1967.

Bernhard, R. H., "Use of Inventories for Reduction of Trim Losses," *The Journal of Industrial Engineering,* 18:11 (Nov. 1967), 668–70.

Byrne, R., Charnes, A., Cooper, W. W., and *Kortanek, K.,* "A Chance-Constrained Approach to Capital Budgeting With Portfolio Type Payback and Liquidity Constraints and Horizon Posture Controls," *Journal of Financial and Quantitative Analysis,* 2:4 (Dec. 1967), 339–64.

Byrne, R., Charnes, A., Cooper, W. W., and *Kortanek, K.,* "Some New Approaches to Risk," *The Accounting Review,* 18:1 (Jan. 1968), 18–37.

Emmons, H., "A Replenishment Model for Radioactive Nuclide Generators," *Management Science,* 14:5 (Jan. 1968), 263–74.

Kortanek, K., Sodaro, D., and Soyster, A., "Multi-Product Production Scheduling via Extreme Point Properties of Linear Programming," presented at the Symposium on Industrial Sequencing, Hoboken, N.J., Dec. 1967 (sponsored by the Stevens Institute of Technology and the Office of Naval Research).

Mandelbrot, B., and *Taylor, H.,* "On the Distribution of Stock Price Differences," *Operations Research,* 15:6 (Nov.–Dec. 1967), 1057–62.

Weiss, L., "Some Properties of a Class of Tests of Fit," *Annals of the Institute of Statistical Mathematics,* 19:3 (1967), 389–99.

■ MATERIALS SCIENCE AND ENGINEERING

Batterman, B. W., "Some Problems in Diffraction Physics," presented at the Symposium on a Quarter Century of Diffraction, Mellon Institute, Pittsburgh, Nov. 1967.

Batterman, B. W., and *Hildebrandt, G.,* "Observation of Pendellösung Fringes in Darwin Reflection," *Acta Crystallographica,* A24 (Jan. 1968), 150–54.

Batterman, B. W., and *Hildebrandt, G.,* "X-Ray Pendellösung Fringes in Darwin Reflection," presented at the Symposium on a Quarter Century of Diffraction, Mellon Institute, Pittsburgh, Nov. 1967.

Bell, T., and *Owen, W. S.,* "The Thermodynamics of the Martensite Transformation in Iron-Carbon and Iron-Nitrogen," *Transactions of the AIME,* 239 (Dec. 1967), 1940.

Betsch, J. C. and *Winchell, P. G.,* "The Line Tension of a Dislocation Bent at a Small Obstacle," *Scripta Metallurgica,* 2 (1968), 51–54.

Blakeley, J. M., "Method for Production of Optical Diffraction Gratings From Single Crystal Materials," *Applied Physics Letters,* 11 (Dec. 1967), 335–37.

Blakely, J. M., and *Maiya, P. S.,* "Surface Energies From Transport Studies," *Surfaces and Interfaces—Chemical and Physical Characteristics* (Syracuse University Press, 1967), pp. 325 ff.

Christ, B. W., and *Smith, G. V.,* "Strengthening of Polycrystalline Iron by Nitrogen," *Transactions of the ASM,* 60 (Dec. 1967), 732 ff.

Christ, B. W., and *Smith, G. V.,* "Yield and Flow Stress Increase in Pure Polycrystalline Iron During 600°C Treatment After Wet Hydrogen Purification," *Scripta Metallurgica,* 1 (Dec. 1967), 123 ff.

Kramer, E. J., and Bauer, C. L., "Internal Friction and Young's Modulus Variations in the Superconducting, Mixed, and Normal States of Niobium," *The Physical Review,* 163:2 (Nov. 1967), 407–19.

Roberts, M. J., and *Owen, W. S.,* "The Strength of Martensitic Iron-Nickel Alloys," *Transactions of the ASM,* 60:4 (1967), 687 ff.

Ruoff, A. L., "Linear Shock-Velocity-Particle-Velocity Relationship," *Journal of Applied Physics,* 38 (Dec. 1967), 4976–80.

Ruoff, A. L., "Vacancy Concentrations in Metals During High Temperature Deformation," *Lattice Defects and Their Interactions,* ed. R. R. Hasiguti (New York City: Gordon and Breach, 1967), pp. 961–1000.

Tsui, R. T. C., "Internal Friction and Transmission Electron Microscopy Studies of Magnesium—I. Internal Friction. II. Electron Microscopy," *Acta Metallurgica,* 15 (Nov. 1967), 1715 ff.

Tabor, J. B., and *Li, C. Y.,* "The Effect of Aqueous Environment on Surface Hardening of Silver Chloride," *Acta Metallurgica,* 15 (Dec. 1967), 1861 ff.

Wei, R. P., Talda, P. M., and *Li, C. Y.,* "Fatigue Crack Propagation in Some Ultra-High-Strength Steels," Scientific Technical Publication No. 415, the American Society for the Testing of Materials, 1967.

■ THEORETICAL AND APPLIED MECHANICS

Block, H. D., "Simulation of Statistically Composite Systems," *Prospects for Simulation and Simulators of Dynamic Systems,* ed. G. Shapiro and M. Rogers (New York City: Spartan Books; London: Macmillan and Co. Ltd., 1967), pp. 23–68.

Chang, C. S., Pimbley, W. T., and *Conway, H. D.,* "Analysis of Metal Fatigue Based on Hysteresis Energy," presented at the meeting of the Society of Experimental Stress Analysis, Chicago, Nov. 1967.

Conway, H. D., "The Indentation of an Orthotropic Half Plane Having Inclined Principal Axes," *Journal of Applied Mechanics,* 34 (Dec. 1967), 1031–32.

Hough, G. R., *Moran, J. P.,* and Erickson, J. C., Jr., "Performance of a Jet-Flapped Hydrofoil Near a Free Surface," *Journal of Ship Research* (Dec. 1967), 224–34.

Pao, Y. H., and Than, S. A., "Wave Function Expansions and Perturbation Method for the Diffraction of Elastic Waves by a Parabolic Cylinder," *Journal of Applied Mechanics,* 34 (Dec. 1967), 915 ff.

Rand, R. H., and DiMaggio, F., "Vibrations of Fluid-Filled Spherical Shells," *The Journal of the Acoustical Society of America,* 42:6 (Dec. 1967), 1278–86.

■ MECHANICAL ENGINEERING

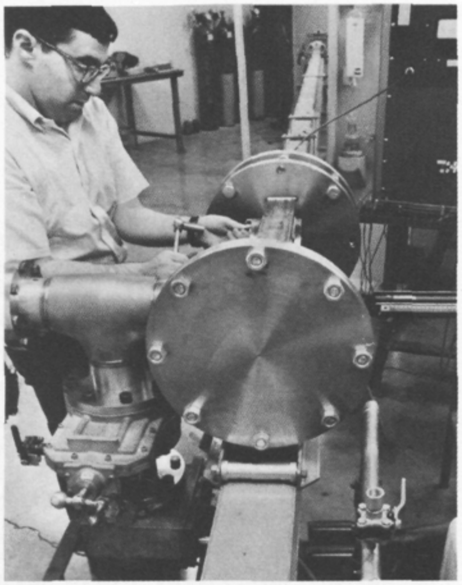
Bhardwaj, R. K., *Gupta, B. K.,* and Prasad, R., "Performance of a Flat-Plate Solar Collector," *Solar Energy,* 11:3–4 (July–Dec. 1967), 160–63.

Booker, J. F., "On Bearings for Reciprocating Machinery," presented at the Conference on Lubrication and Wear, London, Sept. 1967. *Proceedings of the Institution of Mechanical Engineers,* Vol. 182, Part 3A, 1967–68.

Leibovich, S., "On the Differential Equation Governing the Rear Stagnation Point in Magnetohydrodynamics and Goldstein's 'Backward' Boundary Layers," *Proceedings of the Cambridge Philosophical Society,* 63 (Oct.–Dec. 1967), 1327–30.

Polymeropoulos, C. E., and *Gebhart, B.,* "Incipient Dustability in Free Convection Laminar Boundary Layers," *Journal of Fluid Mechanics,* Vol. 30, Part 2 (Nov. 1967), pp. 225–39.

Electrical Power Prospects



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The "wonder of the countryside and indeed of the engineering world" . . . so writes Morris Bishop in *A History of Cornell* of the first successful underground distributing system for electrical power and the first outdoor electric lighting system in the United States. Both were located on the Cornell campus where "electricity was delivered through underground wrought-iron pipes to two campus arc lights."

Devised by Professor William A. Anthony of physics and a student, George S. Moler, the system used a direct-current dynamo which was built by Anthony and Moler and powered by a five-horsepower gas engine. This working demonstration in the 1870's and early inventions and developments by Edison, Tesla, and Westinghouse (the incandescent lamp, alternating current, and a-c electrical power equipment, respectively) fostered the birth of the American electrical power industry.

During this early period of electrical power growth, Cornell University instituted a four-year course in electrical engineering under the aegis of the physics department. With a program offered at Massachusetts Institute of Technology, this course represented the formal beginning of American education in electrical engineering.

While the first electrical engineering graduates concerned themselves primarily with designing, developing, and building the systems for lighting the homes of America and powering its factories, later graduates could direct their attention to the manufacture of devices employing electricity. Thus, the products of electronics—radio, television, telephone, computer, radar—and of electrical machines—refrigerators, air conditioners, washers, and a flood of appliances.

In the face of these new directions, we began to take the technology of electrical power generation for granted. It takes an experience like the New York City blackout of November 1965 to make us realize the extent of our dependence on the electric power utilities. The identification of nuclear fission as a power source and the novel technological and social problems created by it, however, have sparked anew the interest of young men in the question of power sources.

New sources of power and the transmission of growing blocks over greater distances with minimum damage to landscape—these are some of the problems which the power industry and the local, state, and federal government must face. Thus, the underlying theme of this issue: Electrical Power Prospects.

THE EDITOR


HOLLISTER HA